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Closing the blue loops

Responsible and sustainable innovation in the fields of water and ocean

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Closing the blue loops

Responsible and sustainable innovation in the fields of water and ocean

Assessing the need and scope for a knowledge and innovation community (KIC) in the water, marine and maritime (WMM) areas within the European Institute of Innovation and Technology, this report evaluates existing gaps in the innovation ecosystems and makes recommendations on the thematic focus areas with the highest potential for technological development, market deployment and benefits for EU citizens. The report identifies key stakeholders and methods for public engagement, existing funding mechanisms, and legal and regulatory barriers to technological innovation in the targeted sectors. It goes on to offer policy recommendations on how to create an environment conducive to innovation and market deployment in alignment with the European Green Deal and other relevant EU strategies. A key objective is to make the water, marine and martime economic sectors more circular and interlinked, as indicated by the report's title 'Closing the blue loops'. The report identifies existing and emerging technologies with the potential for high impact in the EU, particularly for reaching sustainability goals, and areas requiring further competence building, research, innovation and potentially regulatory change in order to meet these goals effectively.

The report's conclusion is that a WMM KIC would significantly enhance the innovation ecosystem and its contribution to education and entrepreneurship within the relevant sectors. Through targeted addressing of identified gaps and regulatory challenges, a WMM KIC could significantly contribute to Europe's leadership in the global water and ocean economy.

AUTHORS

This study has been written by Siri Granum Carson and Sveinung Sægrov (NTNU), Richard Sempere (CNRS/AMU-Ocean) and Pentti Kujala (Aalto University) with support from Marilou Suc (Blue Connections), at the request of the Panel for the Future of Science and Technology (STOA) and managed by the Scientific Foresight Unit of the Directorate for Impact Assessment and European Added Value, within the Directorate-General for Parliamentary Research Services (EPRS) of the Secretariat of the European Parliament.

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Vasco Guedes Ferreira, Scientific Foresight Unit

To contact the publisher, please e-mail stoa@ep.europa.eu

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Executive summary

This report aims to provide advice and recommendations on how a knowledge and innovation community (KIC) in the water, marine and maritime (WMM) areas can contribute to the development of appropriate framework conditions to transform good ideas into sustainable technology fit for market deployment. The title, 'Closing the blue loops', points to the need to 'close the loops' in the sense of making the water, marine and martime are more interlinked and circular, for example by enhancing water recycling and re-use, reducing wastewater and pollution and, using resources from the planet more sustainabily. The objective of the report is to draw the landscape of current and emerging technologies in the relevant areas, and to point towards the needs for more innovation and potential redesign of regulations. The starting point of the report is the question: how can a WMM KIC support the EU in meeting the climate goals while promoting sustainable change and growth?

The overall aim of the report is to assess and qualify the need to create a KIC within the European Institute of Innovation and Technology (EIT) dedicated to water, ocean, marine and maritime sectors, technologies, and ecosystems. Furthermore, we provide actionable recommendations for the possible setting up of a WMM KIC and for fulfilling its aims in a way that improves the quality of life and benefits European citizens. The SWOT and gap analyses in the report are based on the study of existing literature, relevant use cases and data collected through a survey and a series of in-depth interviews. This methodology unearthed substantial insights into sector-specific challenges, highlighting essential areas requiring policy intervention and enhanced support. The analysis revealed specific policy and regulatory barriers and gaps that, if addressed, could significantly enhance the innovation ecosystem and its contribution to education and entrepreneurship within these sectors. The further analysis points out in what way a WMM KIC can contribute to improvement – among other things, through targeted investment and closing of skills gaps.

To address the challenges identified in the inland water, marine and maritime sectors effectively, it is essential to benchmark against best practices in policy and regulatory support for innovation. This involves examining successful models from other KICs, international case studies, and sectors where policy frameworks have significantly fostered innovation and sustainability. By analysing these initiatives, we can extract valuable insights and strategies that could be adapted and applied within the WMM KIC context to overcome current barriers and drive progress. To stay clear of redundancy and to ensure complementarity, it is therefore imperative that a future WMM KIC is developed in close alignment with these initiatives.

As the water, marine and maritime sectors already represent diverse and complex research and innovation ecosystems, a cross-cutting initiative might seem to constitute an overly complex environment for a KIC. However, several of these ecosystems' key challenges and opportunities have relevance across the hydrosphere. This report points towards areas of synergies to be harvested from a *blue alliance*, understood as a crosscutting approach to challenges in the water, marine and maritime sectors and ecosystems. To support the development of a well-integrated WMM KIC, we recommend a special focus on transversal topics such as:

- digitalisation, data management and accessibility
- cybersecurity
- nature-based solutions
- autonomous systems and robotics for ocean and water monitoring
- innovative governance of the hydrosphere
- a circular approach and water reuse, especially for industry, agriculture, and aquaculture.

This report underscores the need for a WMM KIC within the EIT framework. The analysis demonstrates that by fostering a dynamic ecosystem of collaboration, innovation and sustainability, WMM KIC is poised to play a pivotal role in advancing the EU's environmental, economic and societal objectives. Furthermore, the strategic alignment with EU policies, the engagement of diverse stakeholders, and the targeted addressing of identified gaps and regulatory challenges underscore the WMM KIC's capacity to contribute significantly to Europe's leadership in the global blue economy.

Bridging these identified gaps empowers the WMM KIC to spearhead innovation, promote sustainable methodologies, and bolster ecosystem resilience, aligning with the EU's strategic goals for a sustainable and prosperous future.

The report identifies a high potential, as well as crucial policy, regulatory and systemic shortcomings that, once addressed, could markedly enhance the innovation landscape across the inland water, marine and maritime sectors. In synthesising the findings from our analyses, it becomes evident that the establishment of a WMM KIC is not only strategically beneficial but also imperative for leveraging the EU's innovative potential to address the urgent challenges and opportunities within the water, marine and maritime sectors.

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1. Introduction

1.1. Background

Oceans, seas, and inland waters play a central role in the preservation of critical ecosystems, climate-related dynamics, and biodiversity, as well as for transportation, provision of food, renewable energy and the needs of the industry (IPCC, 2022). There are many topics of growing concern regarding the way we utilise these indispensable resources. Among top concerns are water scarcity, floods, threats towards water quality, water and wastewater treatment, non-sustainable fishing and aquaculture, lacking ocean preservation, adverse marine and freshwater ecosystems management, and potential shortage of critical raw materials. Responsible innovation and technology development, including a more innovative public-private and cross-sector cooperation, is critical for finding sustainable solutions to the challenges of the hydrosphere.

As an overarching roadmap, the EU Green Deal gives the direction to ensure a robust green and blue transition for Europe. The Green Deal stimulates change in a number of potential key sectors for the KIC WMM, including carbon-neutral energy, hydrogen, sustainable extractive industries, e-based learning, e-health, connectivity and infrastructure, security, sustainable tourism, green technologies, fisheries and agriculture.

Water is of great value in the EU economy. The EU's water dependent sectors generate €3.4 trillion, or 26% of the EU's annual gross value added, and employ around 44 million people. EU water policy is very important to European citizens.[1] A third of the world's population lives in an area comprising less than 4% of submerged land. The supply, treatment and distribution of water is critical to the welfare of our societies, but climate change represents a significant threat towards the availability and quality of this vital resource. An analysis based on numbers from the World Bank shows that in the absence of efficient water allocation and policy measures, water scarcity could cause declines of up to 10% in GDP in many regions of the world by 2050 (Global Center on Adaptation, 2019). Conversely, the implementation of efficient measures would have a significant mitigating impact. Water-related investments can generate a mix of public and private benefits both from valued goods and services and from reduced water-related risks. However, as the sector requires long-term commitment and many of the benefits are not easily monetised, the viable business models and defined revenue streams associated to investments remain limited (OECD, 2022, p. 4).

Europe is in a comparatively favourable position, since most European countries would only need to invest 0.5% of their national GDP in order to deliver sustainable water management, while in other countries this can exceed 4% of GDP (Water Europe, 2023, p. 9). This notwithstanding, European investments in water management is not increasing to the extent that could be expected, indicating a lack of visibility for the innovations and their business potential (BlueInvest, 2024, p. 54 ff.), despite increasing public attention to the key role of the sector. Recognising the need to focus explicitly on the mounting sustainability challenges connected with waters, such as increasing water scarcity and flood risks, the European Economic and Social Committee in 2023 launched the EU Blue Deal to raise awareness of the importance of addressing water as a priority at European Scale (EESC, 2023).

The size of the global ocean economy was in 2010 estimated at USD 1.5 trillion, or 2.5% of global gross value (OECD, 2016). Pre-covid, the OECD projected a significant acceleration in economic activity in the ocean, with a conservative estimate of a doubling in size of the gross value of ocean-based industries by 2030, to around 3 trillion USD (OECD, 2016). Employment in ocean industries as a whole was estimated to more than double by 2030, reaching a number of over 40 million, and

[1] The public consultation in relation to the *Fitness Check of the Water Framework Directive and the Floods Directive* received more than 370,000 responses in total, which is an exceptionally high number (cf. EC, 2019).

significantly outpacing the overall growth rate of the global workforce. While the pandemic slowed the pace of the projected blue growth, especially in areas like coastal tourism and maritime transport, the pace is currently picking up.

In Europe, the blue economy, including both traditional sectors (transport, ports, naval industry, fishing, aquaculture and tourism) and the emerging domains, (marine energy, renewable energies, blue technology, desalination, robotics, cable) directly provides at least 4.5 million jobs, in addition to the numerous indirect and sub-contracted forms of employments, and generates a turnover of 600 billion euros in Europe (EC, 2021) The Blueinvest report from 2024 shows that the volume of disclosed investments in the European blue economy is three times larger than it was ten years ago, indicating a strong growth pattern for the sector. However, the same report reveals a limited average level of maturity of the blue economy sector overall, indicating a need for targeted efforts to unlock the potential of the European blue economy (BlueInvest, 2024).

The ocean and its resources are indispensable to addressing global challenges by delivering food, jobs, energy, raw material and the prospects of economic growth. Meanwhile, the ocean is under severe stress from overexploitation, pollution, declining biodiversity and climate change. Any acceleration of economic activity in the ocean will therefore have to take place in support of the global sustainability goals and with a holistic ocean management as a basis (OECD, 2016). A study from 2021 maps the main barriers preventing adequate financing of a sustainable ocean economy at a global level, including a weak enabling environment for attracting sustainable ocean finance, insufficient public and private investment in the ocean economy, and the relatively high-risk profile of ocean economic sectors (Sumalia et al., 2021).

In Europe today we see a clear fragmentation of education, science, innovation and technology activities in the water and ocean sectors, and a disconnect between academic, research and entrepreneurial activities (Marrocu et al., 2022). The innovation ecosystem in the ocean and water sectors frequently fails to bring the findings and expertise of innovators towards potential end users, a failing often referred to as the European Paradox (EC, 1995).

We live in an age of unprecedented technological innovation, and new technologies abound in the waters and ocean fields, but their adoption is too slow. On the other hand, a responsible adoption of new technologies requires foresight, inclusiveness, and responsiveness on the side of both innovators and policymakers. Such processes should not be rushed but should rather be properly institutionalised in order to balance efficiency with safety, security, and equity.

1.2. Call for an EIT KIC in the water, marine and maritime sectors

The European Institute of Innovation and Technology (EIT) drives innovation in Europe by supporting entrepreneurs, innovators and students across Europe to turn their best ideas into reality. This unique model is based on supporting the building of partnerships across sectors, and since it was established in 2008, the EIT has funded nine such knowledge and innovation communities. The KICs carry out activities covering the whole innovation chain, from education to business creation. The EIT could be the right instrument at EU level to enhance cross-border, multi-disciplinary collaboration and to fully exploit the potential of the knowledge triangle in the water, marine and maritime sectors. A KIC, with its holistic and integrated approach, has all the elements to help address the major economic, environmental and societal challenges. The water- and ocean-related fields have a strong knowledge base and high market potential. Hence, a KIC could potentially strengthen the innovation ecosystems throughout Europe to tackle water- and ocean-related challenges, train the next generation of innovators and entrepreneurs, and identify and support innovative solutions.

On the background of the challenges and opportunities presented in 1.1, the need for a KIC in the areas of freshwater and marine waters as well as in maritime domain has been promoted over a number of years by politicians, policy makers, industry actors and the academic communities alike. The political frame for a future KIC WMM was detailed in the official journal of the European Union from May 2021, with a decision on the Strategic Innovation Agenda of the EIT 2021-2027:

> *A [...] new KIC, in the field of Water, Marine and Maritime Sectors and Ecosystems (WMM), is proposed to be launched in 2026, with a call for proposals to be published in 2025* (EC, 2021, p. 100).

Appendix 2 of the SIA features a factsheet summarising the challenges in the WMM field and the expected impact of a KIC WMM. The factsheet lists some important synergies and complementarities between the future KIC WMM and other relevant policy initiatives, specifically within Horizon Europe (notably Mission Restore our Oceans and Waters by 2030 and the Sustainable Blue Economy Partnership), and how the KIC should interact at the global level with relevant UN initiatives and the SDGs, in particular SDG 6 'Clean Water and Sanitation', SDG 11 'Sustainable Cities and Communities', SDG 13 'Climate Action' and SDG 14 'Life below Water'. The KIC on WMM should also contribute to priorities established in the European Green Deal, in particular the 'Farm to Fork Strategy', the 'Zero pollution action plan for air, water and soil', the 'initiatives to increase and better manage the capacity of inland waterways' and the EU Biodiversity Strategy for 2030. This legal framework provides a useful horizon for the following report on how to prioritise, design, organise and facilitate.an EIT funded WMM KIC.

The European Parliament continues to oversee the activities of the EIT, and is keen in providing additional evidence to inform the ex-ante analysis of the Commission on the potential launch of a WMM KIC call for proposals as soon as possible, and ideally already in 2024. As part of the preparation, this report aims to provide useful recommendations to the discussion around the setting up of an EIT funded WMM KIC. In addition, it aims to advise how a KIC can contribute to the development of the appropriate framework conditions to transform ideas into new technological developments and to their market deployment in view of improving the quality of life and benefitting Union citizens. The study draws the landscape of topics and relevant relations to meet the climate goals supporting sustainable change and growth, of current and emerging technologies, and point towards the needs for more research, more innovation and possible re-design of regulations.

1.3. Overview of the relevant sectors

The freshwater, marine and maritime sectors and activities are often separated, but at the same time closely connected. Examples include aquaculture where both fresh- and saltwater are necessary resources, and marine robotics developing technologies relevant for monitoring of both inland and coastal waters. However, as a starting point, we define the four main (partly overlapping) areas of the KIC WMM in the following way:

- **Inland water sector**: Industries and institutions that provide water and wastewater products and services throughout the value chain as well as support to area planning, river- and lake management. Among the most important are water engineering, water and wastewater plant construction, equipment supply, specialist water treatment chemicals and modelling tools.
- **Marine sector**: This term may be used broadly as covering all industries and institutions relating to the seas and oceans, or more narrowly to signify fisheries, aquaculture, and other forms of capturing, harvesting, or cultivating from the seas and ocean.
- **Maritime sector**: Again, the term is sometimes used broadly, but more narrowly it signifies industries and institutions relating to transport in or on water. Among the most important are maritime and inland shipping, ports, dikes, canals, sluices, shipbuilding, shipbuilding supply.

- **Marine/maritime technology**: The terms are used interchangeably and encompass marine engineering, offshore wind energy, ocean observation, and maritime research and development.

In the following, we treat the marine and maritime sectors together under the joint headline 'Blue Economy' (1.3.2) while the inland water sector is treated separately (1.3.1). We then highlight some themes and technologies that are transversal, and therefore of special relevance to a crosscutting KIC WMM (1.3.3).

1.3.1. Key areas of the inland or freshwater sectors

The inland water sector comprises several topics reflecting the needed water resources for multiple use including energy, food production, industrial processes, and domestic water. Some important areas for the interaction of knowledge, innovation and societal impact are listed below, referring to the European Water Association's 'Special note for Water KIC' (EWA, 2024).

Water resources: Groundwater mapping and modelling of water resources, emerging contaminants in inland water, risk mitigation of groundwater contamination, and managing aquifer recharge. Integrated river basin management, including sediment management.

Supply of clean and healthy drinking water: Target and non-target analysis of organic chemicals, filtration and treatment of drinking water, Monitoring and analysis of pathogens, and managing of ageing distribution systems.

Making water systems safe and efficient: Smart water distribution system (computer-based support), leakage detection and corrosion control, microbial ecology of water systems, and optimal utility design.

Flood resilient management of stormwater in rivers and cities: Overloading of sewage systems, flooding of water supply systems, stress level prediction on sewage systems, urban stormwater solutions, and development of nature-based solutions.

Pollution control through efficient and sustainable wastewater treatment: Resource recovery and GHG-emissions reductions, extraction and utilisation of heat and other resources (e.g. brine mining), and water reuse in industry.

Clean water for energy production: Sustainable and cost-effective water supply for green energy production. Extensive use of ultrapure water for Power-to-x / Green Hydrogen.

1.3.2. Key sectors of the blue economy (marine and maritime sectors)

The blue economy encompasses a wide range of sectors that utilise ocean and water resources and contribute to economic growth, innovation, and sustainability in Europe. Among the key sectors for the marine and maritime economy in Europe are:

Waterborne Transport and Logistics: Transport on ocean and waterways plays a crucial role in facilitating trade, connecting European countries with global markets, and supporting economic activities such as shipping, port operations, and logistics services.

Fisheries and Aquaculture: Fisheries and aquaculture are important sectors for food security, employment, and economic development in Europe. Sustainable fishing practices, aquaculture innovation, and value-added seafood products contribute to the blue economy's growth.

Marine Renewable Energy: Europe is a global leader in marine renewable energy, including offshore wind, wave energy, floating solar and tidal energy. Investments in renewable energy infrastructure and technologies support clean energy transition, reduce carbon emissions, and create jobs in coastal regions.

Coastal and Maritime Tourism: Coastal and maritime tourism is a significant economic driver in Europe, attracting millions of visitors each year to coastal destinations, beaches, and marine attractions. Sustainable tourism practices, nature-based tourism, and cultural heritage preservation contribute to the blue economy's vitality.

Blue Biotechnology and Pharmaceuticals: Blue biotechnology harnesses marine organisms and resources for medical, pharmaceutical, and biotechnological applications. Research and innovation in areas such as marine natural products, drug discovery, and bioprospecting contribute to economic growth and scientific advancement.

Ocean Observation and Monitoring: Ocean observation and monitoring technologies provide essential data and information for marine research, environmental management, and maritime safety. Investments in oceanographic research, monitoring networks, and satellite-based observation systems support sustainable ocean governance and resource management.

Marine Engineering and Infrastructure: Marine engineering and infrastructure projects, including port development, coastal protection, offshore structures, and marine construction, support maritime activities and coastal communities' resilience to climate change and natural hazards.

Marine Science and Research: Marine science and research contribute to advancing knowledge of marine ecosystems, biodiversity, ocean dynamics, and climate change impacts. Collaborative research initiatives, scientific expeditions, and ocean exploration programmes support innovation, education, and sustainable management of marine resources.

Blue Skills and Education: Blue skills and education programmes provide training and capacity-building opportunities for professionals, students, and workers in maritime-related sectors. Investments in vocational training, higher education, and lifelong learning support workforce development and enhance competitiveness in the blue economy.

Maritime Security and Defence: Maritime security and defence initiatives address challenges such as piracy, illegal fishing, maritime terrorism, border control and cybersecurity. Investments in maritime surveillance, maritime domain awareness, and defence capabilities contribute to protecting Europe's maritime interests and ensuring maritime safety and security.

These sectors, among others, collectively contribute to the blue economy's growth, resilience, and sustainability in Europe, fostering economic prosperity, environmental stewardship, and social well-being in coastal and marine regions.

1.3.3. Transversal topics

Water, marine and maritime sectors already represent diverse and complex ecosystems of research and innovation, hence a cross-cutting initiative might seem to constitute an overly complex environment for a knowledge and innovation community. On the other hand, as several of the key challenges and opportunities of these ecosystems have relevance across the hydrosphere, there are considerable synergies to be harvested from a 'blue alliance' – for example when it comes to sharing of expensive research infrastructure and systems for environmental surveillance. To support the development of a well-integrated KIC WMM, transversal topics should be taken into consideration such as:

- Digitalisation, data management and accessibility
- Cybersecurity
- Nature-based solutions
- Autonomous systems and robotics for ocean and water monitoring
- Innovative governance of the hydrosphere
- Circular approach and water reuse, especially for industry, agriculture, and aquaculture

This list of transversal topics is drawn from a combination of our literature review and stakeholder feedback through surveys and interviews, and is further analysed in chapter 3.4 (table 1).

1.4. The opportunity for a WMM KIC

The analyses presented in in this report indicate a clear need for a KIC in the water, marine and maritime areas. Furthermore, they point towards significant potential synergies between a WMM KIC and:

* Other European research and innovation initiatives, specifically Mission Restore our Ocean and Waters by 2030, and

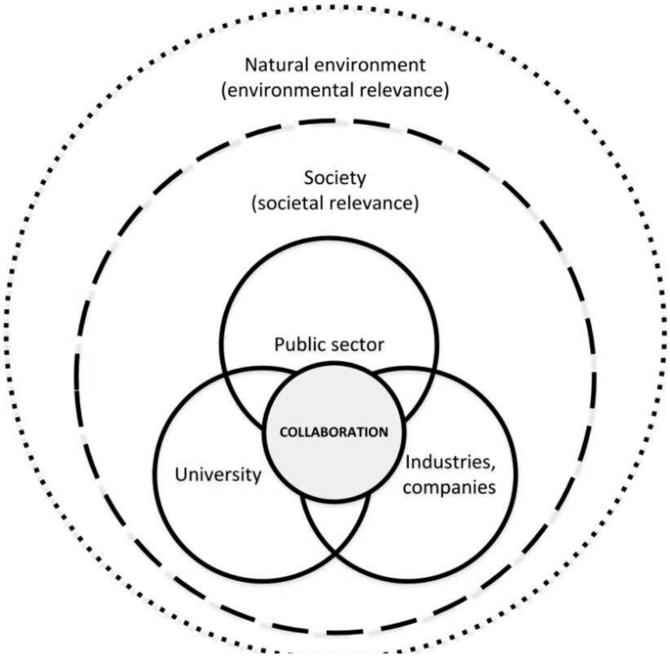
* Existing EIT KICs such as EIT Climate-KIC, EIT Digital, and EIT Food.

To effectively address the challenges identified in the inland water, marine, and maritime sectors, it is essential to benchmark against best practices in policy and regulatory support for innovation. This involves examining successful models from other KICs, international case studies, and sectors where policy frameworks have significantly fostered innovation and sustainability. By analysing these initiatives, we can extract valuable insights and strategies that could be adapted and applied within the WMM KIC context to overcome current barriers and drive progress. To stay clear of redundancy and to ensure complementarity, it is therefore imperative that a possible WMM KIC is developed in close alignment with these initiatives.

The nine established EIT KICs offer a wealth of best practices in fostering innovation that can provide valuable insights for WMM KIC. Their innovation model emphasises collaboration and knowledge exchange among government, academia, industry, and civil society, in line with the *triple helix model of innovation*, which refers to a set of interactions between academia, industry, and government as the key to innovation and economic development (Etzkowitz and Leydesdorff, 1995). This model is a central element in the thinking behind the EIT knowledge and innovation communities. It facilitates socially accountable policies and nurtures innovative ideas by connecting expertise with resources and reducing innovation risks through early investment support.

However, to succeed with the creation of a holistic knowledge and innovation community in water, marine and maritime sectors and ecosystems, it is vital to consider the expansion of this model into the *quadruple* and *quintuple helix models*, referring to the necessity of pulling civil society and the natural environment into the core of the innovation process in order to achieve a successful adaptation of new technologies (Carayannis and Campbell 2009; Peris-Ortiz et al., 2016). The innovation process should include five 'helices' (understood as subsystems of the innovation system) from the start: education system, economic system, natural environment, the public (civil society), and the political system (see Figure 1). The idea behind is that 1) a knowledge democracy is key to advance knowledge and innovation, and that 2) ecological concerns is a necessary constraint, but also a driver, of innovation.

Figure 1: The quintuple helix model (Rosenlund, 2017)



Source: Rosenlund, 2017

The EIT organisation also adopts an *Open Innovation* approach, defined as 'a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology' (Chesbrough, 2003). By leveraging external knowledge, networks, and ecosystems, EIT KIC facilitates the creation of new solutions in collaboration with various stakeholders, including the public sector and cities. This approach emphasises the importance of user-driven innovations and the benefits of engaging diverse actors in the innovation process.

For WMM KIC, adopting similar strategies should involve:

- *Implementing Collaborative Innovation Models*: Emulating the knowledge helix and open innovation approaches to enhance cross-sector collaboration and stakeholder engagement in water sector innovations.
- *Leveraging Tailored Support Programmes*: Developing programmes to provide targeted support for innovators in the ocean and water sectors at various stages of development and scaling.
- *Fostering a Global Innovation Community*: Building a network of partners across the public and private sectors to facilitate knowledge exchange and co-creation of marine, maritime and inland water sector innovations.

Case studies featured in the annex of this report exemplifies the implementation of such strategies within the WMM sectors. In developing WMM KIC, it is crucial to strategically delineate its focus areas to enhance and complement, rather than overlap with, the initiatives of other knowledge and innovation communities (KICs). Some of these encompass ocean-water issues within their frameworks – for example, several projects and initiatives within EIT Food and Climate KIC are ocean and water related, which opens up for the possibility of setting up complementary WMM KIC activities. On the other hand, the lack of water- and ocean-related activities within EIT Health may open up for new collaborations, for example supporting developments within new biotechnology for medical purposes. In general, aligning closely with the existing KICs is vital to ensure best practice in the setting up and governance of the WMM KIC.

This approach ensures that WMM KIC can leverage unique strengths and fill specific gaps in innovation and sustainability, fostering synergies rather than redundancies within the broader ecosystem of EIT KICs. Careful coordination and clear communication between KICs will be key to maximising collective impact on Europe's water and ocean sustainability goals.

2. Methodology

2.1. General methodology and resources used for the study

The development of this study is based on the use of the following tools:

- Analysis of the existing literature, references, and accessible data
- Mapping of key stakeholders
- Analysis of existing standards and legislative files in Europe
- Analysis of documented case studies
- Analysis of the information provided by relevant actors in the water, maritime and marine sectors and ecosystems jointly, in particular through the use of personal interviews and a survey.

Based on the study of the existing literature, references, relevant use cases and accessible data, the analysis assesses the most relevant topics in the water, marine and maritime sectors with the purpose of confirming and qualifying the need to create a knowledge and innovation community (KIC) within the EIT dedicated to water, ocean, marine and maritime sectors, technologies and ecosystems.

Before embarking on the data collection, an initial mapping of key stakeholders were performed in connection with a workshop that took place on January 11 2024 in the European Parliament in Brussels. Here, key stakeholders for an ocean and water KIC were identified as encompassing academia, research organisations, relevant industry sectors, vocational education and training providers, pan-European platforms, municipalities, policy makers, and NGOs.

Marilou SUC (Blue Connection), a Blue Growth Consultant specialised in the Blue Economy, was engaged to support the analyses of the available data. Specifically, Blue Connection contributed to the SWOT analysis and the Gap analysis, and furthermore helped with activating a broad network of actors within the marine sectors. Corresponding activation of the water and maritime sectors were supported by, respectively Water Europe and European Water Association (EWA), and the Waterborne technology platform.

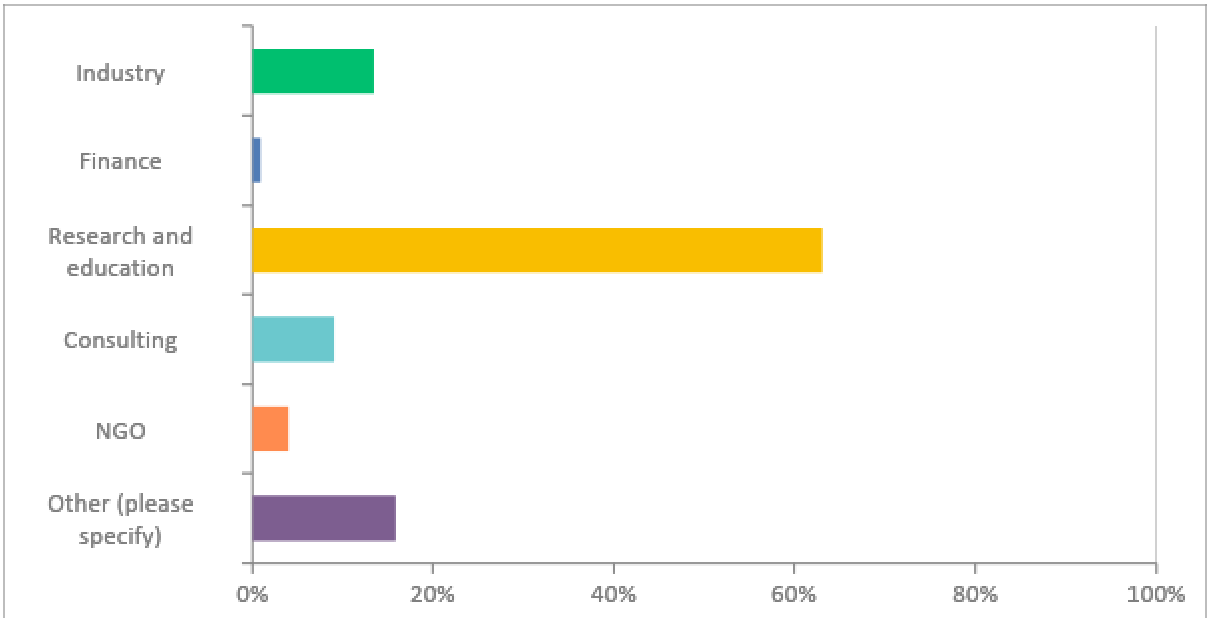
2.2. Survey and interviews

The survey was developed jointly by the expert group and distributed among a broader expert panel for input during the first week of February. The survey was launched via Surveymonkey on Tuesday, February 13, 2024, and closed on Monday, February 26. The link to the survey was spread via the expert group's extended network, via e-mail lists and SoMe channels.

The number of complete responses was 453. A survey response is one survey taker's submission of a survey, whether they completed the survey or only partially completed it.

- **Complete responses**: The respondent answered all required questions they saw and clicked Done on the last page of the survey.
- **Incomplete or partial responses**: The respondent entered at least one answer and clicked Next on at least one survey page, but didn't click Done on the last page of the survey.
- **Disqualified**: The respondent selected an answer option that disqualified them due to Skip Logic in the survey.

Figure 2: Survey respondents divided on sectors



As figure 2 indicates, the research and education sector is by far the most well-represented group of respondents. The reason is probably that the expert group has closer connections to academia than other sectors, so that in the limited time span of the survey we succeeded best in reaching out to this sector. We have addressed this bias by collecting extra responses and performing in-depth interviews with representatives from other sectors, notably from finance and industry, to ensure that these perspectives are well represented in the findings of the report. Note also that the specifications provided in the 'others" category show that almost all of the respondents here represented the governance/public sector, regional and national clusters, SMEs, or other end users. Hence, seen together with the 'industry' category, the total number of respondents from the end-user side was close to 30%.

We experienced some technical problems with the survey, leading to several questions lacking in the version that was published in Surveymonkey, particularly pertaining to the rating of important topics in the water sector. Recognising the need for balance, this was supplemented by an extended user survey for the inland water sector with contributions from 19 European countries covering all parts of Europe, and by targeted in-depth interviews with industry stakeholders to glean insights into industry-specific challenges and innovation potential. The stakeholder group included industry leaders, academic researchers, and representatives from professional associations within the inland water, marine and maritime sectors across various European countries.

The participants of the survey were first presented with a list of nine open-ended questions. The questions were the following:

What is a sustainable innovation for you?

- Which existing, emerging, and affordable technologies have the highest potential for impact in the water, marine and/or maritime sectors, in particular to reach sustainability and climate goals?
- Could you identify any legal and regulatory barriers or enablers for sustainable technological innovations in the water, marine and/or maritime sectors?
- What do you think are the main bottlenecks to achieve a successful process from research, via education and innovation, to implementation of new knowledge?

- How important is open-source knowledge and data sharing for European innovation in the water, marine and/or maritime sectors, and why?
- Could you assess existing funding mechanisms and propose future models for sustainable financing of the Water KIC?
- What academic training needs to be developed or created to stimulate sustainable innovation in the water, marine and/or maritime sectors?
- What infrastructures and/or digital services are most urgently needed for the water, marine and/or maritime sectors?
- Could you offer policy recommendations and business models for creating an environment conducive to innovation and effective market deployment, in alignment with the European Green Deal and other relevant EU strategies?

While the responses to the open-ended questions gave us a rich material to work on with a lot of relevant input, the relatively low rate of participants completing the whole survey indicates that this first part of the survey may have been too demanding.

The list of open-ended questions were then followed by three sector-specific parts, where respondents were asked to range the overall potential of different innovation domains, using a number from 1-10.

The outcome of the reviews are presented as the number of respondents who graded the importance of the topic as 8, 9 or 10:

Inland water sector:

- Removal of contaminants of emerging concern, including microplastics from drinking water.77%
- Technologies and solutions aiming at water supply resilience (drought).77%
- Securing sustainable water use, irrigation, and fit for purpose water quality.73%
- Removal of contaminants and plastics from water flows to ocean.72%
- Improving treatment of wastewater towards contaminants of emerging concern. 72%

The following topics received the highest scores from the additional survey (percent of received answers):

- Asset management of urban water systems (both grey and green). 50%
- Shifting the paradigm from wastewater treatment facilities to resource recovery facilities, including water reclamation, energy production, nutrient recovery, and biosolids beneficial use. 47,5%
- Nature-based solutions for stormwater management and flood reduction 45%
- Accelerate the use of AI for system optimisation, (e.g. reduction of water losses from distribution systems; smart monitoring; decentralised control) 45%

Marine sector

- Diversify and develop aquaculture in a more sustainable way; including new species and aquaculture for algae; 73%
- Develop new tools and technologies for observation of the oceans (autonomous underwater vehicles and sensors in the ocean); 71%
- Identify existing European (local and international) marine pollution policies and regulations and create recommendations to prevent, mitigate, and respond to marine pollution incidents; 68%
- Develop methods and tools to measure impact of pollutants, including anthropogenic sound/noise and light, on marine biodiversity; 67%

Maritime sector

- Develop and demonstrate solutions for the use of climate-neutral, sustainable alternative fuels applicable to ships with high energy demand (e.g. long distance shipping); 74%
- Develop and demonstrate solutions for port-based supply infrastructure (i.e. infrastructure for bunkering of alternative fuels and electricity); 61%
- Mitigate cybersecurity risk in the context of maritime transport, autonomous ships and distributed networks; 61%

The interviews were performed as semi-structured, digital talks, with the same list of open-ended questions as a starting point but allowing for adjustments according to the expertise and interest of the interviewees. A total of 25 interviews were conducted as part of the study.

All data has been collected and treated in accordance with GDPR in order to protect the privacy of our informants.

2.3. Analyses

A detailed description of the methodology used for the SWOT and Gap analysis is featured in 2.3.1 and 2.3.2. The case studies featured in the annexes are primarily based on literature studies and interviews with key people in the sector.

Beyond the overview presented in 2.2, we do not provide an overall ranking of the barriers and enablers, nor the strengths, weaknesses, opportunities, and threats (SWOT) presented in chapter 3. The relative importance of each barrier, enabler, or aspect of the SWOT varies significantly based on the respondents' role, the specific sector they are involved in, and their position within the innovation chain or knowledge triangle chain. For example, an innovator might view regulatory hurdles as a major barrier, while a policymaker might see funding limitations as more significant. Similarly, strengths and opportunities might be perceived differently by researchers versus industry stakeholders.

One potential approach to ranking these would be to count the number of respondents who suggested each point for the SWOT analysis or the barriers and enablers analysis. However, since the analyses also draws on insights derived from previous studies and reports, this further complicates the creation of a clear ranking. Given the limited scope of this study, hence also a lack of representativeness of the sample, we do not have a basis for a structured and qualitative view of the relative importance of each factor, which also acknowledges the inherent variability in their perceived significance across different stakeholders and sectors. Further studies is needed to provide the basis for such a ranking. However, a careful evaluation of the rich material we derived from the data collection provides a sound basis for a qualitative analysis of the needs of the sectors.

2.3.1. SWOT analysis methodology

The methodology for the SWOT analysis (chapter 3. 5) encompasses a comprehensive approach, engaging a variety of sources and stakeholder inputs to ensure a robust evaluation. Key components of the methodology include:

- *Stakeholder Consultations*: Through a survey (in total 453 responses). The biggest group of contributors came from the research and education sectors, but with a significant number of responses also from industry and end users.
- *Policy Document Review*: Critical examination of strategic documents, notably 'Bridging Knowledge Gaps towards 2030' (Pace et al., 2023) and the EU Mission 'Restore our Ocean and Waters' framework, provided foundational insights into sustainable blue economy trends and strategic planning needs. The Mission in

particular shaped the review with its comprehensive approach to ocean and water health, particularly its novel concept of 'lighthouses' for regional collaboration. This policy serves as a model for how the WMM KIC can integrate its initiatives within EU efforts for environmental sustainability and innovation. These resources were instrumental in aligning WMM KIC's objectives with the EU's policy framework, offering a model for integrating WMM KIC initiatives with broader environmental sustainability and innovation efforts.

- *Analysis of Innovative Project Outcomes*: An assessment of outcomes from Horizon Europe-funded projects in water-related sectors enriched the analysis with empirical data on innovation impacts, challenges, and best practices, suggesting pathways for future sustainability and innovation efforts.
- *Trend Analysis*: Engaging with experts and reviewing recent sectoral advancements highlighted technological and ecological trends shaping the water, marine, and maritime sectors' future, informing the strategic direction and potential contributions of WMM KIC.

This methodology draws extensively on insights from the European Union's strategic documents and research initiatives, as well as the experiences and outcomes of the different actors involved in the sectors covered by the future WMM KIC. It ensures that the SWOT analysis is grounded in a comprehensive understanding of the EU's innovation landscape, policy environment, and the specific needs and dynamics of the water, marine, and maritime sectors.

2.3.2. Gap analysis methodology

The gap analysis (chapter 3.6) adopts a streamlined, multi-step approach to identify and propose solutions to policy and regulatory gaps affecting the water sector's innovation ecosystem. The methodology integrates data collection, stakeholder engagement, and benchmarking to ensure a comprehensive and evidence-based analysis.

- *Data Collection*: Initial efforts focused on gathering relevant policies, regulations, and strategic documents from EU and national levels, alongside secondary data from academic and industry sources. This foundational step aimed to map the current policy landscape impacting the water, ocean, marine, and maritime sectors.
- *Stakeholder Engagement*: Insights from a wide array of stakeholders were solicited through surveys and interviews. This phase aimed to capture diverse perspectives on barriers to innovation, drawing from policymakers, industry experts, and academia.
- *Benchmarking Process*: An analysis of international best practices in policy support for innovation served to identify actionable models that could be adapted to the EU context. This involved comparing the EU's regulatory framework against those noted for enabling significant advances in similar sectors.
- *Analysis and Synthesis*: The collected data and stakeholder feedback were analysed to pinpoint specific policy and regulatory gaps. This synthesis highlighted discrepancies between current frameworks and the needs for fostering a robust innovation ecosystem within the WMM KIC's scope.

Through this methodology, the gap analysis seeks to deliver targeted recommendations, paving the way for enhanced policy support and regulatory alignment with the WMM KIC's innovation objectives.

3. Strategic analysis

In this chapter we present the results of our strategic analysis in support of the WMM KIC. The goal of the data collection and the methodology presented in chapter 2 was to provide a list of the thematic focus areas with the highest potential for technological development, marked deployment, and benefit for EU citizens. The analyses further point towards potential economic, social, and environmental benefits of investing in these technologies.

3.1. High impact technologies for sustainability in the water, marine and maritime sectors

The interviews and responses to the survey question about existing and emerging technologies with the highest potential impact in the water, marine, and maritime sectors, particularly for achieving sustainability and climate goals, provided a wide array of innovative solutions. In the following, we present a synthesis of the responses. The limited data collection from this report does not provide the basis for a quantitative ranking of the maturity, market potential, or sustainability impact of the technologies. However, a qualitative assessment of the transversal topics with the highest potential impact is provided in chapter 3.4.

3.1.1. Water sector technologies

Integrated water management and sustainability

Nature-Based Solutions & Urban Environment Management: Strategies encompassing both flood prevention, freshwater habitat improvement, stormwater management, and flood reduction. These solutions emphasise the use of natural processes to enhance water sustainability and urban resilience.

Water Conservation Techniques: Focus on technologies for saving and reusing water, such as desalination and atmospheric water generators, alongside improved irrigation methods and smart systems powered by remote sensing and IoT to enhance water use efficiency.

Advanced water treatment and recovery

Innovative Water and Wastewater Treatment: Advanced methods for the removal of contaminants, microplastics, and the desalination of seawater. Techniques include reverse osmosis, UV oxidation based on LED, and alternative biological and electrochemical processes. Enhancements in wastewater treatment processes also ensure the secure supply of water to food production.

Water Treatment and Recovery Systems: Emphasising the circulation and recovery of wastewater, including nutrients and minerals, energy positive wastewater treatment, applicable both inland and on ships, to foster circular water use practices.

Digital and AI-driven water systems optimisation

Management of Water and Wastewater Systems: Deployment of digital twins for comprehensive water and wastewater systems management, coupled with AI-driven optimisation to reduce water losses. Systems for wastewater reuse further underscore the sector's move towards digital and sustainable management practices.

Environmental monitoring and infrastructure maintenance

Advanced Analysis and Monitoring: Leveraging advanced analytics and genomics for water cycle governance, from water resources allocation and management to biodiversity monitoring and conservation. This category underscores the importance of data-driven insights in managing water resources effectively.

Infrastructure Maintenance: Solutions focused on reducing resource waste and contamination due to corrosion and deterioration in water supply and sewer systems and other hydraulic infrastructures. This includes adopting decentralised systems and green chemical technologies to ensure the longevity and efficiency of water infrastructure.

Pollution control and ecosystem restoration

River and Lake Management: Direct strategies aimed at removing contaminants and plastics from water flows, polluted sediments, specifically targeting pollution pathways to oceans and contributing to the broader goal of ecosystem restoration and protection.

3.1.2. Marine sector technologies

Renewable Marine Energy: Emphasising sustainable materials and components, including offshore wind, wave energy, floating solar, and technology for dual use in offshore energy production, such as multi-use offshore energy wind parks. It is important to note that according to the logic of this report, wind parks should be considered, not only from a technology and energy supply point of view, but also in terms of their impact on marine ecosystems and coastal populations.

Biotechnology and Bioengineering: Development of new pharmaceuticals, biomaterials, biofuels, and bioremediation solutions through marine biotechnology and bioengineering, alongside genetics for improving cultures to be less water demanding.

Aquaculture and Ecosystem Management: Sustainable aquaculture practices (e.g., IMTA, algae cultivation), technologies to prevent sea lice attacks and promote circular economy approaches, alongside advanced genomics for ecosystem management and enhancing coastal resilience through ecosystem restoration and engineering solutions.

Sustainable Exploitation of Marine Bioresources: Diversification of aquaculture, exploration of marine metabolites, enzymes, and biomolecules for industrial applications, and sustainable management plans for marine resources.

Environmental Monitoring and Cleanup: Accurate, long-life, and low-cost sensors for automation and remote monitoring, field testing and mitigation of harmful algal blooms, and technologies for ocean clean-up, including waste material and plastic removal and decommissioning of offshore windfarms and oil & gas platforms.

Cleaning European Seas: Measures to identify and mitigate pollution sources, including the development of (bio)remediation measures and technologies for reducing microplastics and contaminants flow to oceans.

Climate Change Risk Management: Utilising digital twins of the ocean for climate risk monitoring, developing new tools for ocean observation including biology, chemistry and physics variables, and assessing the impact of climate change on marine ecosystems to mitigate climate hazards.

Marine Biodiversity Protection: Tools for modelling and monitoring of direct impact of land-sea use change, tools for identifying invasive species origins and impacts, measuring the effect of pollutants on biodiversity, and managing solutions for coastal to deep-sea ecosystems. Other technologies may concern those limiting invasions by various vectors such as ships and aquariums or aquaculture.

Cultural Heritage Valorisation: Discovering and valuing marine and coastal cultural heritage, fostering sustainable innovation in this unique area.

3.1.3. Maritime sector technologies

Vessel Innovation: The development of future vessels that are autonomous, green, and capable of zero emissions/discharges, incorporating renewable energy integration and biofouling management solutions.

Circular Economy and Resource Efficiency: Circular Economy in Shipbuilding and Decommissioning, and innovation in circular/recovery technology for managing wastewater on board ships.

Digital and Security Innovations: Utilisation of virtual reality for testing, prototyping, and planning, alongside cybersecurity measures. Big data and AI applications for autonomous navigation, collision avoidance, predictive maintenance, and processing vast data sets.

Sustainability in Ports and Infrastructure: Green port initiatives including electrification and wastewater management, enhancing port efficiency through automation and smart technologies, and upgrading waste reception facilities.

Traceability and Data Management: Blockchain for enhancing fish farming quality and traceability and preventing overexploitation of marine resources, coupled with big data analytics for ocean and ecosystem observation.

Greener, Smarter, and Safer Maritime Transport: Solutions for using sustainable alternative fuels, high-capacity battery solutions for short-distance shipping Including inland shipping), wind propulsion, and clean port infrastructure. Advances in digitalisation, AI, and autonomous ships (MASS), including intelligent navigation and condition-based maintenance. Developing robust safety and cybersecurity measures for autonomous ships and maritime facilities.

3.2. Barriers and enablers: Legal, regulatory and social dynamics shaping sustainable innovation in the water, marine and maritime sectors

The identification of legal, regulatory barriers, and social acceptance or enablers for sustainable technological innovations in the water, marine, and maritime sectors reveals a complex landscape that innovators must navigate. These factors can significantly influence the deployment and success of sustainable technologies. Organising these elements into barriers and enablers offers a structured view of the challenges and supports available for advancing sustainability in these sectors. Again, the analysis does not provide a quantitative ranking of the main barriers or enablers. The relative importance according to respondents varies according to their place within the innovation ecosystem, but the topics brought up delivers a good basis for the SWOT and Gap analyses, delivering a qualitative assessment of how a WMM KIC may contribute to improving the innovation ecosystem within the relevant sectors.

3.2.1. Barriers

Legal and Regulatory Hurdles: Innovators face a complex and fragmented regulatory landscape, with several legal regulations potentially jeopardising the development of a circular economy. Specific challenges include the lack of specific regulations for the multi-use of offshore systems and fragmented responsibilities across national governments, hindering a unified approach to marine development.

Competence Deficiency: General a lack of available staff in R&I, development and operations, in particular in the engineering fields underlying the sectors. Declining interest from the next generation.

Social Acceptance Challenges: Significant social barriers exist, such as the poor social acceptance of wastewater reuse, both for drinking and in agriculture, and the resistance to new technologies due to lack of understanding or information about their safety and benefits.

Technical and Expertise Gaps: There is a lack of expertise for emerging technologies such as autonomous vessels, blockchain, and advanced sensors. This gap extends to the need for a diverse range of experts in policy formulation and a consensus-building process before the introduction of new technologies.

Safety, Security, and Liability Concerns: Issues related to safety and security implications of new technologies, data sharing and privacy concerns, and liability and insurance in autonomous technology operations present significant barriers. Hereunder also cybersecurity risks and the security of all marine infrastructure at sea and on the sea floor.

Environmental Impact and Governance Complexity: Balancing innovation with environmental protection poses challenges, exacerbated by the complexity of governance arrangements and the lack of efficient regulatory incentives for cooperation across sectors.

Economic and Funding Limitations: The lack of funding and a sense of urgency by politics and businesses to invest in sustainable technologies, along with innovation disparities between regions, limit the level of activity and development.

3.2.2. Enablers

Growing Environmental Awareness: There is an increasing focus on reducing environmental impact and fostering sustainable practices among the public and private sectors, supported by innovation cultures that embrace technological trends.

Stricter Legislation: Legislation such as the Urban Wastewater Treatment Directive (UWWTD), Environmental Quality Standards (EQS), and the Industrial Emissions Directive (IED) acts as enablers by setting higher standards for environmental protection.

Incentive Programmes and Supportive Frameworks: The establishment of regulatory sandboxes, dedicated funding mechanisms for sustainable maritime technologies, and capacity-building initiatives facilitate testing and development of new solutions.

Collaboration and Capacity Building: The promotion of collaboration among public and private stakeholders, marine spatial planning with an ecosystemic approach, and the encouragement of cross-border water management enhance the support for sustainable innovations.

Public Dialogue and Information Sharing: Initiatives for wide public dialogue and the sharing of information regarding the benefits and safety of new technologies can improve social acceptance and support for sustainability efforts.

By addressing these barriers and leveraging the enablers, stakeholders in the water, marine, and maritime sectors can significantly advance the adoption and effectiveness of sustainable technological innovations, aligning with global sustainability and climate goals.

3.3. Key infrastructures and policy measures for advancing water, marine and maritime sector technologies

Focusing on the infrastructures needed to specifically support innovation within the water, marine and maritime sectors, the responses emphasise the importance of establishing and enhancing collaborative, technological, and knowledge-sharing infrastructures. Again, the data do not provide the basis for a quantitative ranking or an overview over the existing inventory, but provide useful input for a qualitative assessment of the most promising thematic areas for a WMM KIC, which will be further developed in 3.4.

3.3.1. Observatories and data management

Observatories for Water and Marine Stakeholders: The creation of observatories at both country and EU levels is crucial for coordinating efforts across water and marine stakeholders. This infrastructure will improve governance and spread the impact of solutions developed by the KIC, incorporating platforms like Danubius-RI, Marinerg-I, JERICO, SeadataNet, Fondation Open Sea, and MERCATOR Ocean.

Digital and Data Infrastructure: Essential for sustainable maritime infrastructure development, high-speed connectivity and data sharing, and management platforms integrate and leverage marine data effectively.

3.3.2. Collaborative and educational infrastructure

Living Labs and Pilot Sites: Establishing living labs as regulatory sandboxes that cover various aquatic environments, from rivers and estuaries to open seas, is vital for testing and validating innovative solutions in real-world settings.

Academic Collaboration: Supporting the creation of European MSC and Doctoral programmes and promoting shared use of existing research laboratories/facilities via mobility programmes are key for fostering academic-industry collaboration.

Innovation Hubs and Business Accelerators: Infrastructure supporting innovation hubs and business accelerators can catalyse entrepreneurship and the development of SMEs within the blue economy sectors.

3.3.3. Knowledge sharing and innovation support

Open Scholar Platforms: Sharing knowledge through open scholar platforms are crucial for advancing research and innovation.

Autonomous Vehicles: Utilising autonomous and remote-operated vehicles like AUVs, SUVs, ROVs, and gliders are vital.

Co-location of Stakeholders: Facilities that enable the co-location of stakeholders from different sectors encourage knowledge and equipment sharing, essential for transitioning from academia to industry.

Research and Development Centres: Development of R&D centres, incubation hubs for water, marine and maritime startups, and collaborative research centres that bring multidisciplinary teams together to address water and marine challenges.

Technology Testing and Demonstration Sites: Facilities for technology testing and demonstration, including demo and pilot plants, are necessary for progressing toward market-ready sustainable solutions.

Education and Training Centres: Promoting interdisciplinary education and practical training, such as field cruises and operation of advanced equipment, prepares future professionals for industry challenges.

Regulatory and Policy Support Infrastructure: Streamlining regulatory processes and providing policy support can significantly enhance the innovation ecosystem, making it more conducive to growth and development.

By focusing on these infrastructure developments, the water and marine sectors can substantially bolster their innovation capabilities, facilitating the transition of groundbreaking ideas from conception to implementation, thereby driving sustainable and competitive advancements in these crucial areas.

3.4. Transversal topics for the water, marine and maritime sectors and ecosystems

The diverse feedback received from the stakeholders reflects the various challenges and priorities of the different industries involved. However, focusing on a technology-centric approach, we identified common technologies and innovations that align with the needs across the marine, maritime, and water sectors. Table 1 focuses on these key technologies and innovations, illustrating their transversal nature and potential benefits across the WMM KIC sectors and ecosystems.

Table 1: Key technologies for the WMM KIC based on transversal potential

Technology	Applications
Resource Recovery	- Resource recovery facilities (energy production, water reclamation, nutrient recovery, and biosolids beneficial use)
Artificial Intelligence (AI)	- AI for system optimisation (reduction of water losses, smart monitoring, decentralised control)
	- AI for searoute optimisation for shipping
	- AI for river flow forecasting and flood prediction
	- AI techniques for ship collision and grounding risk modeling
	- AI for resilience modelling of water critical infrastructure
	- AI for predictive maintenance of offshore infrastructure
	- AI and digital twins to build scenarii to anticipate and build action schemes (SeaGPTs), including accurate performances for all the marine sectors
	- AI detection for biodiversity monitoring
Nature-Based Solutions	- Nature-based solutions for stormwater management and flood reduction
	- Nature-based solutions for river and ecosystem restoration
	- Nature-based solutions for agriculture run-off control
	- Anchor systems not harmful to the marine environment
Digital Twins	- Digital Twins for efficient monitoring and systemic management of complex water ecosystems
	- Digital twins for managing water and wastewater systems
	- Digital twins for monitoring freshwater and marine environments
	- Digital twins of the ocean for climate risk monitoring
	- Digital twins for early event detection (harmful algae bloom, typhoon, etc.)

Technology	Applications
Marine renewable Energies	-Marine renewable energies development
New Ocean Observation Technologies	- New technologies for precise and global observation of the Ocean from space to the deep sea (Sensors, systems, connectivity's including IoT, data management and exploitation)
	- Smart cables with sensors
	- Satellite detection for coastal corrosion monitoring, impact of climate change
Removal of Contaminants	- Removal of contaminants of emerging concern, including microplastics from drinking water
	- Removal of contaminants and plastics from water flows to ocean
Develop Systems for Irrigation	- Develop systems for irrigation water saving in agriculture
Safety and Security	- Safety and security of Drinking Water Systems
	- Safety engineering practices and risk assessment for autonomous ships
	- Mitigating cybersecurity risk in maritime transport
	- Resilience modelling of water critical infrastructure and cascading effects
	- Mitigation systems to reduce the impact on marine ecosystems (underwater noise, collision, etc.)
Pollution Monitoring	- Pollution monitoring and control from point sources or diffuse pollution from urban runoff
Water and Wastewater Treatment	- Systems and services for water reuse (water reclamation, storage, conveyance)
	- Improving treatment of wastewater towards contaminants of emerging concern
	- Seawater desalination using renewable energy
	- Water treatment (ballast water, industrial water, PFAS, aquaculture)
Autonomous Robotics	- Robotics for inspection and rehabilitation of water systems
	- Robotics for autonomous ships navigation
	- Remotely controlled shipping
	-Robotics for deep sea exploration
	- Robotics for offshore infrastructure inspection (O&G, Offshore wind farm, aquaculture farm, etc.)
Decarbonisation	- Decarbonisation of the maritime sector and supply chain optimisation (H2, electrification of port infrastructure, new fuels)
	- Wind propulsion vessel
Sustainable fisheries and aquaculture	- Sustainable fisheries and aquaculture, alternative proteins, IMTA and other optimised solutions
Fishing Fleet Modernisation	- Modernisation of fishing fleet and ports with less energy-consuming engines, hybrid propulsion, alternative fuels, and other innovative solutions

Technology	Applications
Carbon removal solutions	- Carbon removal solutions, taking into account ethical aspects
Climate-neutral Fuels	- Climate-neutral, sustainable alternative fuels for ships
	- High-capacity batteries for short distance shipping
	- Non-fuel based propulsion (such as wind)
Metabolite Exploration	- Explore and exploit metabolites and biomolecules
Enzyme and Gene Exploration	- Explore and exploit enzymes and genes
Digitalisation	- Digitalisation technologies, big data analytics for smart maritime activities
	- Digitalisation of ports and link to Maritime Autonomous Surface Ships (MASS)
	- Digitalisation for condition-based maintenance of ships
Early Warning Systems	- Early warning tools to detect pollutants
Resource Management	- Management plans for sustainable exploitation of coastal to deep-sea biotic resources
	- Management of urban water systems (both grey and green)

By focusing on key technologies and innovations, this table highlights the crosscutting applications that could benefit all aspects of the WMM KIC, aligning with stakeholders' diverse needs while emphasising the most frequently mentioned or prioritised technologies.

3.5. SWOT analysis

The SWOT analysis is designed to evaluate the potential for establishing a knowledge and innovation community (KIC) focused on water, marine, and maritime (WMM) sectors within the European Union. It aims to identify internal strengths and weaknesses inherent to the proposed KIC framework, as well as external opportunities and threats that could influence its operational success and strategic impact.

3.5.1. In-depth evaluation of strengths

The establishment of WMM KIC rests on Europe's solid foundation of strengths, well-prepared to lead the sustainable blue economy. Central to these strengths is Europe's vibrant innovation ecosystem, characterised by leading research institutions, a legacy of cross-border collaboration, and cutting-edge technological infrastructure, essential for developing innovative solutions in inland water, marine, and maritime sectors.

Strategically aligned with pivotal EU policies like the European Green Deal, Horizon Europe, and the Blue Growth Strategy, WMM KIC's goals are in sync with the European Union's broader objectives.

This synergy is further supported by Europe's comprehensive policy landscape that encourages innovation and sustainable growth within the blue economy. The EU's comprehensive policy frameworks, such as the European Green Deal, the Maritime Spatial Planning Directive, the Blue Growth Strategy, and the Water Framework Directive, provide a strong regulatory foundation for sustainable water, marine, and maritime activities. These frameworks support innovation, environmental protection, and sustainable development.

The essence of collaboration across Europe, marked by robust networks and partnerships, bolsters co-innovation and the deployment of sustainable solutions. Europe's leadership in the blue economy is underpinned by its commitment to sustainability and climate goals, positioning the WMM KIC to contribute significantly towards climate resilience and biodiversity conservation. The European Union, through its member states and collaborative efforts between the European Commission and the European Investment Bank (EIB), presents a comprehensive financial support system for the Water, Marine, and Maritime (WMM) sectors. This system provides funding and investment opportunities through programmes like Horizon Europe and the European Maritime and Fisheries Fund (EMFF), aimed at fostering research, innovation, and technology development. Additionally, initiatives like the 'EU Blue Champions' scheme and the Blue Invest platform enhance the WMM knowledge and innovation community's (KIC) capacity for impactful innovation by providing targeted financial advisory services and facilitating access to finance for early-stage businesses, SMEs, and scale-ups.

The opportunity for channelling of funding and investment through these programmes and initiatives, along with the comparable availability of skilled workforce, provides a robust support system for the KIC's endeavours. Moreover, increasing public awareness and engagement, bolstered by significant global events hosted in Europe, enhance community support for sustainable water, marine and maritime initiatives.

3.5.2. Comprehensive assessment of weaknesses

While the strengths provide a solid foundation, acknowledging and addressing the inherent weaknesses is crucial for the KIC's success. Fragmentation within the blue economy sectors and insufficient integration across disciplines and industries are significant barriers that the WMM KIC must overcome to ensure a unified approach to tackling complex challenges.

Limited access to funding for SMEs and startups, due to complex application processes and high competition, and regulatory hurdles that slow innovation adoption, are identified as critical weaknesses. Despite some improvements, there are still relatively few projects funded for projects with intermediate TRL levels 4-7 ('the innovation valley of death'), and a lack of funding for collaborative projects between Academia and SMEs.

A particular point of concern is the marine and inland water sectors' chronic underfunding (OECD, 2022; Sumalia et al., 2021), which significantly limits opportunities for research, innovation, and sectoral growth. This underinvestment starkly contrasts with the potential high returns of ocean-related initiatives, highlighting an urgent need for enhanced financial support, especially considering the marine sector's pivotal role in achieving sustainable development goals, particularly SDG14 (Life below water), which notably receives the lowest level of investment (WEF, 2022).

While Europe is a leader in the development of marine technology, we are rather slow in the implementation phase, compared to e.g. the US. The slow introduction of innovation in most water-related areas are not least due to very costly and long-term investments in infrastructure that makes the sector very conservative. However, exceptions exist, not least in the aquaculture sector.

Furthermore, the fragmented policy frameworks across European regions and countries pose substantial barriers. There exists a pressing need for a more cohesive and integrated approach to policy making to stimulate growth and innovation within the inland water, marine and maritime sectors. Such an approach would not only streamline regulatory processes but also foster a more conducive environment for sector-wide advancements.

In addition to funding and policy challenges, the WMM KIC faces a rapidly growing skills gap leading to a need for workforce development within several specialised areas of the blue economy. Enhancing a broader public awareness and stakeholder engagement is equally important to forge a robust support system for WMM KIC's endeavours.

Moreover, the challenge of data availability, sharing, and integration across sectors and regions impedes informed decision-making and innovation. Despite the promising initiative of the European Digital Twin Ocean to democratise marine data access, hurdles such as data standardisation, interoperability, and real-time access persist, potentially limiting the initiative's effectiveness. This limitation is also present in the inland water sector.

Addressing these challenges head-on is essential for WMM KIC to ensure a coordinated, well-funded, and innovative approach to tackling the complex challenges faced by Europe's inland water, marine, and maritime sectors.

3.5.3. Leveraging opportunities for growth

The WMM KIC is positioned to capitalise on a myriad of opportunities that can bolster its impact within the blue economy. Technological advancements in water, marine and maritime sectors open new horizons for innovation, while the European Green Deal provides a strategic framework for aligning WMM KIC initiatives with EU environmental objectives.

The push for interdisciplinary and cross-sectoral collaboration presents an opportunity for the WMM KIC to serve as a conduit for integrated solutions to inland water, marine, and maritime challenges.

Evolving policy and regulatory landscapes offer chances for the WMM KIC to influence supportive frameworks that facilitate innovation. Access to European and global markets, coupled with an increasing focus on sustainability, provides a fertile ground for commercialising innovative solutions. The water sector, being closely related to climate adaptation policies, may benefit from growing investments, for instance in flood control systems, nature based solutions, reservoir management, and in river restoration and re-naturalisation.

New funding and investment initiatives, notably BlueInvest,[2] alongside a growing emphasis on education and workforce development, further enriches the spectrum of opportunities for WMM KIC, driving its mission forward and reinforcing its role in promoting sustainable growth within the blue economy. This necessity for ecosystemic and transboundary approaches is evident in the call for 'climate-smart' marine spatial planning highlighting the critical role of the WMM KIC in facilitating comprehensive and cohesive action.

Digital Twins of the Ocean are virtual representations that serve as a digital co-creation space, fostering interdisciplinary research and collaboration between scientists, policymakers, entrepreneurs, and citizens.[3] This technology encourages innovative approaches to managing marine ecosystems and economic activities. The EU’s Integrated Maritime Policy's emphasis on sea basin strategies and international cooperation, particularly in the Atlantic, Baltic, Mediterranean, and Black Seas, opens avenues for the WMM KIC to engage in collaborative research and innovation efforts, expanding its impact beyond European borders.

3.5.4. Navigating external threats

However, the path forward is fraught with threats that the WMM KIC must adeptly navigate. Climate change and environmental degradation pose existential risks to marine and freshwater ecosystems, necessitating adaptive and resilient strategies.

Economic volatility and funding uncertainties could impact resource availability, while diffuse research efforts and a skills gap may slow the pace of innovation.

[2] https://blueinvest-community.converve.io/

[3] Cf. https://digitaltwinocean.mercator-ocean.eu/

Regulatory barriers, technological disruptions, and competition on the global stage are additional threats that require strategic attention. Societal and political shifts, alongside data security and geopolitical tensions, represent further challenges that the WMM KIC must address to ensure its initiatives are both impactful and sustainable.

3.5.5. Strengths, weaknesses, opportunities, threats (SWOT) analysis

The SWOT analysis illuminates the strategic imperatives for the WMM KIC, highlighting the need for a holistic and adaptive approach to foster innovation and sustainability within Europe's blue economy.

By building on its strengths, addressing its weaknesses, seizing opportunities, and mitigating threats, the WMM KIC can significantly contribute to the European Union's environmental, economic, and societal goals.

Table 2: SWOT analysis

STRENGHTS	WEAKNESSES
• Strong Research and Innovation Base • Advanced Technological Infrastructure • Comprehensive Policy Framework for water, marine and maritime sectors in Europe • Collaborative Networks and Partnerships • Advanced Digital Infrastructure: European Digital Twin Ocean – Ocean Observation network • World-leading in development of Blue Technology • Market Leadership in the Blue Economy • Commitment to Sustainability and Climate Goals • Funding and Investment Opportunities • Skilled Workforce • Growing Public Awareness and Engagement • European Leadership in Maritime Policy	• Challenges in Cohesion and Cross-Sectoral Collaboration • Limited Access to Funding for SMEs and Startups and for applied research • Insufficient funding and investment challenges • Regulatory and Policy Hurdles • Increasing Skills Gap and Lack of Workforce Development for the future • Unevenly Distributed Public Awareness and Stakeholder Engagement • Insufficient Climate Change Adaptation and Resilience • Limited Data Availability and Technological Integration • Lack of shared platforms for infrastructure, testing facilities, and capacity-building • Limited technology transfer and commercialisation

OPPORTUNITIES	THREATS
• Advancements in Blue Economy Technologies • Leveraging the European Green Deal and Global Sustainability Trends • Interdisciplinary and Cross-Sectoral/Transboundary Collaboration • Policy and Regulatory Evolution • Access to European and Global Markets Funding and Investment Initiatives • Education and Workforce Development	• Climate Change and Environmental Degradation • Economic Volatility and Funding Uncertainties • Diffuse Research Efforts • Regulatory and Policy Barriers • Technological Disruption, Adoption Rates Competition, and International Rivalries • Societal and Political Shifts • Data Security and Cyber Threats • Geopolitical Tensions and Resource Conflicts

3.6. Gap analysis

The gap analysis is an essential strategic tool aimed at identifying and bridging the policy, regulatory, and systemic discrepancies that presently inhibit the full realisation and effectiveness of a knowledge and innovation community (KIC) focused on the Water, Marine, and Maritime sectors within the European Union.

This analysis aimed at identifying and bridging the policy and regulatory gaps that currently hinder innovation, entrepreneurship, and educational advancements in the ocean and water domains. By focusing on these areas, the analysis aims to uncover specific challenges and opportunities for policy intervention, ultimately supporting the WMM KIC's mission to foster innovation, enhance competitiveness, and contribute to environmental sustainability.

3.6.1. Policy and regulatory gaps

The European Union's comprehensive framework of policies, directives, and initiatives serves as a foundation for innovation and sustainability in the inland water, marine, and maritime sectors. However, a detailed analysis reveals specific policy and regulatory gaps that, if addressed, could significantly enhance the innovation ecosystem and its contribution to education and entrepreneurship within these sectors.

Despite the extensive regulatory framework, certain areas have been identified where existing policies may not fully support or may inadvertently hinder innovation. Table 3 presents these areas (gaps), examples of how they materialise (example problem), and potential solutions which a future WMM KIC may provide (example solution).

Table 3: Gap analysis I: Policy and regulatory gaps

Gap	Example problem	Example solution
Integration and Coherence Across Policies: There is a need for greater integration and coherence among policies and directives. Overlapping regulations and the lack of a unified approach can create confusion and increase the administrative burden for stakeholders, hindering innovative projects and initiatives.	Diverse national regulations on water reuse can lead to inconsistent practices across the EU, affecting cross-border water management projects.	*Advocate for EU-wide guidelines on water reuse to streamline practices and foster uniform standards.*

Adaptation to Emerging Technologies: The rapid pace of technological advancement in water treatment, conservation, and maritime technologies outpaces the current regulatory framework. There is a lag in the adaptation of policies to accommodate new technologies, leading to a regulatory environment that can be perceived as restrictive rather than enabling.	Rapid developments in AI for water management outpace existing data protection regulations, potentially hindering implementation.	*Establish a task force to regularly update regulations in line with technological advancements, ensuring innovations like AI-driven water management are efficiently integrated.*
Funding and Investment Mechanisms: While initiatives like Horizon Europe and the European Maritime and Fisheries Fund provide significant support, gaps in funding and investment mechanisms for early-stage innovations and startups in the water sector persist. These gaps impact the ability of entrepreneurs to scale their solutions and bring them to market.	Early-stage water tech startups often struggle with securing funding due to high initial costs and perceived risks by investors.	*Create a dedicated EU fund for water innovation, offering grants and low-interest loans to early-stage companies focusing on sustainable water technologies.*
Stakeholder Engagement and Collaboration: Although stakeholder engagement is a cornerstone of many directives, there remains a gap in effective collaboration between policymakers, industry, academia, and NGOs. This gap affects the identification of practical needs and the development of regulations that fully support innovation and sustainability goals.	Fragmented communication channels between water sector researchers and industry professionals' slow innovation transfer.	*Develop an EU-wide digital platform for knowledge exchange, connecting researchers, entrepreneurs, and industry professionals to enhance collaboration.*
Skill Development and Education: The current policy framework does not sufficiently address the need for skill development and education tailored to the evolving demands of the water sector. Bridging this gap is essential for fostering an innovative ecosystem and supporting entrepreneurship.	A shortage of professionals trained in both water management and digital technologies limits the sector's innovation potential.	*Launch interdisciplinary degree programmes and continuous professional development courses focused on merging ocean and water sustainability with digital skills.*
Regulatory Harmonisation: Regulatory frameworks should be harmonised across borders to facilitate innovation, reduce bureaucratic hurdles, and support the development of a cohesive water management strategy.	Divergent regulations on marine protected areas across EU member states complicate cross-border conservation efforts and sustainable fisheries management.	*Work towards EU-wide harmonisation of marine conservation standards and practices, involving stakeholders in a transparent consultation process to ensure the regulations are both effective and feasible.*

Regulatory Agility: Need for adaptable regulations that swiftly accommodate technological advancements, ensuring a dynamic response to innovation within the water sector.	The slow regulatory response to new desalination technology applications can delay their deployment.	*Implement a 'regulatory sandbox' environment allowing temporary relaxation of norms for testing and scaling innovative water solutions.*

3.6.2. Insights from stakeholder engagement

To refine our comprehension of the barriers impacting innovation and entrepreneurship in the water, marine, and maritime sectors, we broadened our stakeholder engagement, incorporating an extensive collaboration with industry professionals.

This approach, blending survey data, in-depth interviews, and case studies, unearthed substantial insights into sector-specific challenges, highlighting essential areas requiring policy intervention and enhanced support. This proactive and comprehensive engagement strategy emphasises several critical gaps where a WMM KIC could contribute with improvement, investment, or restructuring in order to achieve the desired outcomes.

Table 4: Gap analysis II: Barriers impacting innovation and entrepreneurship in the WMM sectors.

Gap	Example problem	Example solution
Collaborative Ecosystems: Need to foster enhanced collaboration across sectors, emphasising co-creation and knowledge exchange between the private sector, research institutions, and policymakers to drive innovation.	Lack of collaboration between urban planners and water management experts results in missed opportunities for integrating nature-based solutions in urban development.	*Initiate cross-sectoral partnership programmes that incentivise integrated urban and water planning projects.*
Support for Digital and AI Integration: Need for policies that support the digital transformation and AI integration in water management, including the use of digital twins and smart systems for optimised operations.	Existing policies do not fully support the implementation of digital twins in water management due to data sharing concerns.	*Develop guidelines and standards for data sharing and privacy in the implementation of digital twins and AI in water management systems.*
Nature-Based Solutions and Sustainability: Emphasise the integration of nature-based solutions in urban and agricultural water management to enhance sustainability and resilience against extreme weather events.	Fragmented communication channels between water sector researchers and industry professionals' slow innovation transfer.	*Develop an EU-wide digital platform for knowledge exchange, connecting researchers, entrepreneurs, and industry professionals to enhance collaboration.*
Data-Driven Management: Lag in use of advanced analytics and comprehensive environmental monitoring to inform data-driven water management and policy decisions.	Limited access to comprehensive water quality data hampers the effective management of water resources.	*Support the development and deployment of sensor networks across water bodies to gather real-time, comprehensive water quality data.*

Social Engagement and Public Acceptance: Lack of strategies to improve social acceptance of new technologies through public engagement, transparent communication, and community involvement in technological deployments.	The introduction of wastewater reuse in agriculture faces scepticism due to public concerns over safety and quality.	*Launch an education campaign showcasing successful case studies of wastewater reuse, emphasising the safety measures and benefits, to build public trust and acceptance.*
Capacity Building and Skill Development: Insufficient support for interdisciplinary education and training programmes to develop the next generation of skilled professionals in the water sector.	The emerging field of smart water management requires skills in both water science and information technology, which current education programmes rarely offer together.	*Develop joint degree programmes between universities and industry partnerships that combine water resource management with digital technology training, backed by internships that offer practical experience.*
Innovative Financing for Water Infrastructure: Need for diverse and sustainable financing models and business plans to support the development and scaling of water sector innovations.	Traditional financing models often do not cater to the unique needs of sustainable ocean and water projects, which may have longer payback periods.	*Introduce green bonds or sustainability-linked loans specifically designed for ocean and water infrastructure projects (ex: Marine renewable energies), offering favourable terms for projects that achieve certain environmental impact metrics.*
Asset Management and Circular Economy: Policies do not fully support resilient infrastructure and circular economy practices, focusing on resource recovery and efficient asset management in water systems.	Ageing water infrastructure leads to significant losses and inefficiencies, yet investment in modernisation is hampered by cost concerns.	*Advocate for policies that provide financial incentives for upgrading to more efficient, circular water systems, such as tax breaks or subsidies for technologies that enable the recovery and reuse of water, energy, and nutrients.*
Cross-Sector Collaboration and Multi-Use Approaches: Need for policies that enable cross-sector collaboration and the multi-use of marine and freshwater resources, fostering an integrated approach to resource management.	The potential of multi-use offshore platforms combining aquaculture, energy generation, and marine protection is underutilised due to sectoral silos.	*Facilitate workshops and funding opportunities that encourage consortia from different sectors to develop integrated offshore projects, showcasing the benefits of collaborative resource management.*

The identified policy and regulatory gaps have a tangible impact on the innovation ecosystem within the water, marine and maritime sectors. Barriers to the integration of emerging technologies and the scaling of innovative solutions hinder the sector's potential to contribute to environmental sustainability and economic growth.

Moreover, insufficient collaboration and support mechanisms affect the capacity for innovative education and entrepreneurship, limiting the development of a skilled workforce and innovative start-ups capable of addressing future challenges in the water sector.

3.7. Strategic pathways and action plan for WMM KIC development

In support of the development of the WMM KIC within the European Institute of Innovation and Technology (EIT) framework, this section outlines why a KIC appears to be the right tool to address critical gaps in the water, marine, and maritime sectors. The following strategic actions are vital for leveraging the unique capabilities of the KIC instrument, designed to catalyse innovation, foster collaboration, and ensure impactful societal and economic benefits.

- **Adopt an Impact-Led Approach**: A WMM KIC should implement a strategic agenda focused on societal and economic impacts, underpinned by measurable Key Performance Indicators (KPIs). This approach, inspired by the EIT's impact framework, emphasises strategic planning, performance monitoring, and evaluations to ensure progress toward strategic goals.
- **Foster Responsible and Open Innovation**: Emulating best practices from other KICs, WMM KIC should promote policies encouraging a diverse and dynamic partnership across the knowledge triangle. This would enable rapid validation of ideas and their translation into impactful innovations.
- **Legal and Governance Framework**: Establishing a legal entity that reflects WMM KIC's commitment and enables agile decision-making is crucial. Adopting best practices in governance and management will ensure that WMM KIC remains responsive to innovation landscapes.
- **Intellectual Property Policy**: Developing a clear intellectual property policy will manage and exploit innovations effectively, contributing to WMM KIC's sustainability and fostering an environment of trust and collaboration among partners.

The SWOT analysis in section 3.5 highlighted the fertile ground for establishing a WMM KIC, in the form of excellent research and innovation environments and cutting-edge infrastructure and a strong policy framework. However, it also revealed crucial vulnerabilities, specifically in terms of limited access to funding and regulatory hurdles that slow down the adaptation of innovation. The strategic alignment with EU policies, the engagement of diverse stakeholders, and the targeted addressing of identified gaps and regulatory challenges underscore WMM KIC's capacity to address the weaknesses and significantly contribute to Europe's leadership in the global blue economy.

The Gap analysis in section 3.6. addressed policy and regulatory gaps as well as other barriers impacting innovation and entrepreneurship in the ocean and water sectors. By analysing concrete problems arising from these gaps, it became clear how a WMM KIC may develop a toolkit designed to close the gaps and remove the blockages from the ocean and water value chains.

In synthesising the findings from both the SWOT and Gap analyses, it is evident that the establishment of a WMM KIC is not only strategically beneficial but also imperative for leveraging Europe's innovative potential to address the urgent challenges and opportunities within the water, marine, and maritime sectors.

4. Policy options and their assessment

Based on the findings of this report, we present policy options and recommendations for how to best create an environment conductive to innovation and effective market deployment for the water, marine and maritime sectors and ecosystems, in alignment with the European Green Deal and other relevant EU strategies. An overarching objective is to create integrative, flexible, and collaborative frameworks and affordable solutions to the unique sustainability challenges within the water, marine, and maritime sectors.

We present four policy options which are all realistic, however some of them may only be deliverable with unacceptable political, social and regulatory consequences or high cost.

4.1. Policy option A: No WMM KIC

This option considers that there is insufficient support for the creation of the WMM KIC, either because of a failure to recognise its usefulness, or because of an assumption that the costs will exceed the benefits. The immediate benefit of abandoning the plan to launch the WMM KIC is that the planned investment from the EIT is released for other causes. However, based on the present analyses, it is hard to imagine an area where the need to scale up investments, activities, and capacity building is more precarious than in the water, marine and maritime sectors. Thus, the risk of abandoning the KIC would be a less targeted use of the planned investments.

A further risk is that the intended contribution from the WMM KIC towards the green transition of European industries would fail to materialize, thus delaying the necessary transition in these areas. Similarly, as the contribution from the KIC to education and capacity building in these areas would fail to appear, the foreseen skills gap within these sectors would likely increase.

The abandonment from the strategic agenda of the EIT would further create uncertainty within the European research and innovation environments regarding the long-term thinking and planning of investments in strategically important areas. This lack of predictability may have further negative political, social, and regulatory impacts, such as weakened public trust in the general research and innovation policies of the EU and as a consequence declining support of the policy frameworks of the SDGs and the EU Green Deal.

4.2. Policy option B: The goals of the WMM KIC are pursued through existing tools or instruments

There are several existing tools and instruments, both within Horizon Europe and other national, European, and international systems, dedicated to funding research, innovation and education within the water and ocean sectors. A possible policy option would be, rather than launching the WMM KIC as planned, to ramp up investments into the existing tools or instruments. Mission Restore our Oceans and Waters by 2030 stands out, particularly in terms of its focus on cross-sectoral collaboration and citizen engagement. Also, the BlueInvest initiative may conceivably be accelerated to further promote sustainable and innovative technologies and solutions for the blue economy.

A potential benefit of pursuing this option would be that the transaction costs of setting up a new KIC would be saved, and that existing initiatives would be fuelled. However, the EiT KICs are distinct from all other mechanisms in the European research and innovation ecosystems and have specific benefits in terms of amending the upscaling 'Valley of Death' and industrialising the developments from national and Horizon Europe R & I results. In addition, a WMM KIC can contribute substantially to address the skills gap and strengthen necessary competence building in these areas. Thus, the risk of relocating the intended KIC investments into other instruments or area would be to miss out on the chance to effectively address a well-documented weak point in the European research and innovation system.

4.3. Policy option C: Pursuing the goals of a WMM KIC through the existing KICs

The analyses have highlighted significant potential overlaps between WMM KIC and the existing KICs. A few of the existing KICs fund ocean- and/or water-based initiatives to a limited extent. Based on these findings, a policy option could be to pursue the goals of the planned WMM KIC through targeted enforcements of the already established and working KICs. A benefit of this option is, again, that transaction costs may be lowered while - as opposed to the option presented in 4.2 - the specific benefits of the EIT mechanism may be preserved. In this case, the specific expertise developed through the EiT system would also be preserved.

On the other hand, this option has clear risks in terms of disrupting the goals and functioning of the existing KICs, as ocean and water might be a transversal issue for the other KICs but not the focal point of any of them. For example, the EIT Food focuses on innovation in relation to food-related challenges such as nutrition and food security, while water as an integral component of any food production is not the focal point of any theme or mission of the EIT Food. In conclusion, option C misses out on the ambition of a WMM KIC to build a holistic approach to securing vital resources for the future while strengthening innovation for the whole hydrosphere.

4.4. Policy option D: Launch the WMM KIC as planned

In synthesising the findings from this report, it becomes evident that the establishment of a WMM KIC is not only in line with the European strategic innovation agenda, but also imperative for leveraging Europe's innovative potential to address the urgent challenges and opportunities within the water, marine, and maritime sectors. The analysis demonstrates that by fostering a dynamic ecosystem of collaboration, innovation, and sustainability, WMM KIC can play a substantial role in advancing the European Union's environmental, economic, and societal objectives.

A potential risk with a WMM KIC is that the broad thematic scope could lead to limited resources being spread out too thinly. It is therefore vital to have a targeted objective that conserves the crosscutting benefits while staying clear of redundancies and overlaps with other initiatives.

The strategic alignment with EU policies, the engagement of diverse stakeholders, and the targeted addressing of identified gaps and regulatory challenges underscore WMM KIC's capacity to significantly contribute to Europe's leadership in the global blue economy. Analyses by OECD support the high growth potential from water- and ocean-based industries, projected to doubling from 1,5 trillion USD in 2010 to 3 trillion in 2030 (OECD, 2016). In order for Europe to strengthen its competitiveness within these growing global markets, there is a need for timely and targeted efforts. Furthermore, there is an urgent need to address the prediction of a 56% gap between water supply and demand in Europe by 2030 (World Resource Institute, 2024). As a major water consumer, the industrial sector must confront this need, as the ultimate cost of inaction is predicted to exceed by five times the investments required to tackle upfront the water risks related to industrial activities (Water Europe, 2023). Given the challenges concerning the establishment of viable business models and defined revenue streams for the water sectors (OECD, 2022; BlueInvest, 2024), a knowledge and innovation community could significantly boost this blue transition. In conclusion, the outcome of our analysis lends strong support for establishing a WMM KIC, highlighting its potential to drive sustainable growth and innovation in Europe's water sector, aligned with EU and global sustainability goals.

4.5. Overall assessment of the policy options

Of the four considered options, policy option D stand out as the one with the lowest risk and the clearest benefits. However, it is worth noting that a successful implementation of the WMM KIC depends on a parallel development of a coherent regulatory system and legislation at an integrative level. A holistic approach is conductive for an efficient addressing of mounting water-related challenges such as scarcity, droughts, floods, and pollution. Flexibility and agility in regulation is also important to promote economic models compatible with the European Green Deal. Regulations should incentivise circular economy principles, resource efficiency, and social responsibility, particularly in regions facing high water scarcity.

Policy options B and C share the benefit of lower transaction costs, but also the disadvantage of missing out on the opportunity to target some of the most pressing challenges addressed in the SWOT analysis, such as limited technology transfer and commercialisation and the lack of shared platforms for infrastructure, testing facilities, and capacity-building. There is also the danger of jeopardising the directionality and thereby efficiency of the existing instruments by bringing in new objectives.

Policy option A is the weakest one, as the analyses display urgent needs and challenges in the relevant sectors, with high probability of adverse outcomes if the planned dedicated efforts fail to materialise.

4.6. Conclusion

Our analyses underscore the need for a water, marine and maritime knowledge and innovation community (WMM KIC) within the European Institute of Innovation and Technology (EIT) framework. This report has identified a high potential, as well as crucial policy, regulatory and systemic deficiencies that, once addressed, could markedly enhance the innovation landscape across the water, ocean, marine and maritime sectors.

Bridging these identified gaps empowers the WMM KIC to spearhead innovation, promote sustainable methodologies, and bolster ecosystem resilience, aligning with the EU's strategic goals for a sustainable and prosperous future.

Water is essential for the health of our blue planet and its inhabitants, including for human beings. Our societies are built upon responsible use and sharing of water and ocean-based resources, and securing and improving these systems is key for sustainable development. Innovation in this crucial area should aim to advance equity, diversity, inclusivity and accessibility. A Draft OECD Declaration on Transformative Science, Technology and Innovation Policies for a Sustainable and Inclusive Future (OECD, 2024) underlines that diverging national approaches in the governance of international science, technology and innovation co-operation present challenges to the open exchange of knowledge, and that the transformative potential of emerging technologies that may provide innovative solutions to our global challenges needs to be balanced against the risks of misuse and unintended consequences. An overarching demand for a WMM KIC is that it should contribute to transformative innovation that supports sustainable use and protection of our crucial ocean and water resources.

To foster an environment conducive to innovation and effective market deployment in alignment with the European Green Deal and other relevant EU strategies, policy recommendations and business models should focus on creating integrative, flexible and collaborative frameworks. These frameworks should aim to create affordable solutions to the unique challenges within the water, marine and maritime sectors, to ensure sustainability, circularity, resilience and equity.

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Annex: Case studies

Case studies from the freshwater area (water and wastewater, rivers)

This annex provides some background, as well as some concrete examples of the interaction of knowledge-innovation-business development and societal impact for the inland water sector. The examples are meant to better understand drivers for change and the interaction between knowledge and innovation and can serve as inspiration for a WMM KIC.

1 Information-based asset management of water and wastewater systems

In the 1960–1970's the management of water and wastewater networks was based on current knowledge and experiences of the maintenance staff supported by manual archives. The knowledge of the overall system performance was limited. High water loss and pollution to local and larger recipients was an increasing problem. The situation forced central and local authorities to act. Researchers in many countries started to develop computer models for the hydrodynamic performance of water and wastewater networks. Since there was a well-documented need for this technology, they were soon introduced in fore-front cities and later in most cities and applied by commercial consultants. The obvious need and a favourable cost related to the benefit were the main drivers for the implementation. In addition, came the education of engineers with modelling skills. The introduction of hydraulic models also introduced the need for sensors and instruments for operation of the models, and this forced the industrial development of tools for flow, pressure, and later water quality. This has been an ongoing development over several decades and it continues.

The empowerment of digital capacity and introduction of personal computers opened the opportunity of computer-based information systems for properties and maintenance reports of water and wastewater systems. Such systems were developed in parallel in many countries in an interaction between industrial companies and highly competent engineers from user organisations. The new technological opportunity was caught up by leading engineers and this led to a quick development of first-generation computer-based water management protocols, generating new businesses. This started a development towards more advanced digital tools for prediction of rehabilitation needs, risk analysis and use of AI (machine learning), a development that has created more businesses and has materialised into platforms for asset management and smart water systems, which is regarded as the present-day standard in most developed communities. This development is likely to continue in the form of advanced use of AI, introduced by researchers and industries as of now.

The main message is that the coincidence of timing between realisation of major challenges and the emergence of new technologies and the following close co-operation between researchers, industrial companies and forefront cities led to a powerful development that has existed continuously over several decades and continues. A further important fact to mention is that these developments have been successfully implemented in the various educational systems, as such ensuring a firm embedding in the professional field.

The innovation application and business creation in the water sector as described above has been historically intimately linked to urbanisation and the subsequent public health crisis. The climate crisis may be the next tipping point that will drive significant innovation application and business growth. Looking at the future with this perspective is useful to show that the sector might be entering a new coming of age that will require initiatives like Water KIC to really thrive.

2 Business development in drinking water and wastewater sector

This analysis goes back approximately 50 years. During the 1960s and -70s there was an emerging and growing concern about pollution of water resources. The situation by then can be described by:

- Eutrophication in lakes and fjords – calling for nutrient removal technologies.
- Rivers almost depleted from aquatic life (e.g. river Rhine)
- Groundwater bodies contaminated with a spectrum of pollutants due to (amongst others) waste dumping.
- Emergence of catastrophic events (e.g. the Minamata bay scandal in Japan)
- Coloured drinking water – calling for humic substance removal technologies.

3 Drinking water

Drinking water is produced from groundwater, surface water or sea water. A sustainable production of drinking water is in all cases needed, resulting in focus on saving water, energy, chemicals, etc. in the production. One of the main challenges in many countries has been the removal of organic substances, including pesticides and other micropollutants, or compounds leaching from materials in contact with water. A recurring issue is poor microbiological water quality that pose health threats. This can be done by avoiding contamination of water in the first place by securing wells, pipes and other infrastructure or by applying disinfection to kill introduced contamination. Driving forces for development have therefore been, and are, sustainability and health impact of the water supply.

Processes for removal of organic substances have been developed and new innovations brought to market, often following the structure mentioned above.

Safe hygienic water supply requires disinfection. This has taken place long time using chlorine, which had some adverse effects, e.g. the formation of bromoforms and other trihalomethanes that may pose a health threat. Apart from that, some major outbreaks of diseases have still happened and led to increased focus on systems for disinfection to minimise the weaknesses of the older solutions. This has led to the use of UV technology that is capable of removing bacteria (and to a certain extent virus) from water. Innovations have led to safer water quality technology and is nowadays used in many water supply systems.

Recently focus has turned to e.g. bacteria growth indoors as well as micropollutants like PFAS and microplastics entering the water sources. New research is conducted. This needs to be continued and new solutions brought to the market. On the other side, beneficial microorganisms and probiotics in water treatment can be crucial for maintaining a healthy ecological balance within water systems (Skovhus et al 2022)

The other main challenge on drinking water is availability. In particular Southern European countries are suffering from cyclic drought and permanent scarcity that jeopardises economic and social development. In the last years this has increased due to climate effects and extended to regions that were not in risk. This has led to a large research activity around brackish water and sea water desalination. Europe is leading the research and new developments (membranes, energy saving, brines recovery…) for a desalination market that is worth tens of thousands million euros. These innovations cover not only local needs but expand to a very profitable and active Middle East market. Europe needs to keep its leadership position in front of Asian lower production costs, differentiating with innovative products and a sustainable approach for this energy-intensive process. New research should create a set of solutions to build a new and more sustainable paradigm for scarcity issues.

4 Wastewater and water resource recovery

During the decades, several new or improved process solutions for wastewater have been developed and industrialised. Examples are:

- Physical/chemical processes for removal of phosphorus
- Biological treatment for removal on nitrogen, important for effluents into marine waters
- Moving bed biofilm reactor (MBBR). For removal of organic matters and nitrogen.

The MBBR development started in the late 1980's following the above-mentioned structure of academic, research innovation and industrial co-operation mentioned above. This new wastewater treatment approach became a great success and is to-day applied world-wide.

In the following decades the use of resources from wastewater has become an important issue. The wastewater sludge is digested for production of methane and is a source of sustainable energy to the extent that wastewater treatment plants are self-sufficient in terms of energy consumption. The organic and nutrient component of solid sludge is used as soil fertiliser.

Recent important innovations are related to recovery of nutrients (phosphorus and nitrogen) from wastewater through 'continuous moving bed' combined to chemical precipitation. Some treatment plants operate as resource factories and produce substances for fertilisers as well as soil improvement.

The new EU urban wastewater directive will require more extensive removal of micropollutants such as microplastic, pharmaceutically active compounds and corrosive agents. This will also require intensive cooperation between municipalities and industries. Extensive research has started and there is a strong need for new knowledge and innovation in the coming few decades.

The systematic collaboration between academia, applied research industries and other stakeholders has shown to be a success formula for the technological development of water and wastewater treatment.

5 Business development in urban stormwater management

Modern urban stormwater management incorporates the value of water in an urban setting. For smaller rain events water can be stored locally for gardening, maintenance of green structures and local ponds. Several green innovations have been applied in recent years, including infiltration beds, structured pavements, green roofs, and rain gardens, creating a new generation of green businesses.

It has to be highlighted that the Asset Management of these green innovations is a subject that needs urgent attention, as it has been largely neglected so far. It is expected to be a substantial development of new industrial products for storm water handling in the years to come, as already has started in Australia ~20 years ago.

Larger floods need substantial management. The use of local detention volumes and flood-paths when extreme rains occur and cause major flows are examples.

Meteorological warning systems become more and more important as major floods will occur more frequently and sometimes with a limited warning time. The improved modelling of rainfall/runoff events creates new opportunities for better storm water management in urban areas. This has also been an issue for business development during the last decades. A large number of private companies Europe-wide offer consulting and computer models and specific products such as sensors for monitoring and surface coating to safeguard infiltration.

Future research and innovations should incorporate the impact of climate change. The knowledge/innovation development is driven by the increase of local floods in urban areas and an industry positioned close to the sites of upcoming problems.

6 Business development on water in agriculture

By 2030, global freshwater demand is expected to exceed supply by 40%. The agricultural sector is presently responsible for ca. 70% of freshwater withdrawals worldwide. Thus, freshwater scarcity, food security and energy accessibility are critical interrelated worldwide concerns in the face of the growing global population. Climate change and the resultant changes to the global water cycle will continue to drive innovation in water treatment and fit-for-purpose reuse in conjunction with research and innovation on food production systems within a water-energy-food-climate nexus approach. The availability of water, nutrients and energy in the face of a changing global climate will continue to drive scientific and technological innovation in the current century. The present challenge is to further advance a systems approach to improving food security and translate food system innovations to provide sustainable solutions at multiple scales, ensuring equitable benefit to the world's population.

Advancement of technologies to effectively manage risks associated with irrigation in general, the reuse of various types of wastewaters in agricultural production, and the identification of appropriate institutional and technological options for managing change in the linked human and natural environment, are key to future food security.

7 Business development in water treatment and reuse for field-scale agricultural systems

Increasingly unpredictable patterns of precipitation leading to a spatial and temporal mismatch in water supply and demand necessitate the further development and mainstreaming of environmentally, economically, and socially sustainable water reuse technologies and practices. Freshwater scarcity also threatens natural ecosystems, contributing to biodiversity decline. The sustainability of agricultural systems is inherently linked with the health of natural ecosystems and their capacity to deliver ecosystem services. Thus, technological advancements and mainstreaming of innovative practices must support the long-term sustainability of the wider agro-ecosystem. This has implications related to both water quantity – e.g., the need for equal consideration of ecosystem services or 'environmental water' in agricultural water allocation/use schemes – and water quality, particularly with respect to recycling of water.

The concept of 'fit for purpose' water reuse for effective management of water resources is widely advocated in many areas prone to drought, yet a number of barriers remain to water reuse for production of food crops. Both social and technological innovation are needed to overcome existing barriers to effective water treatment and reuse at scale. In particular, socio-cultural and regulatory barriers to potable water reuse must be addressed. Although non-potable water reuse is more widely accepted, it is not without challenges. Key among the technical challenges associated with non-potable water reuse are concerns related to the potential transfer of antibiotic resistance (e.g., to soil microbial communities) or the uptake and accumulation of antibiotic-resistant genes and/or emerging contaminants of concern by crop plants.

8 Business development in water treatment and reuse for building- to district-scale urban agriculture

Urban gardening is a growing phenomenon in Europe and North America; however, public concern regarding potential adverse health effects from consumption of urban garden produce is also increasing. Whilst the UN FAO recognises urban agriculture as an essential component of food security in low-income countries, water is the limiting factor for food production in many areas. An estimated 70% increase in global food production is required to feed >9 billion people by 2050 (FAO, 2009). The consensus within the scientific community is that whilst future agricultural technologies and practices adopted to increase food production are context specific, they must be sustainable (Foley et al., 2011). In order to meet future food demands, agricultural production must be maximised along with concomitant optimisation of inputs and waste. Continued population growth along with increasing demands on land and water resources dictate that future increases in food production must be derived largely from increased agricultural productivity rather than increases in the area of land under production.

Critical issues for which further technological innovation is needed to mainstream sustainable practices include the treatment and reuse of water in agriculture and improvements in nutrient cycling within food systems. This is particularly relevant for urban agricultural and horticultural systems as urban agriculture moves food production closer to the point of consumption and waste disposal, reducing emissions associated with transport and facilitating nutrient capture and re-use from wastewater and the recovery of nutrients and energy from solid biological wastes. Building- to district-scale advanced water treatment and reuse schemes coupled with high-tech indoor (vertical) farming technologies have the potential to decentralise food production systems, creating opportunities for on-site food production in every building; however, technological innovation is necessary to ensure food safety and human health within circular, 'zero emissions' systems.

Environmental and agricultural sustainability requires innovation in multiple contexts and at a range of scales to enable a paradigm shift from linear to circular resource use in good production systems. Business opportunities associated with the exploitation of innovative water reuse opportunities and potential solutions to water scarcity through the utilisation of unconventional water resources abound.

9 Business development on river system management and energy production

River system management is an important area for a Water KIC due to its major impact on river flood security and freshwater ecology. Yearly floods take human lives and lead to extreme costs. The ongoing climate change increases the vulnerability of near river constructions year by year.

The Water Framework Directive (WFD) including daughter directives on surface waters and groundwaters is a legislation framework and is setting out rules to halt deterioration in the status of EU water bodies and achieve good status for Europe's rivers, lakes, and groundwater. The directive is applied Europe wide (27 countries) and has been instrumental for a substantial mapping of the ecology of the water courses as well as physical changes in them, e.g., flow variations, revision of flood path, building of dams, pollution. Part of the biology of rivers is under threat due to human activities.

An important innovation through the recent decades is the introduction of hydraulic and hydrological modelling and monitoring of rivers and connected catchments. The models combined with real-world observations have provided a sound understanding of the physical behaviour of rivers, flood zones and risk of damage to buildings and road infrastructure as well as the ecological conditions under various circumstances. This is the basis for modern water resource management as well as planning of area disposition, design of roads and railroads and flood protection systems. In this field some future advances are as follows:

- Technological advancements for monitoring and prevention (multi-sensor real-time monitoring, real-time forecasting for fluvial flows and floods)
- Technological advancement to monitor, assess remaining structural strength, and sustainably replace / maintain hydraulic infrastructures
- AI based models and development of artificial intelligence techniques for water availability, river flows and extreme events assessment (floods and drought) as well as AI-based intelligent systems for risk and emergency management
- Citizen science data of hydrological systems and governance approaches in water systems

A huge number of dams have been built for regulation of river flow. The safety of these dams is an issue, and regulations for management of the dams exist and are under continuous improvement. Furthermore, digital-twins for smart management, operation and maintenance of hydraulic structures will certainly enhance dam safety. Further it is acknowledged that the construction of dams has significant effects on the aquatic life in rivers and on water quality. Fish passages and Nature Based Solutions (NBS) have generated increasing attention in recent years as effective approaches for addressing various challenges related to dammed rivers. These approaches will leverage natural processes and ecosystems to achieve multiple objectives, including ecological restoration, flood risk reduction, and biodiversity conservation.

Hydropower is an important renewable energy source. The hydropower capacity in Europe is nearly fully utilised, but rehabilitation of hydraulic machines and tunnels may provide an additional energy benefit. Increasing energy production (and water availability) by augmenting dam crest level with reduced environmental impacts and lower financial investment than the construction of new dams will also be an important issue in the next coming years. In the joint use of removable energy sources hydropower can act as a battery for storage of energy.

A massive amount of ultra-pure water is needed for power to X (also called green H2 or electro fuels). Furthermore, the expected development of nuclear power will require huge amounts of water supply for cooling and safety operations.

10 Lessons learned and perspectives for WMM KIC

The examples shown above demonstrate that a clear description of a major problem such as pollution combined with new opportunities for problem solving have triggered the innovation within inland water systems during the last decades.

The current understanding of severe water related impacts of climate change combined with new opportunities in monitoring water resources can in a similar way act as a principal driver for new innovations that will contribute to solving the upcoming water crises related to shortage of water and excess of water (floods) in Europe.

The future needs for more knowledge-based innovations also include the design of built infrastructure and the social impact of a wetter and wilder future as well as shortage of water. The use of new digital opportunities for further understanding and communication of challenges is very important. There is a need to analyse holistic and resilient perspectives including safety, culture, ecology, use of water resources. This should imply co-creation of knowledge supported by different academic sectors (social, ecology and engineering).

Case studies in the marine and maritime area

This chapter provides some background, as well as some concrete examples of the interaction of knowledge-innovation-business development and societal impact for the ocean sectors. Climate change, chemical pollution, overfishing, biodiversity loss, and habitat modification, all induced by human activities such as industrial development, the growth of coastal cities, maritime transport, population growth and tourism, pose serious threats to the well-being of societies and the health of the oceans (Sigmund et al., 2023). In this respect, international awareness has led to the need for industrial sustainable innovation leading to blue economy, that enable the sustainable harvesting of ocean resources, including seafood, marine bioproducts, and renewable energy (e.g., wind, wave and tidal power), without harming ocean ecosystems and supporting the long-term viability of these resources for future generations. In addition, such innovation can be a significant source of economic growth and job creation in different sectors like offshore renewable energy, sustainable aquaculture, and marine biotechnology by creating high-skilled job opportunities, and contributing to the socio-economic development of coastal communities and beyond (EC, 2021).

Indeed, advanced technologies and methodologies developed through industrial innovation in pollution control, habitat restoration techniques, artificial intelligence (AI), modelling, and bioremediation processes may significantly mitigate human impacts on marine ecosystems (Anthony et al., 2023). Innovations in the marine field can contribute to climate change mitigation efforts, for example, by developing carbon capture and storage techniques or by harnessing clean energy from ocean sources. Similarly, innovative coastal infrastructure and ecosystem-based approaches can enhance societal resilience to climate change impacts, such as sea-level rise and increased storm intensity. The development of advanced research tools and technologies, such as autonomous underwater vehicles (AUVs), new sensors and remote sensing (satellite imagery, radar systems, and LiDAR) technologies as well as environmental DNA (eDNA) technologies, and bioinformatics tools enable enable scientists to explore with high-resolution previously inaccessible ocean areas, improve our understanding of marine ecosystems, and discover new species and genetic resources that could have medical, industrial, or ecological importance (Whitt et al., 2020) . Such technologies associated with AI, machine learning algorithms, underwater communication, and networking as well as modelling and simulation toward the Ocean basin digital twins are essential for simulating complex ocean processes. A modern sustainable aquaculture and fisheries management can significantly contribute to global food security by providing a reliable and sustainable source of protein to a continuously growing population, whereas the development of marine tourism, supported by innovations in sustainable infrastructure and practices, can increase the cultural and recreational value of coastal areas and therefore supports local economies but also fosters a greater societal connection to the ocean, promoting conservation awareness and actions.

The development of a blue economy cannot be envisaged without appropriate education, not only through specialised training at engineer, Master or PhD level, but also through distributing general education to society (European Commission (2022). Specialised programmes in marine biology, oceanography, environmental science, marine engineering, and marine policy can prepare individuals to address the complex challenges of sustainable ocean resource management and to develop environmentally friendly industrial solutions. The marine sector's challenges are inherently interdisciplinary, requiring knowledge that spans across sciences, engineering, economics, and social sciences to develop solutions that are not only technologically viable but also economically and socially sustainable. In addition by embedding environmental education and sustainability principles into curricula at all levels, schools and universities can cultivate a sense of stewardship in future generations, encouraging them to prioritise environmental considerations in their professional and personal lives. Collaborations between industry, governments, universities, and research institutions can drive forward the scientific discoveries and technological innovations necessary for sustainable industrial practices in the marine sector (Wang et al., 2021; Baker et al., 2023).

11 How to increase collaborations between academic research and industry innovation

Improvement of collaborations between academic research and industry innovation in European marine and maritime sectors can be realised through strategic initiatives and concerted efforts from both sectors. Some ways to enhance collaboration include establishment of joint research initiatives, collaborative projects, and consortia that can leverage complementary expertise, and facilitate technology transfer between research institutions and industry stakeholders. Work-based learning programmes, internships, and industry placements for students and researchers contribute to gain practical experience and industry exposure whereas collaborative projects with industry partners can provide valuable insights into real-world applications of academic research and foster skills development among students and early-career researchers. Organisation of collaborative research funding programmes, networking events, workshops, and conferences such as those organised by the 'mission restore the ocean and waters' that bring together researchers, industry professionals, policymakers, and investors to exchange ideas, share best practices, and explore collaboration opportunities in marine science and technology. Similarly, Technology Transfer Offices (TTOs) offices in research institutions facilitate knowledge exchange, intellectual property management, and commercialisation of research outcomes. TTOs can serve as intermediaries between academia and industry, providing support for licensing agreements, spin-off creation, and industry partnerships. Similarly, the formation of innovation hubs, accelerators, and incubators focused on marine technology as well as entrepreneurship of industry-driven research consortia or clusters focused on specific marine sectors or technology areas can bring together multiple industry partners, research organisations, and relevant stakeholders to pool resources, share expertise, and collectively address industry challenges. By implementing these strategies, Europe can foster a culture of collaboration between academic research and industry innovation in marine sectors, driving sustainable growth, competitiveness, and technological advancement in the blue economy.

12 Some examples illustrating how the interplay of research, education, innovation, and business development can induce significant societal impacts

The knowledge, innovation, business, research development, as well as societal impact in marine water sector is a multifaceted process that involves a range of activities from discovery and invention to the application and widespread adoption of new technologies or practices. These interactions are crucial for sustainable development, environmental conservation, and the economic vitality of communities dependent on marine resources. Exploring case studies within the marine waters sectors provides valuable insights into how the amalgamation of research, education, innovation, and business development can collectively forge significant societal impacts. The following examples span various domains-sustainable marine resource management, conservation efforts, renewable energy, and biotechnology, each illustrating the dynamic interplay of these elements. A number of European initiatives have drawn on the strengths of research, education, innovation and business development to push the boundaries of aquaculture towards sustainability and economic viability. Note the following projects.

13 Aquaculture

The AQUIMER Cluster, located in Boulogne-sur-Mer, Northern France, is an example of a project that integrates aquaculture companies with academic research in a single region is which is a significant hub for the seafood processing industry (in the aquaculture and seafood processing sectors) in Europe. The cluster involves various stakeholders including aquaculture companies, research institutions, and educational organisations (University of Lille, IFREMER, Institut Pasteur). It serves as a platform for cooperation aimed at advancing sustainable practices and technological innovations. AQUIMER project focuses on several key areas such as optimising resource use, improving product quality and safety, and developing environmentally friendly production technologies. The cluster helps bridge the gap between research and market application, facilitating the rapid transfer of innovative solutions from labs to local aquaculture businesses. This significantly benefits the regional economy and enhances the global competitiveness of French aquaculture products.

SmartFish H2020 (Norway and EU Partners): This EU-funded project focuses on developing smart technology for monitoring fish health and environmental conditions in aquaculture operations through partnerships with universities that enabled the dissemination of research outcomes and the training of students in the use of advanced aquaculture technologies. The project has led to the creation of IoT-based systems and AI algorithms for real-time monitoring and decision-making, improving efficiency and sustainability. The collaboration with aquaculture businesses ensured that the technologies developed are applicable and scalable, leading to broader industry adoption.

AquaVitae (Low-Trophic Aquaculture in the Atlantic)**:** This EU Horizon 2020 project aimed at enhancing and expanding aquaculture production of low-trophic species (e.g., algae, shellfish) across the Atlantic area. Similarly, the project involved educational outreach and training workshops for stakeholders, promoting knowledge exchange and capacity building in sustainable aquaculture practices. AquaVitae focuses on developing new protocols, feeds, and breeding programmes for low-trophic species, alongside innovative aquaculture systems like IMTA. Finally, by engaging with small and large-scale producers, the project facilitated the commercial application of its findings, promoting economic growth in coastal communities.

The EATiP (European Aquaculture Technology and Innovation Platform): The EATiP coordinates and facilitates research and innovation efforts in the European aquaculture sector. It plays a key role in bridging the gap between industry and academia, ensuring that educational programmes are aligned with the latest industry needs and innovations. EATiP supports the development and deployment of innovative technologies and practices across the European aquaculture industry, whereas the platform fosters collaboration between businesses, researchers, and policymakers to accelerate the commercialisation of innovative aquaculture solutions.

SalMar Ocean Farm 1 (Norway)**:** This project represents a significant investment in offshore salmon farming, with research focused on understanding the impacts of open ocean conditions on salmon farming. Note that the collaborations with academic institutions help in studying the environmental and biological challenges of offshore aquaculture, integrating findings into educational programmes. The project itself is an innovation, being one of the world's first attempts at large-scale, offshore salmon farming. As a commercial venture, Ocean Farm 1 aims to prove the economic viability of offshore aquaculture, potentially transforming how salmon is farmed globally.

14 Offshore Wind Energy

Some examples from the United Kingdom and continental Europe demonstrate the significant role of collaborative efforts across research, education, innovation, and business development in advancing the offshore wind industry. These projects contribute Europe's transition to a sustainable energy future

Hywind Scotland (United Kingdom): As the world's first floating offshore wind farm, Hywind benefits from collaborative research into floating turbine technology, deep-water anchoring, and environmental monitoring. Similarly, Hywind Scotland has facilitated educational partnerships and student involvement, and offered insights into the challenges and solutions associated with floating wind technology. It represented a significant technological leap, proving that offshore wind energy can be harvested in deep waters far from shore, where wind speeds are higher and more consistent. Operated by Equinor, Hywind's success has spurred further investment in floating offshore wind technology, opening up new markets and opportunities for renewable energy development in deep-water environments.

North Sea Wind Power Hub (NSWPH) Consortium: This project involved extensive research into integrated energy systems, grid connectivity, and multinational cooperation on renewable energy distribution. Note that the consortium's work has become a case study in many academic courses focused on sustainable development, international policy, and engineering, highlighting the importance of collaborative education in solving complex global challenges. NSWPH aimed to develop a series of interconnected wind power hubs in the North Sea, showcasing innovation in offshore infrastructure, international energy trade, and grid stability solutions. The consortium includes energy companies and grid operators from several countries, illustrating how cross-border business development and cooperation are vital for the large-scale expansion of offshore wind energy.

Baltic Sea Region Energy Cooperation (BASREC) Wind Energy Initiative: The project focused on the Baltic Sea's potential for offshore wind, BASREC facilitates research into regional wind patterns, environmental impact assessments, and technological needs, whereas it promotes education and knowledge exchange among new and existing professionals in the renewable energy sector through workshops, conferences, and collaborations with universities. The initiative encourages innovative approaches to regional challenges, such as ice loads and ice management on turbines, and the integration of wind energy into the Baltic states' energy grids. The project brought together policymakers, businesses, and researchers, and fosters an environment conducive to the development and expansion of offshore wind projects in the Baltic Sea region.

15 Blue Biotechnology: Pharmaceuticals from the Sea

Some projects explore the genetic and biochemical potentials of marine organisms for pharmaceuticals, cosmetics, and nutraceuticals is a growing field that relies heavily on advanced research in marine sciences and biotechnology, driving business investment in new and innovative products derived from the sea. The societal impacts are profound, offering new treatments for diseases, health-improving products, and even contributing to bioremediation strategies to clean up pollutants in marine environments. Exploring the ocean's biodiversity for new pharmaceuticals involves screening marine organisms for bioactive compounds that can lead to medical breakthroughs. Here are concrete examples of how these elements come together to advance blue biotechnology and pharmaceuticals from the sea

Marine Biotechnology ERA-NET (ERA-MBT) and BlueBio Cofund: These EU-funded initiatives aim to coordinate European research and development efforts in marine biotechnology and support transnational projects exploring marine biodiversity for novel bioactive compounds. Through collaboration with academic institutions, these programmes help train the next generation of marine biotechnologists, providing funding for PhDs and postdocs involved in marine biotechnology research.

Projects under these initiatives have led to the discovery of new marine-derived enzymes, bioactive compounds, and biopolymers with potential applications in medicine, cosmetics, and nutrition. These programmes facilitated the translation of research discoveries into marketable products and services, encouraging the growth of Europe's blue biotechnology sector.

PharmaSea Project: The PharmaSea focused on discovering new bioactive compounds from deep-sea organisms, utilising advanced technologies for deep-sea sampling and high-throughput screening. It involved academic partners that integrated research findings into curricula and offered specialised training in marine biodiscovery and bioprospecting. PharmaSea achieved breakthroughs in the extraction and stabilisation of novel compounds from extreme marine environments, contributing valuable insights into marine natural product chemistry. Collaboration with pharmaceutical companies ensured that promising compounds could be developed into drug leads, showcasing the commercial potential of deep-sea bioprospecting.

Cultivation Methods for Improving their Biotechnological Applications (MACUMBA) : The EU-funded MACUMBA project aimed at developing new cultivation techniques to grow and study marine microorganisms, many of which were previously unculturable. The project provided training for researchers in innovative cultivation and screening techniques, enhancing skills in microbiology and biotechnology. MACUMBA's advancements in microbial cultivation opened up new possibilities for the production of marine-derived pharmaceuticals, enzymes, and biopolymers. The project's outcomes have the potential to spawn new startups and product lines within existing biotech companies, expanding the scope of blue biotechnology applications.

Blue Biotechnology Master's Programme at the University of Las Palmas de Gran Canaria (Spain): This project is closely linked with active research in marine biotechnology, providing students with opportunities to engage in cutting-edge projects. This specialised Master's programme trains students in the principles and applications of blue biotechnology, preparing them for careers in research, industry, or policy. The programme encourages innovation by incorporating entrepreneurship and technology transfer into its curriculum, inspiring students to develop new products and start their own companies. Graduates from the programme contribute to the sector by joining existing companies or founding new ones, driving the growth of the blue biotechnology industry in Europe and beyond.

16 Eco-Tourism and Marine Conservation

The development of eco-tourism and marine conservation in Europe provides excellent examples to preserve marine biodiversity, educate the public and tourists about environmental conservation, and generate income in a sustainable manner. Here are some examples from Europe:

Alonissos Marine Park, Greece: Research: The Marine Park, home to the Mediterranean monk seal (Monachus monachus), is a site of significant research activities focusing on marine biodiversity and conservation methods. The park offers educational programmes for visitors and locals, including snorkelling tours with marine biologists, workshops, and seminars on marine conservation. Eco-friendly tourism practices have been developed, such as strict regulations for boat traffic, eco-certified accommodation, and sustainable local products, minimising the environmental impact on the park. The park supports local businesses that adhere to ecotourism standards, promoting sustainable economic growth while conserving the marine environment.

Azores Archipelago, Portugal: Various eco-tourism operators collaborate with research institutions to provide educational tours, where tourists can participate in data collection and learn about marine ecosystems in the Azores, which are a hotspot for marine research, particularly in marine mammal studies, volcanic underwater ecosystems, and deep-sea environments. The region has seen the development of innovative sustainable tourism practices, such as responsible whale watching, certification schemes for sustainable tourism businesses, and the promotion of local conservation initiatives. The integration of eco-tourism and marine conservation has bolstered the Azores' reputation as a sustainable tourism destination, supporting local economies and funding conservation efforts.

Scilly Isles Marine Conservation, UK: The Isles of Scilly Wildlife Trust conducts ongoing research on marine habitats and species, informing conservation strategies and management practices. The trust and local ecotourism businesses offer educational programmes and guided tours focusing on the unique marine and coastal ecosystems of the Isles. Innovative approaches to community involvement in conservation efforts and sustainable tourism practices have been developed, including citizen science projects and sustainable seafood initiatives. Eco-tourism has been pivotal in driving local economic development, with businesses investing in sustainable practices and contributing to the conservation of the area's natural heritage.

Lofoten Islands, Norway: The Lofoten Islands are a site for research on Arctic marine ecosystems, fish populations, and the impacts of climate change on marine biodiversity. Eco-tourism operators collaborate with researchers to offer educational experiences that highlight the importance of preserving Arctic marine environments. Sustainable tourism practices, such as catch-and-release fishing, environmentally friendly accommodations, and the promotion of local culture and heritage, have been developed to minimise the impact on the environment. The eco-tourism sector in Lofoten supports local economies while promoting marine conservation, showcasing how environmental sustainability can go hand-in-hand with economic benefits.

17 Marine robotics

Marine robotics, including autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), and unmanned surface vehicles (USVs), play crucial roles in oceanographic research, environmental monitoring, offshore industry operations, and maritime security. Here are some examples from Europe:

Oceanic Platform of the Canary Islands (PLOCAN), Spain: PLOCAN is a hub for oceanic research, including the development and testing of marine robotic technologies. It supports projects focusing on the advancement of AUVs, ROVs, and USVs for ocean observation. The hub includes universities and research institutions to provide education and training in marine robotics, oceanography, and related fields. The platform encourages the development of innovative marine robotic solutions, such as autonomous surface vehicles for environmental monitoring and data collection in the Atlantic Ocean. By providing a test site and technical support for companies and startups, PLOCAN facilitates the commercialisation of marine robotic technologies and promotes business growth in the marine sector.

Norwegian Forum for Autonomous Ships (NFAS), Norway: NFAS promotes research in autonomous ship technology, which includes advancements in marine robotics for navigation, safety, and operations at sea. The forum works closely with academic institutions to integrate autonomous ship technology and marine robotics into engineering and maritime studies, ensuring an educated workforce for the future maritime industry. NFAS members, including businesses and research institutions, collaborate on innovative projects to develop and test autonomous shipping solutions, contributing to advancements in marine robotics. Through collaboration between industry and academia, NFAS accelerates the commercialisation of autonomous maritime technologies, supporting Norway's leading position in the maritime sector.

Robotics Innovation Centre (RIC), German Research Centre for Artificial Intelligence (DFKI), Germany: RIC conducts cutting-edge research in robotics, including marine robotics, focusing on the development of intelligent autonomous underwater vehicles for various applications. DFKI and RIC work with universities to offer courses and research opportunities in robotics, providing students with hands-on experience in developing and operating marine robotic systems. The centre develops innovative solutions for underwater robotics, such as autonomous inspection and maintenance technologies for offshore wind farms and underwater infrastructure. RIC collaborates with industry partners to bring robotic innovations to market, facilitating the growth of Germany's technology sector and the broader application of marine robotics in the economy.

The Scottish Association for Marine Science (SAMS), UK: SAMS conducts extensive research in marine science, including the use of marine robotics for environmental monitoring, deep-sea exploration, and data collection in challenging marine environments. SAMS offers education and training programmes in marine science and technology, incorporating marine robotics into its curriculum to prepare students for careers in marine research and industry. The institution is involved in the development and deployment of innovative marine robotic systems, enhancing the capabilities for scientific research and environmental monitoring. By partnering with technology companies and startups, SAMS supports the commercial development of marine robotic technologies, promoting their application in sustainable marine management and conservation.

The Robotic department of the French Research Institute for Exploitation of the Sea, IFREMER (Institut Français de Recherche pour l'Exploitation de la Mer) La Seyne/Mer, France, IFREMER conducts cutting-edge research in marine sciences and technology, including the development and deployment of marine robotics like autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), and unmanned surface vehicles (USVs), which are crucial for deep-sea exploration, environmental monitoring, underwater archaeology, and the maintenance of underwater infrastructure. IFREMER is actively involved and a partner in education and training particularly with the Ocean Sciences Institute in Aix-Marseille University and Bretagne Occidentale University. Innovation takes place through the development of new technologies and methodologies for marine research and exploration. IFREMER collaborates closely with industry particularly through participation in the marine/maritime cluster (Pôle Mer Méditerranée and Pôle Mer Bretagne). This collaboration can take the form of joint research projects, technology licensing agreements, or consultancy services, where IFREMER's expertise in marine robotics is leveraged to solve industrial challenges.

These examples illustrate Europe's leadership in the field of marine robotics, driven by a collaborative approach that integrates research, education, innovation, and business development. This ecosystem not only advances technological capabilities but also ensures the sustainable use and exploration of marine environments.

18 Development of new fuels for the maritime sector to achieve Zero Emissions

The development of new fuels for the maritime sector has been strongly regulatory driven as IMO (International Maritime Organisation) and especially MEPC (Marine Environment Protection Committee) of IMO started 25 years ago to develop restrictions for SOx and NOx content of the used fuels. The rules have been tightened slowly and today only 0.1 % sulphur is allowed in ships navigating in European waters and for Nox Tier 3 will require vehicles to have essentially zero fuel vapour emissions in use. In addition, discussions at IMO have resulted in the development of an Energy Efficiency Design Index (EEDI) for ship design since 2013 addressing the minimum energy efficiency level for new ships, getting slowly stronger towards 2030. Since 2018, the EU has required from ship owners the MRV (Measuring, Reporting and Verification) system on each vessel to measure and report carbon dioxide emissions. Monitoring should be done on a per voyage basis and on an annual basis for each fuel used onboard the ships. IMO has launched the CII (Carbon Intensity Indicator) to measure ship's energy efficiency and is given in grams of CO_2 emitted per cargo-carrying capacity and nautical mile. The first year of the attained annual operational CII verification will be 2024 for the operation in calendar year 2023. Vessels, based on their performance, will receive an environmental rating of A (major superior), B (minor superior), C (moderate), D (minor inferior) or E (inferior performance level). The rating thresholds will become increasingly stringent towards 2030.

Launched on 14th of July 2021, the Fit for 55 Package is a package of European Commission proposals to make the EU's climate, energy, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels. The European Union Emission trading system (EU ETS) is based on the idea that creating a price for carbon offers the most cost-effective way to achieve the significant cuts in global greenhouse gas emissions that are needed to prevent climate change from reaching dangerous levels. This will start in 2024. FuelEU Maritime is a regulation which aims to support the decarbonisation of the shipping industry. Upon entering into force from 1 January 2025, it will increase the share of renewable and low-carbon fuels in the fuel mix of international maritime transport in the European Union (EU).

For this reason, the industry has shifted towards a gradual decrease in emissions through the implementation of better transitional solutions until alternative fuels eventually become low-cost fuels. Since this topic is very broad and interdisciplinary, the regulatory challenges can be handled using available technologies in green maritime transport such as: (i) alternative fuels; (ii) hybrid propulsion systems and hydrogen technologies; (iii) the benefits of digitalisation in the maritime sector aimed at increasing vessel efficiency; (iv) hull drag reduction technologies; and (v) carbon capture technologies. (Vidovi'c et al., 2023)

The Waterborne TP platform has initiated several European projects focusing on safe storage of specific sustainable alternative fuels, including LNG, methanol and ammonia. Dedicated calls have been developed also for methanol and hydrogen in the Work Programme 2021 / 2022. Projects in the Work Programme 2023 have also recently started regarding development of ammonia cracker and PEM fuel cell combinations as well as demonstration of hydrogen usage in a bulk carrier and passenger ship with fuel cell. This has been complemented by several national research programmes and ship designs developed in industrial research. For methanol and drop-in-fuels, fast progress has been made and the technology is maturing. The lack of an established distribution and bunkering network in ports and along inland waterways across is an issue and the incipient implementation of green corridors Europe is considered to be a major constraint for a large-scale roll-out of new sustainable alternative energy solutions to provide a feasible service to both maritime shipping and inland navigation. Coexisting different fuels in a port and bunkering them to ships in different modes offers an additional challenge in terms of fuel standards and safety aspects.

Scope and research needs as stated by Waterborne TP are: The proposed orientation is of utmost importance and a critical topic for research and demonstration to ensure that we get proper and safe maintenance requirements and storage systems for all future sustainable fuels (hydrogen, methanol and ammonia), particularly concerning their integration into shipboard systems. This is highly relevant given the rising prominence of especially methanol as a promising fuel for maritime applications and numerous installations are expected for operational roll-out in the near future offering invaluable experiential data for internal combustion engines (ICE's). For hydrogen and ammonia additional RD&I is needed for safe storage and handling. For the upscale of sustainable alternative fuels in ICEs, there is a need for flexible solutions. This includes the development of new fuel injection systems and mixing of sustainable alternative fuels with currently used LNG and MGO or HFO since new built ships delivered will not have access to enough SAF to bunker in the beginning of operation and thus flexibility in fuel usage is the key technology needed. In addition, there is also a need to further research on slippage and fugitive emission factors related to the use of these fuels. Another field where there is need for development is aftertreatment of specific issues for different fuel types like ammonia slip and possibly N2O for ammonia and formaldehyde for methanol. For fuel cells, research is still needed on integrating different types of fuel cells and the application of different hydrogen carriers (LOHC, ammonia, methanol, etc.) into current ship systems as well as optimise its operation together with all systems in a ship. The focus should also extend to fuel availability studies as well as risk assessment and reliability methodologies particularly when employing liquid fuels like green methanol, ammonia, or hydrogen. Establishment of robust certification processes, link to regulations, and rigorous testing protocols for diverse fuel blends are also needed to ensure operational safety at sea and unified quality standards for alternative fuels. In addition, any proposed on-board CCS technologies should be able to guide class guidelines into regulations/standards with a detailed list on how to obtain approval in-principle. The proposition and guidelines must also take into account the operational profile and logistics of the vessel in conjunction with post logistics, feasibility and availability, and utilisation /transportation of on-board captured carbon. Furthermore, measures for storing sustainable alternative fuels on board under development are often technically advanced and come with high cost being in the pilot phase. R&D activities are needed on cost saving/reduction technologies in order to further develop cost efficient measures as well as to ensure the systems are integrated into the shipboard systems. This needs to be done in cooperation with the design and retrofitting pillar. In ports the development of multi fuel barges with different kinds of alternative fuels to be supplied simultaneously to ships need to be started. Linked with safety the following schemes should be addressed:

- Identify regulatory barriers and hazardous scenarios for different alternative fuels (key fuels to cover: methanol and ammonia)
- Formal safety assessments / risk assessments; qualitative as well as quantitative
- Develop risk control options; including the development/setting of safety distances for bunkering of methanol and, as a priority, of ammonia.
- Simulation projects of the different new systems and their integration into real vessels warrant attention.

In the shipbuilding industry, prototypes represent significant capital investments. To mitigate design risks and optimise performance, considerable emphasis is placed on employing simulation models and digital twins. Virtual prototyping and Hardware-in-the-Loop testing are crucial terms of verification, especially for the (safety) automation systems. The development of new technologies must be holistic, encompassing not just storage tanks, engines, or injection mechanisms. Their impact on factors like load-steps, load acceptance, and vibrations must be thoroughly understood to facilitate design of high-performing, maintainable, and safe vessels. This all embraces a need for development of advanced simulation models and digital twins of ship systems to demonstrate complicated ship solutions for ultimately reaching the close to zero-emission ship setup.

19 Business development for autonomous ships

Development of autonomous shipping has been totally opposite to the new fuels described above as the regulatory bodies have been really passive in developing the international regulations for more autonomous shipping. IMO has defined the level of autonomy for conducting Regulatory Scoping Exercise (RSE), but otherwise the regulatory development has been really slow. The industrial interest to increase the autonomy on shipping started by the maritime industry about 10 years ago.

Vice president Iiro Lindborg from Groke Technologies (Lindborg, 2021) has made an excellent summary of the state-of-art related to autonomous shipping. In the following, the main findings by Lindborg (2021) are summarised based on the main building blocks needed. The situation for Remote Operation centres

(ROC) and optimisation of related algorithms is pretty good as a lot of companies are available to develop various algorithms needed, IT Infrastructures are available but they need some reshaping before they are useful for autonomous shipping e.g. the location of the control centres not yet defined and whether they will be company based or centralised giving service for shipping companies.

Real time stable and secure high bandwidth connectivity from ships to shore is not yet available. We can rely on satellite connectivity, but real time data transfer is still delayed and the connection is not always stable with a number of sea areas with bad connectivity. In this area a number of companies are working and developing new solutions like low orbiting satellites are promising. In addition, the society's need for 24/7 connectivity is driving this development. However, the lack of real time stable connectivity has to be taken into account in the future development so that the systems onboard ships can also survive when the connectivity is lost.

Onboard the ship: autonomous control systems are well developed onboard and several demonstrations are available and this area is developing fast. But still the main topics are related to navigation and linking the navigation with the propulsion system configurations, but topics like monitoring and fault tolerances are missing as well as what the systems should do in breakdowns and how to continue the autonomous operations after breakdowns need more work. The current version of the MASS code includes the requirement that the systems onboard the ship have to be able to move to a 'safe navigation state' so called minimum risk manoeuvre fallback state. Situational awareness systems are looking at what is happening outside the ship and a number of various systems are available. This is the area on which the first business cases have emerged already. Reliable prime mover/auxiliaries, condition based monitoring/predictive maintenance and electrical propulsion systems are well established but the link to the autonomous shipping activities is still weak.

Communication between the ships is naturally an important topic to be studied in future. A system for fully autonomous navigation requires new approaches on how to communicate between the nearby ships and how to detect other vessels and avoid them automatically using e.g. advanced camera systems.

Lindborg (2021) also summarises the available demos on this area: 1st remote controlled Tug Svitzer Hermod developed by Rolls-Royce, 2017, 1st autonomous Roadferry Falco developed by Rolls- Royce, 2018, demonstration of autonomous sailing and fleet operation centre in Japan, demonstration of autonomous sailing included berthing and unberthing in Japan, demonstration of remote control and collision avoidance in South Korea and in Singapore, demonstration of unmanned transatlantic LNG vessel by South Korean companies, zero emission autonomous shipping over one fjord in Norway (Asko and Yara Birkeland), enhancing capabilities of a harbour tug by Wärtsilä, remote operated tug using joystick done by ABB and Keppel, develop a remotely operated tug by Kongsberg and Svitzer, development of autonomous command and control system by Seamachines and Damen, autonomy to yacht system by Sea Machines and Rolls-Royce, autonomous container ship (300-800 TEU) by Chinese consortium and autonomous catamaran to transport batteries by PowerX.

The safety and reliability of autonomous ships are critical for the successful realisation of an autonomous maritime ecosystem. Research and collaboration between governments, industry, and academia are vital in achieving this goal. Chaal et al. (2023) conducts a bibliometric review of the research on the risk, safety, and reliability of autonomous ships aiming to provide researchers and maritime stakeholders with a structured overview of the topics, development trends, and collaboration networks in this research field. 417 papers published between 2011 and 2022 were identified covering 940 authors, 31 countries, and 227 journals. Three main themes were determined in this research domain: 'safety engineering and risk assessment for decision making', 'navigation safety and collision avoidance', and 'cybersecurity risk analysis'. Meanwhile, it was identified that research on cybersecurity in autonomous shipping is moving to overlap with safety, which requires future co-analysis methods. Additionally, the analysis of the most cited 30 papers suggests that further research is needed in the topics of unmanned machinery operation risks, online risk tools, system-theoretic safety analysis, human factor, and the determination of suitable risk acceptance criteria for safety assessment of autonomous ships. Furthermore, the analysis revealed that the development of unambiguous COLREGs regulation is crucial for the development of safe collision avoidance algorithms for MASS.

This report evaluates the need and scope for an EIT Knowledge and Innovation Community (KIC) focused on water, marine, and maritime areas (KIC WMM). It identifies existing gaps in innovation ecosystems and recommends thematic focus areas with the highest potential for technological development, market deployment, and benefits for EU citizens. Key stakeholders, public engagement methods, funding mechanisms, and legal and regulatory barriers are analysed. Policy options are provided to foster innovation and market deployment in alignment with the European Green Deal and other EU strategies. The report highlights high-impact technologies for sustainability goals and areas needing further research and regulatory changes. It concludes that a WMM KIC would enhance the innovation ecosystem, education, and entrepreneurship in the relevant sectors, bolstering Europe's leadership in the global water and blue economy.

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