# D4.1.3. Technology foresight paper

InnovaMare project

Blue technology - Developing innovative technologies for sustainability of Adriatic Sea

WP4 – Creation and establishment of innovation ecosystem model for underwater robotics and sensors

# Project References

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| Consultant: | Mreža znanja d.o.o.<br>HR – 10000 Zagreb<br>Božidarevićeva 13 |
| Authors: | Đuro Kutlača, PhD<br>Nikola Vladimir, PhD<br>Domagoj Račić<br>Ivana Mihaljević<br>Sofija Stanić<br>Zvonimir Račić<br>Vedran Budimir |

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# 1 Introduction

This document presents a technology foresight within the InnovaMare project. The main goal is to identify and anticipate emerging maritime technologies, with emphasis on underwater robotics and sensors, which will meet the societal needs and market demands of other participants in the Blue economy sector. In order to achieve that, an analysis of the current situation and trends in the field of maritime technologies for detection, monitoring and prevention of marine pollution was conducted. The analysis is followed by the identification of key challenges and opportunities alongside the determination of emerging technologies in the field.

## 1.1 InnovaMare project

InnovaMare is a strategic project that aims to enhance collaboration on technology transfer by creating an innovative underwater robotics and sensors network. The project's mission is to create a cross-border innovation ecosystem in Šibenik, Croatia, as the leading centre of cooperation, knowledge and technology transfer that will be used to develop new innovative solutions in underwater robotics and sensors. There are 14 project partners from Croatia and Italy, with the Croatian Chamber of Economy as the lead partner. To include all relevant stakeholders in creating a new innovation ecosystem between Croatia and Italy, project partners come from both public and private sectors:

1. **Universities**: University of Dubrovnik; University of Trieste; University of Rijeka, Department of Biotechnology; University of Zagreb, Faculty of Electrical Engineering and Computing,
2. **Institutes**: National Institute of Oceanography and Applied Geophysics, Italy; Institute Ruđer Bošković, Croatia; The Institute of Marine Science (CNR- ISMAR), Italy,
3. **Open innovation hub**: Maritime Technology Cluster FVG, Italy,
4. **Local government**: Šibenik-Knin County, Croatia,
5. **Agencies and chambers**: Apulia Regional Agency for Technology and Innovation (ARTI), Italy; Croatian Chamber of Economy; Regional Union of the Chambers of Commerce of Veneto Region, Italy,
6. **Enterprises**: Communication Technology S.R.L., Italy and Geomar d.o.o, Croatia.

The Adriatic Sea, which is connecting the two partner countries, is facing major impacts from overfishing and pollution. Solid waste, direct discharge of wastewater and oil pollution are key negative factors for the degradation of coastal and marine ecosystems. For that reason, the InnovaMare project is set up on a **mission-oriented approach** rather than focusing on sectors, because mission-oriented policy focuses on problem-specific societal challenges, which many different sectors interact to solve. In this case project partners are focusing on using mix of policy instruments together with innovation stakeholders to **increase effectiveness of innovation activities of underwater robotics and sensors in the direction of sustainability of Adriatic Sea as a crucial strategical societal challenge on cross-border level**. Among the nine main InnovaMare project outputs, there is a Digital Innovation Hub (DIH), that will be in the centre of a newly established innovation ecosystem. The InnovaMare DIH establishment will contribute to connecting key stakeholders with a common goal - **preservation of marine sustainability and prevention of marine pollution**.

Bearing in mind that technology is one of the most important tools for the implementation of both prevention and clean-up of marine pollution, one of the activities of the InnovaMare project is to detect which technologies exist in the market and what are the trends in future technologies. That will be done through a process called **technology foresight** and it will result with a strategic document that clearly and simply presents to innovation stakeholders the future trends and challenges in technology development and activities to be implemented in response to future trends in marine protection and sustainability in general. **The purpose of technology foresight** is to inform and direct innovation policy regarding the identified challenge (in this case, marine pollution and sustainability of the Adriatic Sea) towards improved planning and decision-making at the strategic and operational levels, for companies, scientific research organizations and for policy makers, by anticipating future market demand and the development of innovative technologies as future offer.

This document represents the **technology foresight of the maritime technologies for detection, monitoring and prevention of marine pollution, with emphasis on underwater robotics and sensors**, following the three main steps:

- analysis of current situation and available technologies,
- identification of key challenges and opportunities (future demand) and
- identification of emerging innovative technologies (future offer).

In the following chapters, the technology foresight process (concept and the chosen Delphi method) is being described. As in introduction to the topic and to the technology foresight process itself, an overview of the socio-economic context, the problematic of marine pollution and the relevant strategic framework on the EU level is given. The main stages of TF process are following in chapters 3 to 6 (Analysis of the current EU and global trends in the field of maritime technologies together with an Analysis of current technologies for detection, monitoring and prevention of marine pollution, with emphasis on underwater robotics and sensors). Chapter 5 (identification of key challenges and opportunities in the relevant field – future demand) and chapter 6 (identification of emerging innovative technologies in the relevant field – future offer) are formed on the basis of the questionnaires following the Delphi method. After the Delphi implementation and a reached consensus, future demand and offer are identified.

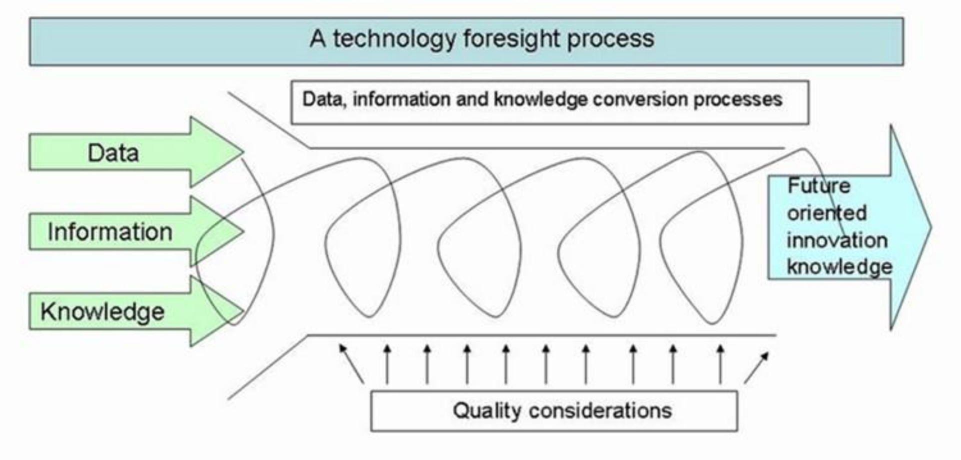
## 1.2 Technology foresight and the Delphi method

In this chapter the technology foresight as a concept is explained, the definition and application of TF are given, together with some examples and methods. The Delphi method is described in detail, as it is the method used in the InnovaMare technology foresight process.

### 1.2.1 Technology foresight

Technology foresight is a prediction methodology for determining the most likely technological developments in the mid-term future. The term “technology foresight” (TF hereinafter) was introduced by two innovation researchers from the Science Policy Research Unit at University of Sussex, John Irvine and Ben Martin in the ‘80s. According to them, technology foresight represents a systematic exercise aimed at looking into the **longer-term future of science technology and innovation** in order to make **better-informed policy decisions** (Irvine and Martin, 1984).

**Figure 1 Technology foresight process**



*Source: Melkas, H., Uotila, T. (2007)*

TF as a methodology was used for the first time in Japan in 1970s for its national technology planning studies. Back then, they called it “forecast activity” and it inspired Irvine and Martin for their seminal work when they introduced the term “foresight”. The difference between two terms is significant - forecasting activities are typically performed by closed-circles of experts and provide a mere prediction of future contingencies from a single point of view. Foresight activities, on the other hand, support a broader view of the world that is synergistically integrated with policy strategy (Pietrobelli and Puppato, 2015). That way the TF process gives insights for forward looking science and technology policies that “create” rather than “predict” the future, enhancing the dialogue among different stakeholders (pre-selected experts, relevant for the topic) (Miles, 2010). During the 1980s France started using TF, then Sweden, Australia and Canada. The popularity of the TF methodology grew significantly in the 1990s, in Europe and globally, in order for countries to remain competitive. It was used as a tool to identify fast, market-oriented and forward-looking innovation policies agreed by the government and the private sector (UNIDO, 2005).

TF has tried to help societies and economies to **define strategic areas where the future of science and technology would lead**. The foresight methodology is being used by **countries** (technology foresight in Slovenia in 2005), **regions** (technology foresight in Vojvodina in 2006), **large companies** (strategic foresight at Deutsche Telekom AG) and **other organizations**. Companies use strategic foresight to identify and react upon opportunities and threats in their environment and anticipate future changes (Rohrbeck and Thom, 2008). The **main advantage of technology foresight** is bringing together all the relevant stakeholders in the innovation system (scientists, researchers, academia, industry, policy makers) to develop a common vision of the future developments and emerging technologies, that will probably produce the greatest economic and social benefits. The timeframe of foresight usually ranges between 5 and 30 years.

Foresight is not only one technique or one method, but it is an **umbrella term for methodologies and approaches** that take volatility, uncertainty, complexity and ambiguity as their starting point, explore possible and probable futures, including a preferred one, and generate insights and 'cross-sights' that enable transformative actions in the here and now. The premise of foresight is that **the future is still in the making** and it can be actively influenced or even created, rather than passively accepted as a given (UNDP, 2015). A very precisely defined main objective of TF was made by Giorgio Sirilli, an Italian researcher from the Italian National Research Council, in his article "A mini-technology foresight in Italy" published in 1997. According to Sirilli, **the main objective of TF** is to identify potentially important technologies **early enough to facilitate their development and utilisation**. The TF exercise was carried out in Italy between 1994 and 1996 and the result was the proposition of an extensive agenda for science and technology policy in the country. All stakeholders, including governments, enterprises, research institutions and general public they all have interest in identifying the new emerging generic technologies which are likely to have a large impact on society, the economy and the environment (Sirilli, 1997). Nevertheless, foresight is not a substitute for traditional planning. Foresight enhances existing planning methods by broadening horizons and giving new perspectives; by enabling planning in an uncertain and unpredictable reality (the future) and by opening up space for other stakeholders in the future (UNDP, 2015).

According to the UNDP's "Foresight: the Manual", there are some facts that should be properly addressed in the beginning of the TF process and clear to all the participants, in order to avoid misunderstandings and potential weaknesses. All the participants must **understand what foresight is and isn't**, what it can and can't do, and how it can be used. It is not an easy exercise, because it takes creativity and ability to think of something new and transformative. Therefore, **foresight activities need extensive preparation**, including selection of methods that emphasise and stimulate creativity. In the end, the **selection of participants** in the foresight exercise matters significantly. The choice of participants has a huge impact on the quality of the insights and the sustainability of implementation. This selection can be seen as a pre-activity, where the facilitator analyses and chooses institutions, experts, companies - stakeholders who can provide quality insights relevant to the defined challenge and to the relevant area.

After relevant stakeholders have been identified, the facilitator leads them through chosen TF methods in order to achieve the main objective – identification of the key challenges and opportunities in the relevant area and **anticipation of the future market demand**, together with the identification of the emerging technologies in the field which represent a **future offer** from the scientific and industry stakeholders.

There are many foresight methods and techniques available that are considered part of futures analysis. For a full-scale foresight exercise more methods can be used and combined, in different stages of planning or decision-making. Methods differ from long-term processes and quantitative data collection/analysis to participatory workshops and qualitative assessment of narratives. UNDP’s Manual (2015) identifies some of the most popular ones and most widely tested methods and approaches:

- Visioning
- Forecasting
- Backcasting
- Roadmapping
- Windtunnelling
- Text mining
- Relevance Trees
- Technology Sequence Analysis
- Scenario Planning
- Delphi method
- Cross-impact method
- Expert panel
- Modelling, simulation & gaming
- Future Search
- Conference Model

**Visioning** is a method for determining a compelling vision of a preferred future. It is being used in project design, strategic planning or at the beginning of a process (project initiation). The goal is to create a shared vision of a desirable future of a team, organisation, company etc.

**Backcasting** is a method that defines a desirable future and then works backwards to identify major events and decision that generated the future. That way an organisation can consider what actions, policies and programs are needed in the present in order to connect with the desired future. This method shows participants that the future can change depending on the choices that are being made along the way.

**Roadmapping** is a popular method and an important tool for collaborative planning and coordination. It’s being used by companies as well as industries to help experts to forecast, plan and coordinate technology developments. The process result is a document (a roadmap) that identifies the critical system requirements, the product and process performance targets, and the technology alternatives and milestones for meeting those targets.

**Scenario planning** is one of the most well-known and most cited technique for thinking about the future. Scenarios are stories set in the future that explore how the world would change if certain trends were to strengthen or diminish, or various events were to occur. This method does not predict the future but identifies a limited set of examples of possible futures. Scenario planning can be used when evaluating current strategies or formulating new ones.

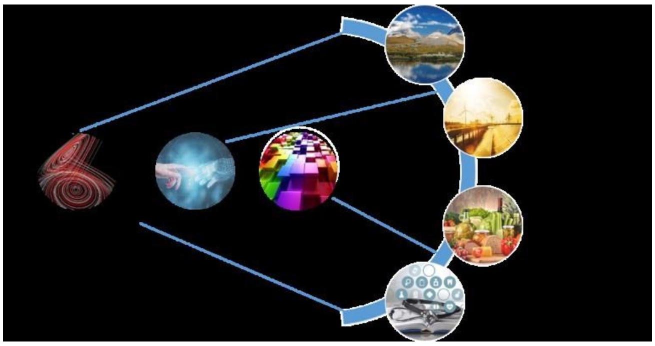
**Delphi method** or **Delphi survey** is one of the most common methods and it is used to structure group communication processes to deal with complex issues. It involves a pre-selected group of experts and includes several surveys, depending on previous responses. The method is described in detail later in the text, for it is the method chosen for the technology foresight in the InnovaMare project.

Foresight has multiple applications and is being used by various stakeholders. Following examples will illustrate different levels, areas and purposes of TF in Italy, Croatia, Slovenia and the Autonomous Province of Vojvodina.

### *Science and Technology Foresight in Italy*

The Science and Technology Foresight Project was supported by National Research Council of Italy, Area Science Park and Italian Ministry for Education and Research. The Project aimed to define a medium to long-term vision (5 to 30 years) in order to elaborate coherent research strategies, and to address some serious socially relevant problems related to environment, health, food, energy, security and transportation. The basis of the working method in this process were face-to-face workshops of the preselected experts. The foresight workshops were inter-disciplinary, the invited researchers provided different expertise to the panels, they were encouraged to address problems in a systemic, non-linear way, to identify innovative and disruptive, future developments. The Project has involved the international scientific community (not just the Italian researchers) in the effort of identifying innovative, scientifically based, medium/long term solutions of problems within the four areas: energy, food, health, water, as well as the cross-sectoral topic of breakthrough innovative materials.

**Figure 2 Areas covered in the Italian foresight project**



*Source: The Project website, available at: http://www.foresight.cnr.it/*

The Science and Technology Foresight Project was **driven by societal needs**, and it was interested in **identifying innovative technologies**, while it put the **scientific research at the centre**. And the results of scientific research would **impact the society** and the identified needs.

### *Scientific and Technological Foresight in Croatia*

The Scientific and Technological Foresight project (STF) is a strategic project, implemented by Croatian Ministry of Science and Education and University of Zagreb Computing Centre – SRCE as partner. The main objective of Croatian STF project is to **improve the framework of the national system of research, development and innovation**. In order to achieve the main objective, several goals were set: to define the legal framework regarding research information management in Croatia; to create a national research information system, abbreviated as CroRIS, and to implement scientific and technological mapping and foresight. The Project implementation started in 2017 and the end is planned in 2023.

### *Technology Foresight in Slovenia*

The TF study in Slovenia was conducted as part of the preparation process for the midterm national R&D Programme 2006 - 2010. This was the first national foresight exercise, and it was conducted in 2004 (from late 2003 to early 2005). The TF had several objectives: to promote the continuous forward-thinking practice in society, to foster dialogue among main stakeholders in the innovation process, and to set preliminary R&D priorities for the future research and technology policy. The technology foresight study in Slovenia was commissioned by the Ministry of Education, Science and Sport and the Ministry of the Economy. Based on the **previous research studies and expert panel discussion** eight thematic fields were chosen:

- information and communication technologies,
- advanced materials,
- biotechnology, pharmaceuticals, nutrition,
- environmentally acceptable manufacturing,

- sustainable construction,
- traffic and mobility,
- life-long learning,
- medicine – care for the elderly.

The Delphi method was chosen for the exercise. The participants - experts in research organizations and firms - were asked to evaluate approximately 40 topics in the eight investigated fields.

The TF exercise in Slovenia created better understanding of the evolutionary paths of key technologies. At the same time, it created a bridging role from national research activities to 6th and 7th European Framework Programmes. It developed more bottom-up approaches in order to identify long-term research and technological priorities for Slovenia (Stanovnik, Kos, 2005).

### *Technology foresight in AP Vojvodina*

A technology foresight was conducted within the strategic document "Basic Directions of Technology Development of AP Vojvodina". The main focus areas of the technological development were computer engineering, communications and automated systems sector. The ICT industry was identified as the sector with lots of potentials, not only for its own fast growth at the time (2005/2006), but also for its contribution to the development of many other sectors. The ICT industry, thus, was identified as a huge chance and possibility of AP Vojvodina to approach European integrations and standards, and for the economy in APV to achieve an outbreak into the global market. Like in Slovenia, the Delphi method was chosen for the exercise and it included several rounds of custom made questionnaires answered by the preselected experts (Kutlača, Šenk, 2007).

After a wider introduction to the concept of (tecnology) foresight, definition, objective, common methods and several examples from neighbourhood countries, in the following chapter, the Delphi method is being described.

### 1.2.2 Delphi method

The **Delphi method** belongs to the systematic, qualitative and subjective-intuitive methods of foresight that combines the benefits of expert analysis with elements of the wisdom of crowds (Dalkey & Helmer, 1963). Linstone and Turoff (2002) characterize Delphi as a **technique** to structure group communication processes to deal with complex issues and to obtain a useful result for the set objective. UNIDO (2003) defines Delphi as a **forecasting process** of gathering a panel of experts who are knowledgeable about a certain topic so they can forecast the outcome of future scenarios, predict the likelihood of an event, and engaging them in a several rounds of questionnaires. Young & Jamieson (2001) consider Delphi a well-suited method for consensus-building.

Delphi research has been used for numerous activities, including:

- establishing programmatic objectives,
- planning for budget modifications,
- identifying essential professional competencies within a specific context,
- supporting various elements of curriculum development,
- collecting historical data,
- exploring perceptions related to potential policy changes,
- understanding personal motivations and values,
- investigating urban and regional planning possibilities,
- futuring or exploring potential future options to determine what is likely to happen, what may change, and what effects can be anticipated (Harder, Place, & Scheer, 2010; Conner, Roberts & Harder, 2013).

According to Delbecq, Van de Ven and Gustafson (1975:11) the Delphi technique can be used for achieving the following objectives:

- to determine or develop a range of possible program alternatives,
- to explore or expose underlying assumptions or information leading to different judgments,
- to seek out information which may generate a consensus on the part of the respondent group,
- to correlate informed judgments on a topic spanning a wide range of disciplines,
- to educate the respondent group as to the diverse and interrelated aspects of the topic.

### *Historical perspective*

Delphi was developed in the 1950's by the RAND (Research and Development) Corporation in Santa Monica, California and it was primarily intended for military forecasting purposes during the Cold War. The 1950´s Delphi study “The Use of Experts for the Estimation of Bombing Requirements” was designed to apply expert opinion to the selection, from the viewpoint of a Soviet strategic planner, of an optimal U.S. industrial target system and to estimation of the number of A- bombs required to reduce the munitions output by a prescribed amount. The technique employed involved the repeated individual questioning of the experts (by interview of questionnaire) which led to a group consensus (Dalkey & Helmer, 1963).

In the last several decades, the Delphi research methodology is widely used for facilitating group communication and encouraging consensus among a panel of experts in science, technology, business, health care, education and other areas. Hsu and Sandford (2007) point out the various fields of study in which the Delphi process has been used, such as program planning, needs assessment, policy determination, and resource utilization to develop a full range of alternatives, explore or expose underlying assumptions, as well as correlate judgments on a topic spanning a **wide range of disciplines**.

### *Characteristics of the Delphi Method*

The Delphi technique is a means of reaching a group consensus through multiple rounds of anonymous feedback or iterations (Geist, 2010; Martin & Frick, 1998). Delphi, in contrast to other data gathering and analysis techniques, employs multiple iterations designed to develop a consensus of opinion concerning a specific topic. Ludwig (1994) indicates that Iterations refer to the feedback process that allows and encourages the selected Delphi participants to reassess their initial judgments about the information provided in previous iterations. Thus, in a Delphi study, the results of previous iterations regarding specific statements and/or items can change or be modified by individual panel members in later iterations based on their ability to review and assess the comments and feedback provided by the other Delphi panellists.

Other notable characteristics inherent with using the Delphi technique are the ability to provide **anonymity** to respondents, a **controlled feedback** process, and the suitability of a **variety of statistical analysis** techniques to interpret the data (Dalkey, 1972; Ludlow, 1975).

Anonymity is an important benefit while it reduces the possibility of certain individuals influencing group decision-making more than others (Geist, 2010; Linstone & Turoff, 2002).

Controlled feedback in the Delphi process is designed to reduce the effect of noise. The controlled feedback process consists of a well-organized summary of the prior iteration intentionally distributed to the subjects which allows each participant an opportunity to generate additional insights and more thoroughly clarify the information developed by previous iterations. Through the operation of multiple iterations, subjects are expected to become more problem-solving oriented, to offer their opinions more insightfully, and to minimize the effects of noise.

Additionally, the ability to use statistical analysis techniques is a practice which further reduces the potential of group pressure for conformity (Dalkey, 1972). More specifically, statistical analysis can ensure that opinions generated by each subject of a Delphi study are well represented in the final iteration because. The tools of statistical analysis allow for an objective and impartial analysis and summarization of the collected data.

Finally, the Delphi process is beneficial because it allows for participation without scheduling or geographic restrictions, meaning that all stakeholders may be able to participate (Geist, 2010).

### *The Delphi process – main roles and implementation steps*

The main participants involved in the Delphi process are **researchers or analysts** and the **panel of experts**. The role of the researcher is twofold: the first is that of “planner,” and later that of “facilitator” as opposed to “instrument” in the case of more traditional qualitative designs. In carefully designed and executed panels, the risk of researcher bias is minimal, as the researcher’s primary task is that of planner/coordinator/recorder, and the back-and-forth communication between researcher and panel members provides for internal process auditing (Avella, 2016).

Selecting individuals who meet expertise qualifications for panel membership is critical and cannot be overstressed. In the Melynk et al. study (2009), publication in scholarly journals provided a minimum qualification threshold for researcher participation on the panel. Generally speaking, participant invitation criteria should include those measurable characteristics that each participant group would acknowledge as those defining expertise, while still attempting to recruit a broad range of individual perspectives within those criteria. Years in specific practice and holding specific certifications or credentials are examples a researcher might use in choosing panel members.

There is no standard or typical number of groups that would constitute the panel, although two or three groups are those most often seen in the literature. The number of groups necessary for participation should be based on those stakeholder groups most directly affected by the topic of the study.

The size of the overall panel is another consideration. There is no standard when it comes to panel size; neither has it ever been established what constitutes a large or small panel. Akins, Tolson and Cole (2005) noted that panels have been conducted with just about any size. They also noted that panels of less than 10 are rare, as are panels over 1,000. Typical panels seem to fall in the 10 to 100-member range and consist of either two or three expert groups, again depending on stakeholder interest.

The first major task in a Delphi study is to **choose a facilitator** within the organization. The person needs to be neutral, collect data and have sense of interest in the topic.

Then the facilitator **selects a group of experts** based on the topic being examined and sends them a questionnaire with instructions to comment on each topic based on their opinion, experience or previous research.

Third step is to **define and explain the main problem** and the **survey objectives**. Experts need to understand and clearly evaluate what they are commenting about.

The survey consists of **several rounds of questionnaires**. After each round of questionnaires, the experts are presented with an aggregated summary of the last round, allowing each expert to adjust their answers according to the group response. Since the responses of the participants are anonymous, they are encouraged to speak openly. The facilitator then modifies the anonymous comments received to formulate better questions. The process is run again, in a series of rounds, until a consensus of forecasts is achieved.

After **reaching a consensus**, the facilitator analyses the findings from all the rounds. Then combines responses together to build a strong point of view to help predict future outcomes, risks, opportunities and lessons learnt.

### *Advantages and disadvantages of the Delphi Method*

Delphi provides benefit and value when it is determined to be the most suitable approach to address the research problem and answer the research question. Yang et al. (2012:78) noted its suitability for studies that exhibited the following properties:

- subjective expertise and judgmental inputs,
- complex, large, multidisciplinary problems with considerable uncertainties,
- possibility of unexpected breakthroughs,
- causal models cannot be built or validated,
- particularly long-time frames,
- opinions required from a large group (anonymity is deemed beneficial).

Following are some benefits and weaknesses of using Delphi. The main advantage comes in achieving consensus in areas of uncertainty or in situations lacking in causation (Powell, 2003). The Delphi method seeks to aggregate opinions from a **diverse set of experts**, and it can be done without having to bring everyone together for a physical meeting. Pursuit of a Delphi design is **highly cost-effective** (Williams & Webb, 1994). It is the researcher's time, as well as the time of participants (all of whom are volunteers), that constitute the principal cost. It also enables **avoiding direct confrontations** of the experts with each other

(Dalkey and Halmer, 1963) and allows **anonymity**, which encourages creativity, honesty and a balanced consideration of ideas while reducing the risk of group dynamics negatively influencing outcomes (Donohoe and Needham 2009; Iqbal and Pipon-Young 2009). Since the responses of the participants are anonymous, individual panellists do not have to worry about repercussions for their opinions. Not knowing who said what eliminates overt judging of individual contributions by other panel members. Through the feedback given in Delphi, an individual expert may enrich his/her insight into empirical factors or theoretical assumptions allowing them to correct any misconceptions (Dalkey and Helmer, 1963).

Regarding the Delphi shortcomings, the method does not result in the same sort of interactions as a live discussion. A **live discussion** can sometimes produce a better example of consensus, as ideas and perceptions are introduced, broken down, and reassessed. The method is **time-consuming** since it consists of several rounds of questionnaires. Also, response times can be long, which slows the rate of discussion. Furthermore, it needs **high participant-motivation** and therefore is **vulnerable to drop-outs**. Participants might also drop out due to the long temporal commitment, distraction between rounds, or disappointment with the process (Donohoe and Needham, 2009). The same authors also note that use of monetary payments or moral persuasion to convince the participants may introduce bias into the results. It is also possible that the information received back from the experts will provide no innate value and that the disagreements may not be properly resolved.

### *InnovaMare Technology Foresight: Delphi method*

In order to clarify how the Delphi method will be conducted, a graphic representation of the main implementation steps that need to be taken in order to get the best future predictions was made by the organization.

**Figure 3 The Delphi implementation steps**

*Source: Created by the author.*

First, a facilitator who is responsible for research and data collection and for successfully conducting the survey was chosen within the latter organization.

In the second step, the organization identified the experts that would participate in the survey. The panel of experts consisted of European and globally recognized experts with valuable knowledge and experience in both technology foresight process and the Delphi method, as in the relevant technologies for the maritime (robotics and sensor systems) sector. Two sub-groups were selected: experts from the academic and business enterprise sector.

Third step was done in agreement with the project coordinator - Croatian Chamber of Economy and it included defining the problem and the goals for “InnovaMare Technology Foresight”.

Then the organization conducted two rounds of questions. In the first round, the facilitator asked general questions to gain a broad understanding of the experts view on the selected research topic. After comparing and summing up the responses by removing irrelevant material, the facilitator sent an aggregated summary to the experts who were given a chance to comment further and readjust their answers according to the group response. In the second round the questions were formulated based on the answers to the first round. The facilitator delved deeper into the topic to clarify specific issues, tried to compare and once again summarize all the answers, while looking for common viewpoints.

At the end, a strong group consensus was reached. The collected data was analysed and a clearer view of the emerging maritime technologies, alongside the key challenges and opportunities was gained.

## 1.3 Socio-economic context

In the following chapter the characteristics and the contribution of the Blue economy to the socio-economic indicators in relevant countries is given.

The Blue economy, targeting the fostering sustainable and integrated development of marine and maritime sectors as a whole, directly employs over 4.45 million people in the EU and accounts for 1.5% of EU gross value added (GVA) (The Blue Economy Report, 2022). The Blue economy sectors generated gross value added of EUR 183.9 billion in 2019. Among the latter are included:

- fisheries, aquaculture and processing,
- marine renewable energy (offshore wind and ocean energy),
- coastal and maritime tourism,
- maritime transport, ports and shipbuilding,
- marine extraction of oil, gas and minerals,
- other sectors (blue bioeconomy and blue biotechnology, seawater desalination, maritime security and surveillance, maritime spatial planning).

The Blue economy is a wide, fast-moving segment of the economy, which over the past decade has taken important steps to improve and diversify. Coastal tourism which is the largest Blue economy sector in terms both of jobs and of value added, continues to grow, but causes problems to the environment and local communities.

The maritime technology sector in Europe consists of more than 22,000 maritime equipment companies (including SMEs) and around 300 shipyards. Together they employ more than 900,000 experienced people and generate an annual production value of EUR 112.5 billion. Based on orderbook value, consisting of both civil and naval new builds, the European shipbuilding industry ranks second in the world after the USA (mainly naval shipbuilding) and is bigger than its direct Asian competitors. European manufacturers and suppliers produce almost 50% of the global production of maritime and marine equipment (industriAll Europe and SEA Europe’s, 2018).

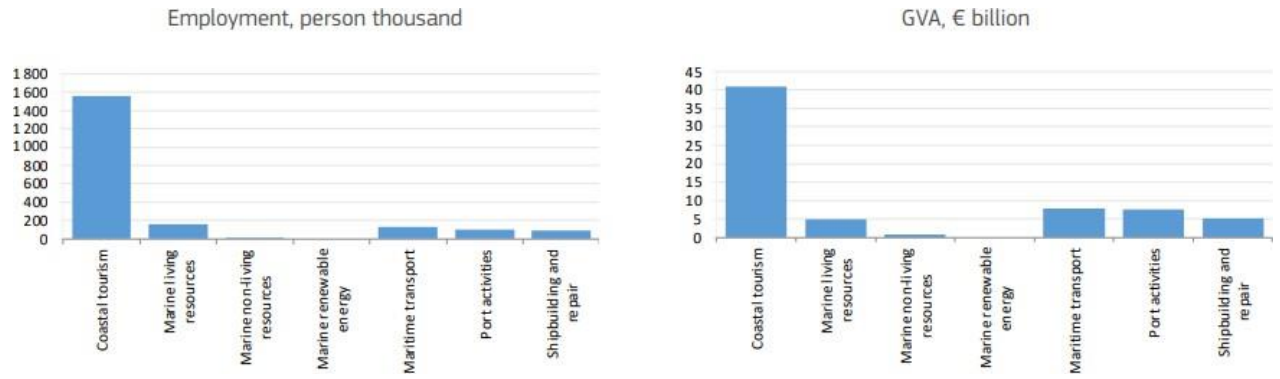
Nevertheless, the traditional sectors of the shipbuilding and offshore oil and gas industries are decreasing steadily, while the biggest successes can be seen in the energy sectors, where the EU is a global leader in both offshore wind and ocean energy. Other promising sectors include 'blue' biotechnology and desalination.

These and other economic activities have an increasing impact on the marine environment, from visible pollution such as plastic clutter and oil spills to invisible one - microplastics and chemicals. The effects of climate change and greenhouse gas emissions are disastrous on the oceans and local communities in those areas, ranging from changes in water temperature, to acidification, rising sea levels and recurrent flooding and erosion. Together with the major threat posed by biodiversity loss, which is driven by climate change and pollution, these impacts pose a challenge for both Blue economy as well as for society.

### *Mediterranean*

In the Mediterranean, the Blue economy generated EUR 67 billion GVA in 2019 and 2.05 million jobs. The main sectors include coastal tourism with EUR 39 billion GVA and 1.52 million jobs, which is followed by maritime transport, living resources and port activities with EUR 7 billion of GVA each.

**Figure 4 The Mediterranean Sea basin Blue economy by sector 2018**


Employment, person thousand

GVA, € billion

*Source: The Blue Economy Report 2022*

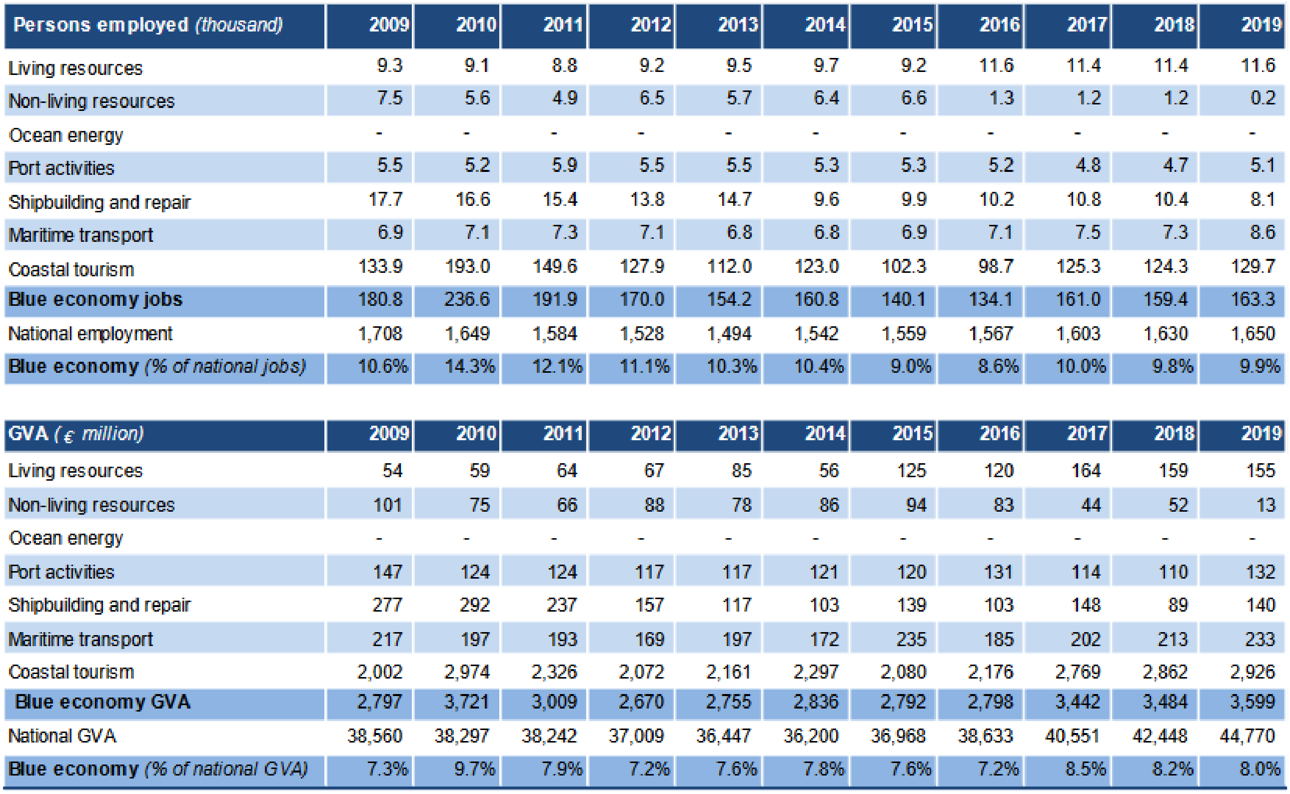
In the Adriatic and Ionian Region, the Blue economy generated EUR 25 billion of GVA in 2018 and 1.02 million jobs, most of which in the coastal tourism sector, followed by maritime transport and living resources.

### *Croatia*

The Croatian Blue economy employs 162,260 people and generates around EUR 3.6 billion of GVA. The latter not only help 8% to the national economy in terms of GVA, but also 9.9% in terms of jobs. Totally, blue-based GVA increased 29% in comparison with to 2009 due merely to coastal tourism and marine living resources sectors. Shipbuilding and repair, port activities, marine non-living resources and maritime transport all declined in comparison to 2009. Contrarily, Blue economy jobs reduced 10% compared to 2009, while only the marine living resources and maritime transport sectors experienced growth.

Coastal tourism is the dominant sector of the Blue economy in Croatia. The latter contributed with 79% to jobs and 81% of GVA in 2018. Both marine living resources and shipbuilding and repair sectors are key factors when it comes to blue jobs (7% and 5%, respectively). Albeit on a declining trend, the shipbuilding sector continues to be one of the most significant industrial sectors in Croatia. The current Croatian industry is small within the context of global shipbuilding; nevertheless, it plays an important role within the national economy.

Figure 5 Socio-economic data of the Blue economy sectors in Croatia



| **Persons employed** *(thousand)* | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Living resources | 9.3 | 9.1 | 8.8 | 9.2 | 9.5 | 9.7 | 9.2 | 11.6 | 11.4 | 11.4 | 11.6 |
| Non-living resources | 7.5 | 5.6 | 4.9 | 6.5 | 5.7 | 6.4 | 6.6 | 1.3 | 1.2 | 1.2 | 0.2 |
| Ocean energy | - | - | - | - | - | - | - | - | - | - | - |
| Port activities | 5.5 | 5.2 | 5.9 | 5.5 | 5.5 | 5.3 | 5.3 | 5.2 | 4.8 | 4.7 | 5.1 |
| Shipbuilding and repair | 17.7 | 16.6 | 15.4 | 13.8 | 14.7 | 9.6 | 9.9 | 10.2 | 10.8 | 10.4 | 8.1 |
| Maritime transport | 6.9 | 7.1 | 7.3 | 7.1 | 6.8 | 6.8 | 6.9 | 7.1 | 7.5 | 7.3 | 8.6 |
| Coastal tourism | 133.9 | 193.0 | 149.6 | 127.9 | 112.0 | 123.0 | 102.3 | 98.7 | 125.3 | 124.3 | 129.7 |
| **Blue economy jobs** | 180.8 | 236.6 | 191.9 | 170.0 | 154.2 | 160.8 | 140.1 | 134.1 | 161.0 | 159.4 | 163.3 |
| National employment | 1,708 | 1,649 | 1,584 | 1,528 | 1,494 | 1,542 | 1,559 | 1,567 | 1,603 | 1,630 | 1,650 |
| **Blue economy** *(% of national jobs)* | 10.6% | 14.3% | 12.1% | 11.1% | 10.3% | 10.4% | 9.0% | 8.6% | 10.0% | 9.8% | 9.9% |

| **GVA** *(€ million)* | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Living resources | 54 | 59 | 64 | 67 | 85 | 56 | 125 | 120 | 164 | 159 | 155 |
| Non-living resources | 101 | 75 | 66 | 88 | 78 | 86 | 94 | 83 | 44 | 52 | 13 |
| Ocean energy | - | - | - | - | - | - | - | - | - | - | - |
| Port activities | 147 | 124 | 124 | 117 | 117 | 121 | 120 | 131 | 114 | 110 | 132 |
| Shipbuilding and repair | 277 | 292 | 237 | 157 | 117 | 103 | 139 | 103 | 148 | 89 | 140 |
| Maritime transport | 217 | 197 | 193 | 169 | 197 | 172 | 235 | 185 | 202 | 213 | 233 |
| Coastal tourism | 2,002 | 2,974 | 2,326 | 2,072 | 2,161 | 2,297 | 2,080 | 2,176 | 2,769 | 2,862 | 2,926 |
| **Blue economy GVA** | 2,797 | 3,721 | 3,009 | 2,670 | 2,755 | 2,836 | 2,792 | 2,798 | 3,442 | 3,484 | 3,599 |
| National GVA | 38,560 | 38,297 | 38,242 | 37,009 | 36,447 | 36,200 | 36,968 | 38,633 | 40,551 | 42,448 | 44,770 |
| **Blue economy** *(% of national GVA)* | 7.3% | 9.7% | 7.9% | 7.2% | 7.6% | 7.8% | 7.6% | 7.2% | 8.5% | 8.2% | 8.0% |

*Source: The Blue Economy Report 2022 (Annex 1)*

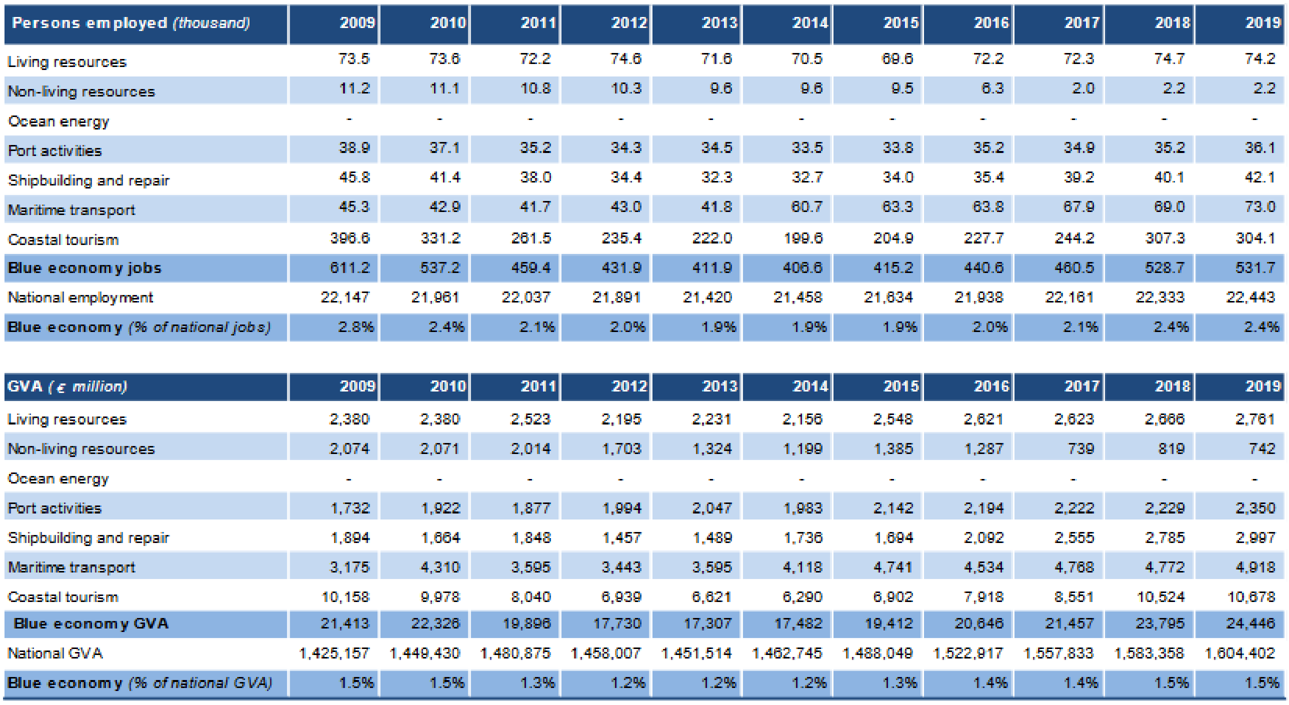
### *Italy*

The Italian Blue economy employs around 531,750 people and generates over EUR 24.4 billion in GVA. In 2019, it contributed with 2.4% to national jobs and 1.5% to national GVA. Both the share of Blue GVA and the jobs experienced a low period between 2011 and 2015 but have moved slowly back to 2009 figures. More precisely, the blue jobs have declined by 13% in comparison to 2009 while GVA has gone up by 14%. Except for maritime transport and, to a small degree, marine living resources, all other sectors have experienced a significant decline in employment in comparison to 2009.

As in Croatia, the coastal tourism is the dominant sector of the Blue economy in Italy which contributed 57% to blue jobs and 44% to GVA in 2019. Marine living resources and maritime transport sectors each generate 14% of jobs and in terms of GVA, 11% and 20.1% of respectively, which makes them also a considerable contributor to the Blue economy. Namely, except marine non-living resources and marine renewable energy sectors, all the remaining blue sectors are notable contributors to Italy's economy. A further decline in the marine non-living resources sector is expected due to moratorium on offshore oil and gas exploration permits and increased fees which, on the other hand, allows the government to prioritise renewable energy development and move towards decarbonisation instead.

At the EU level and in terms of GVA generation, Italy was in the third place in maritime transport, (14% of the EU total, coastal tourism (13%), marine non-living resources (16%) and shipbuilding and repair (19%).

Figure 6 Socio-economic data of the Blue economy sectors in Italy



| **Persons employed** *(thousand)* | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Living resources | 73.5 | 73.6 | 72.2 | 74.6 | 71.6 | 70.5 | 69.6 | 72.2 | 72.3 | 74.7 | 74.2 |
| Non-living resources | 11.2 | 11.1 | 10.8 | 10.3 | 9.6 | 9.6 | 9.5 | 6.3 | 2.0 | 2.2 | 2.2 |
| Ocean energy | - | - | - | - | - | - | - | - | - | - | - |
| Port activities | 38.9 | 37.1 | 35.2 | 34.3 | 34.5 | 33.5 | 33.8 | 35.2 | 34.9 | 35.2 | 36.1 |
| Shipbuilding and repair | 45.8 | 41.4 | 38.0 | 34.4 | 32.3 | 32.7 | 34.0 | 35.4 | 39.2 | 40.1 | 42.1 |
| Maritime transport | 45.3 | 42.9 | 41.7 | 43.0 | 41.8 | 60.7 | 63.3 | 63.8 | 67.9 | 69.0 | 73.0 |
| Coastal tourism | 396.6 | 331.2 | 261.5 | 235.4 | 222.0 | 199.6 | 204.9 | 227.7 | 244.2 | 307.3 | 304.1 |
| **Blue economy jobs** | 611.2 | 537.2 | 459.4 | 431.9 | 411.9 | 406.6 | 415.2 | 440.6 | 460.5 | 528.7 | 531.7 |
| National employment | 22,147 | 21,961 | 22,037 | 21,891 | 21,420 | 21,458 | 21,634 | 21,938 | 22,161 | 22,333 | 22,443 |
| **Blue economy** *(% of national jobs)* | 2.8% | 2.4% | 2.1% | 2.0% | 1.9% | 1.9% | 1.9% | 2.0% | 2.1% | 2.4% | 2.4% |

| **GVA** *(€ million)* | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Living resources | 2,380 | 2,380 | 2,523 | 2,195 | 2,231 | 2,156 | 2,548 | 2,621 | 2,623 | 2,666 | 2,761 |
| Non-living resources | 2,074 | 2,071 | 2,014 | 1,703 | 1,324 | 1,199 | 1,385 | 1,287 | 739 | 819 | 742 |
| Ocean energy | - | - | - | - | - | - | - | - | - | - | - |
| Port activities | 1,732 | 1,922 | 1,877 | 1,994 | 2,047 | 1,983 | 2,142 | 2,194 | 2,222 | 2,229 | 2,350 |
| Shipbuilding and repair | 1,894 | 1,664 | 1,848 | 1,457 | 1,489 | 1,736 | 1,694 | 2,092 | 2,555 | 2,785 | 2,997 |
| Maritime transport | 3,175 | 4,310 | 3,595 | 3,443 | 3,595 | 4,118 | 4,741 | 4,534 | 4,768 | 4,772 | 4,918 |
| Coastal tourism | 10,158 | 9,978 | 8,040 | 6,939 | 6,621 | 6,290 | 6,902 | 7,918 | 8,551 | 10,524 | 10,678 |
| **Blue economy GVA** | 21,413 | 22,326 | 19,896 | 17,730 | 17,307 | 17,482 | 19,412 | 20,646 | 21,457 | 23,795 | 24,446 |
| National GVA | 1,425,157 | 1,449,430 | 1,480,875 | 1,458,007 | 1,451,514 | 1,462,745 | 1,488,049 | 1,522,917 | 1,557,833 | 1,583,358 | 1,604,402 |
| **Blue economy** *(% of national GVA)* | 1.5% | 1.5% | 1.3% | 1.2% | 1.2% | 1.2% | 1.3% | 1.4% | 1.4% | 1.5% | 1.5% |

*Source: The Blue Economy Report 2022 (Annex 1)*

Presented data show that the Blue economy sectors play an important role in both Italian and Croatian economies. The dominant sector in both countries is coastal tourism, which is inseparably connected to clean and healthy Adriatic Sea. The presence and the possibilities of the Adriatic Sea enable the development of coastal tourism, while a significant number of tourists during the summer season has a positive impact on the economic growth, but at the same time has a negative impact on the sustainability and pollution of the Sea. In next chapters overviews of marine pollution and current situation in the Adriatic Sea are given.

## 1.4 Marine pollution

According to UN Factsheet: People and Oceans (2017) more than 600 million people (around 10% of the world's population) live in coastal areas that are less than 10 meters above sea level. Nearly 2.4 billion people (about 40% of the world's population) live within 100 km of the coast. Fish is one of the most important sources of animal protein, accounting for about 17% of protein at the global level and exceeds 50% in many least-developed countries. The ocean-economy, which includes employment, ecosystem services provided by the ocean, and cultural services, is estimated at between USD 3-6 trillion/year. Fisheries and aquaculture contribute USD 100 billion per year and about 260 million jobs to the global economy. Approximately 50% of all international tourists travel to coastal areas.

Pollution of marine environment has significant effect on ecosystem structure and function, human health and economic activities in coastal regions, regarding:

- biodiversity loss,
- eutrophication,
- health problems due to direct exposure to contaminants or consummation of contaminated sea food,
- tourism,
- fisheries,
- aquaculture,
- coastal property value.

Around 80% of all pollution in seas and oceans comes from land-based activities. More than 8 million tonnes of plastic enter the oceans each year and as much as 80% of all litter in oceans is made of plastic. Beside its effect as solid pollutant, plastic is also source of harmful chemicals. Nitrogen loads to oceans roughly tripled from pre-industrial times due to fertilizers and wastewater. Pollution and eutrophication (excessive nutrients in water) are also caused by run off from the land, which cause dense plant growth and the death of animal life. Increased nutrient loading from human activities, combined with the impacts of climate change and other environmental change has resulted in an increase in the frequency, magnitude, and duration of algal blooms, which can contaminate seafood with toxins and affect tourism and recreational activities. Oil and chemical spills remain a concern.

## 1.5 Adriatic sea

Adriatic Sea is a part of the Mediterranean Sea with surface area of 138,600 km2 and it is a semi-enclosed sea. The Adriatic receives a large amount of freshwater from numerous rivers, with an annual average of 5,700 m3/s. Of this amount, about 28% (1,585 m3/s) comes from the Po river, in the north-western corner and shallowest part of the basin. The second most important freshwater inflow is the set of Albanian rivers and surrounding drainage bringing in average 923-1,244 m3/s. It is estimated that on the coast of the Adriatic

Sea lives about 3.5 million inhabitants, mainly concentrated in urban centres at the Italian and Croatian coasts (Randone, M. 2016).

Croatian economy is highly dependent on tourism and majority of tourist income results from activities in the coastal area, resulting in pressure on environment. In seven Croatian coastal counties in 2018 was realized 94.7% of all overnight stays and 86.5% of all arrivals in Croatia. The increasing human use of the marine and coastal space, in particular through (over-)fishing, maritime transport, tourism, construction, and – in the Northern Adriatic – the exploration and exploitation of hydrocarbons has intensified the pressure on the entire ecosystem of the Adriatic.

Maritime commercial transport in the Adriatic generally is rather dense and comprises container and hydrocarbon (oil and LNG) vessels. On top of the larger container vessels or tankers come the regional fishing fleets, and, during the summer period, recreational vessels such as sailing and motorboats or yachts.

Plastic and other debris are emphasised as major issue. Assessment of abundance, distribution and composition of floating and seabed macro and micro litter in the Central Adriatic Sea showed that average calculated concentrations of floating macro (175 items/km$^2$), floating micro (127 thousand particles/km$^2$) and seabed micro litter (36 particles/100 g dry weight) show similar values as other published studies from the Mediterranean Sea (Palatinus et al, 2018).

InnovaMare partner countries are Italy and Croatia. Having the Adriatic Sea between them, these two countries share numerous interests, including the preservation of its sustainability and prevention of its pollution. By putting its sustainability as a main objective of the InnovaMare project and by doing a technology foresight of maritime technologies that will detect, monitor and prevent marine pollution, the InnovaMare project partners emphasize the value of the Adriatic Sea, both environmental and socio-economical, but are also being active promotors and protectors of its sustainability.

# 2 EU policy framework and relevant strategies

The goal of this chapter is to inform and direct policies regarding the identified challenges (in this case, prevention of marine pollution and sustainability of the Adriatic Sea) towards improved planning and decision-making at the strategic and operational levels, for companies, scientific research organizations and for policy makers, by anticipating future market demand and the development of innovative technologies as future offer.

**The Blue Growth Strategy (BGS)** is the current long-term policy framework for stimulating economic activities relating to oceans, seas, islands, coastal and outermost regions and maritime sectors. The BGS was adopted by the Commission in 2012 and it has a threefold function:

- to develop sectors that have a high potential for jobs and sustainable growth,
- to provide knowledge, legal certainty and security in Blue economy,
- to develop sea basin strategies to ensure tailor-made measures and to foster cooperation between countries.

The BGS gives special attention to five Blue economy sectors, both well established (coastal and maritime tourism) and emerging ('blue' energy, 'blue' biotechnology), showing high potential for job creation and innovation. In order to foster the growth in the various sectors, the BGS lists certain key enablers such as maritime spatial planning, research and innovation, maritime surveillance and efforts to improve skills. The emerging sectors will play an important role in the EU's transition towards a carbon-neutral, circular and biodiverse economy.

**The European Green Deal (EGD)** is a new growth strategy of the EU to promote ambitious environment, climate and energy policies, with the ultimate objective to boost **sustainable development** and transform the EU into a climate-neutral, fair and prosperous society, with a modern, resource-efficient and competitive economy. It is a roadmap how to move to a clean, **circular economy** and adapt to **climate change**, restore **biodiversity** and cut **pollution** (EC, 2020). It describes investments needed and financing tools available and explains how to provide a just and inclusive transition to help those that are most affected by the move towards the green economy. Further, the EGD is an integral part of the Commission's strategy to implement the United Nations' 2030 Agenda and its seventeen sustainable development goals.

The Green Deal covers all sectors of the economy, notably transport, energy, agriculture, buildings, and industries such as steel, cement, ICT, textiles and chemicals.

In order to help the EU, achieve its 2050 climate neutrality goal, it is necessary to rethink policies for clean energy supply across the economy, industry, production and consumption, large-scale infrastructure, transport, food and agriculture, construction, taxation and social benefits. To accomplish these goals, it is essential to boost the value given to protecting and restoring natural ecosystems, to the sustainable use of resources and to improving human health. This is where transformational change is most needed and potentially most beneficial for the EU economy, society and natural environment. The EU should also promote and invest in the necessary **digital transformation** and tools as these are essential enablers of the changes.

The EGD has the following **objectives**:

- make the EU climate neutral by 2050,
- protect human life, animals and plants by reducing pollution,
- contribute to guaranteeing a fair and integrated transition,
- develop reliable and affordable clean energies and the transition funding,
- convert agriculture and rural regions.

**The EU Biodiversity Strategy for 2030** is a comprehensive, ambitious and long-term plan **to protect nature and reverse the degradation of ecosystems**. The strategy aims to put Europe's biodiversity on a path to recovery by 2030, and contains specific actions and commitments:

- establishing a larger EU-wide network of protected areas on land and at sea,
- launching an EU nature restoration plan,
- introducing measures to enable the necessary transformative change.

The actions proposed under the strategy include strengthening protected areas in Europe and restoring degraded ecosystems by **increasing organic farming, reducing the use and harmfulness of pesticides and planting trees**. Improving the condition and diversity of agroecosystems will increase the sector’s resilience to climate change, environmental risks and socioeconomic shocks, while creating new jobs, for example in organic farming, rural tourism or recreation.

The objective of the strategy is to put Europe’s biodiversity on a path to recovery by 2030, bringing benefits for people, the climate and the planet. In the post-COVID-19 context, the strategy aims to build our societies’ resilience to future threats such as the impacts of climate change, forest fires, food insecurity and disease outbreaks, including by protecting wildlife and fighting illegal wildlife trade.

**The Farm to Fork Strategy** aims to help the EU achieve climate neutrality by 2050 by shifting the current EU food system towards a sustainable model.

In addition to **food security and safety**, the strategy’s **main goals** are to:

- ensure sufficient, affordable and nutritious food within planetary limits,

- ensure sustainable food production through, inter alia, a substantial reduction in the use of pesticides, antimicrobials and fertilisers and an increase in organic farming,
- promote more sustainable food consumption and healthy diets,
- reduce food loss and waste,
- combat food fraud in the supply chain,
- improve animal welfare (COM, 2020).

The strategy sets out both regulatory and non-regulatory initiatives, with the common agricultural and fisheries policies as key tools to support a just transition.

In October 2020, the Council adopted a set of conclusions on the strategy, endorsing the goal of developing a European sustainable food system, from production to consumption.

The aim of the **European Industrial Strategy (EIS)** is to support the **transformation of EU industry** to remain globally competitive and world-leading, pave the way to climate neutrality by 2050 and shape Europe's digital future

The EIS outlines the seven fundamental elements of Europe's industrial transformation and the steps to achieve them:

- creating certainty for industry with a deeper and more digital single market,
- upholding a global level playing field,
- supporting industry towards climate neutrality,
- building a more circular economy,
- fostering a spirit of industrial innovation,
- skilling and reskilling,
- investing in the transition.

The European Commission published a new industrial strategy in March 2020 with the focus on **three priorities**:

- strengthening of the resilience of the single market,
- supporting Europe's open strategic autonomy through dealing with dependencies,
- supporting the business case for the twin transitions.

This **Circular Economy Action Plan (CEAP)** provides a future-oriented agenda for achieving a **cleaner and more competitive Europe** in co-creation with economic actors, consumers, citizens and civil society organisations. The plan presents a set of interrelated initiatives to establish a strong and coherent product policy framework that will make sustainable products, services and business models the norm and transform consumption patterns so that no waste is produced in the first place.

The **objectives** of the action plan aim to:

- make sustainable products the norm in the EU,
- empower consumers and public buyers,
- focus on the sectors that use most resources and where the potential for circularity is high such as: electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, food, water and nutrients,
- ensure less waste,
- make circularity work for people, regions and cities,
- lead global efforts on circular economy.

In December 2020, the European Commission adopted conclusions of the presented circular economy action plan.

The EU action plan “**Towards a Zero Pollution Ambition for air, water and soil – building a Healthier Planet for Healthier People**” aims to secure healthy ecosystems and a healthy living environment for Europeans – both individuals and populations. It will help to create a toxic-free environment across the EU by better monitoring and, reporting, and by preventing and remedying pollution from air, water, soil, and consumer products.

The plan follows the Green Deal strategy, and its main aims are:

- to better prevent and remedy pollution from air, water, soil, and consumer products,
- to mainstream the zero-pollution ambition into all policy developments,
- to further decouple economic growth from the increase of pollution,
- to strengthen the links between environmental protection, sustainable development and people’s well-being.

Bearing in mind the objectives of InnovaMare project, the EU framework was analysed and the main EU strategies and actions taken in the area of sustainable Blue economy were selected, with the special emphasis on the maritime technologies.

# 3 Current global and EU trends in maritime technologies

In this chapter an overview of global and EU trends regarding maritime technologies is given. Considering the term maritime technologies as an umbrella term for numerous technologies and areas, several maritime technologies related to InnovaMare project and its goals were analysed, with the focus on technologies related to marine environment protection, marine pollution and underwater technology. Directions in which the technologies are changing or developing were given, according to the EU Blue Economy Report 2022 (EC 2022) and the Global Marine Technology Trends 2030 (hereinafter GMTT) (Shenoi et al. 2015).

Maritime technologies are the technologies involved in the safe use, exploitation, protection of and intervention in the marine environment. In this regard, the European Association of Universities in Marine Technology (WEGEMT) considers following technologies and fields: naval architecture, marine engineering, ship design, ship building and ship operations; oil and gas exploration, exploitation, and production; hydrodynamics, navigation, sea surface and sub-surface support, **underwater technology and engineering**; marine resources (renewable and non-renewable); transport logistics and economics; inland, coastal, short sea and deep sea shipping; **protection of the marine environment**; leisure and safety.

In 2015, GMTT identified **eight emerging maritime technologies** as the future of maritime. The drivers for these technologies are balanced between environmental and commercial necessity. On the one hand, they are in line with current global trends of marine sustainability, safe and secure maritime transport, reduction of GHG emissions, green and digital transformation, and on the other they encourage new R&D activities, open new markets, and stimulate business development. Advancing maritime technologies according to the GMTT are:

- **shipbuilding** - adopting new shipbuilding technologies and materials,
- **propulsion and power generation** - include future engines, alternative fuels, propulsion energy-saving devices, renewable sources of energy, hybrid power generation, and emissions abatement technology,
- **smart ships** – integration of a variety of connected technologies to improve operational efficiency, ship management, regulatory compliance, decision making, environmental responsibilities and also improve safety and maintenance of vessel and crew through communication networks,
- **big data and analytics** - IT infrastructure will be upgraded to retrieve, store, and process data in real time,
- **advanced materials** - a critical component of improving future ship performance; multi-functional materials, self-cleaning and self-repairing materials,

- **robotics** - three new types of robots that will be in use: a learning robot, a practical robot and a mini-robot, useful for inspections in harsh, dangerous environments,
- **sensors** - utilisation of sensors will represent a powerful opportunity for improvements in the efficiency and safety of vessels and associated equipment's,
- **communications** - the integration of 5G, WiFi and new generation satellites will enable transferring multiple signals at a higher data transmission speed.

The Blue Economy Report 2022 brings a more current view on advancing maritime technologies, that certainly includes all of the above-mentioned technologies from 2015. For the purposes of the Report, the Blue Economy includes activities that are marine-based or marine-related.

- **Marine-based and marine-related activities**

| **Marine-based activities**<br>activities undertaken in the sea and coastal areas | **Marine-related activities**<br>activities which use products and/or produce products and services from the ocean |
|---|---|
| Marine living resources<br>(capture fisheries and aquaculture) | Seafood processing |
| Marine minerals | Biotechnology |
| Marine renewable energy | Shipbuilding and repair |
| Desalination | Port activities, technology and equipment |
| Maritime transport | Digital services |
| Coastal tourism | |

Activities are divided in two sectors: **established sectors**, those that traditionally contribute to the Blue economy, and **emerging and innovative sectors**, which bring new opportunities for investment and hold large potential for the future development of coastal communities.

- **Established and emerging sectors of the Blue economy**

| **Established sectors** | **Emerging sectors** |
|---|---|
| Marine living resources | Ocean energy |
| Marine non-living resources | Blue biotechnology |
| Marine renewable energy (offshore wind) | Desalination |
| Port activities | Maritime defence, security and surveillance |
| Shipbuilding and repair | Research and innovation |
| Maritime transport | Infrastructure |
| Coastal tourism | |

Amongst the established sectors and current trends in maritime technologies, marine renewable energy and maritime transport were analysed.

**Marine Renewable Energy** includes **offshore wind technologies** and **ocean energy technologies**. Both technologies represent an important source of green energy and can make a significant contribution to the EU's 2050 energy strategy. They generate economic growth and jobs, and boosts competitiveness through technological innovation. When it comes to **offshore wind energy**, Europe is world's leader - over 90% of the world's total installed capacity is in Europe. This established sector directly employs 38,000 persons, while another 39,000 are indirectly employed. Most of the EU installed capacity (99%) is located in the North and Baltic Seas. Germany is the EU's main producer with the installed capacity of offshore wind energy (47%), followed by the Netherlands (23%), Belgium (15%), Denmark (14%). The sector is in large expansion. **Ocean energy technologies** are currently being developed and tested to exploit the vast source of clean, renewable energy that seas and oceans offer. Since they are still at R&D stage and not commercially available, ocean technologies are considered emerging sectors and they include floating offshore wind, tidal and wave energy technologies (the most advanced among the ocean energy technologies), floating solar photovoltaic energy (FPV installations) and hydrogen generation offshore.

**Figure 7 A floating offshore wind farm, Scotland, 2021**

Source: *OffshoreWIND.biz (2022)*

**Figure 8 The first tidal platform plugged in the national grid, UK, 2008**

Source: *The Daily Mail (2022)*

**Figure 9 Floating solar system in France, 2018**

**Figure 10 Hydrogen offshore platform, 2020**

*Source: Energy Industry Review (2022)*

*Source: Tractebel (2022)*

Another established sector in Blue economy is **maritime transport**. Maritime transport holds a crucial contribution to decarbonisation, having shipping as the most carbon-efficient mode of transportation. International maritime shipping accounts for less than 3% of annual global GHG emissions and produces less exhaust gas emissions for each tonne transported per kilometre when compared to air or road transport. This sector has a key role in EU economy and trade – it represents around 80% of worldwide goods transportation and one third of the intra-EU trade. Due to the expected growth of the world economy and associated transport demand from world trade, and in order to maintain the environmental-friendly characteristics and to be in line with the Green Deal goals, the maritime transport industry has to continue **improving energy efficiency of ships and shifting to alternative fuels**. Trends of sustainability, new shipbuilding technologies, alternative fuels, renewable sources of energy, advanced materials and smart components in the shipbuilding and maritime transport industries remained the same as in 2015. The European Commission adopted an ambitious Sustainable & Smart Mobility Strategy in 2020, for European transport under the umbrella of the Green Deal, that is based on sustainability, multimodal transport system (for both passengers and freight), enhanced recharging and refuelling infrastructure for zero emission vehicles, and digitalisation and use of new technologies.

Regarding the trend of **new fuels for shipping**, a large-scale uptake of carbon-neutral fuels is essential to achieve 2050 reduction goals. The deployment of zero-emission vessels will require significant modification of the existing shipping value chain, including all the stakeholders, from academia to industry and policy. Pioneering pilots include different fuel options: green ammonia, green methanol, biofuels, green hydrogen and synthetic diesel. From the above, green methanol and green ammonia appear to be the most promising candidates for a deep decarbonisation and in the long run.

Under the emerging sector of Infrastructure, there are sub-sectors of submarine cable networks and the most recent one, robotics. **Underwater robotics** are the result of digitalisation and technological innovation in the maritime sector. Underwater robots can be used for different purposes in the maritime environment, such as surveys, scientific research, oil and gas exploration, border surveillance, infrastructure inspection, and farming. As they enable ocean exploration in challenging environmental situations, underwater robots are being used for surveillance, including defence and military use, but also for industrial and commercial purposes. In 2020, the global underwater robotics market was valued at EUR 2,685 billion and forecasted to reach EUR 6,719 billion by 2028. Despite their importance, the mass uptake of marine robotics and sensors has been limited due to high costs associated to R&D, complexity of underwater operations, such as communication and navigation, as well as technological constraints. The two main types of unmanned water vehicles are Remotely Operated Vehicles (ROV) and Autonomous Underwater Vehicles (AUV). In the following chapters they are being described in detail.

The latter trend in maritime technologies development is the most relevant for InnovaMare project. More precisely, the development of robotics and sensors for the detection, monitoring and prevention of marine pollution is the field of interest for InnovaMare project partners. Identification of these emerging technologies and anticipation of their development will not only lead the project partners towards the main goal – preservation of sustainability and prevention of marine pollution in the Adriatic Sea, but also enable them to identify the key challenges and opportunities in the field and to actively create future offer of the stakeholders (mostly from research and public sectors), that will meet the needs and demands of other participants in the Blue economy.

# 4 Current technologies for detection, monitoring and prevention of pollution in marine environments

## 4.1 Overview

A variety of sensing systems are now available for ocean monitoring including research vessels, robotic vehicles, profiling floats, gliders, drifters, measurements on ships, satellites and sensing nodes with cable networks. These approaches to marine monitoring usually measure or detect temperature, conductivity, pH, salinity, dissolved oxygen, fluorescence due to chlorophyll, turbidity, oil presence, colour dissolved organic matter (CDOM), total nitrogen, total phosphorus, chemicals, metals, etc.

InnovaMare project partners develop and use technologies in the fields of underwater robotics and sensors for environmental protection of Adriatic Sea, as well as for implementation of these technologies on EU and global level.

Selected methods and tools, used for detection, monitoring and pollution in marine environments:

***Research vessels***

The most common approach for marine pollution measurements is to use conventional method of collecting in situ water samples using boats/ships from different depths of water with water samplers. The water samples are analysed in the laboratory to determine the physical and chemical properties of the water. Such methods are accurate but time-consuming and geographically constrained and require trained professionals and laboratory analysis. However, real-time or near real-time measurements of marine pollutants and toxins across a range of spatial scales are necessary for monitoring and managing the environmental impacts and understanding the processes governing their spatial distribution.

***Floats***

Floats can be weighted to be neutrally buoyant at a particular depth, where they drift in the current while emitting periodic sounds. Such floats have been tracked for years by moored sound receivers to provide a long-term look at ocean currents. Trajectories of individual floats show how the water moves horizontally, and trajectories of groups of floats show how the water is mixed by eddies. This information is important for understanding how **water tracers and pollutants are transported by the ocean**. More recently, the sound sources have been moored while the floats act as receivers, surfacing at the end of an approximately two-year lifetime to report their data via satellite to a shore station. Other floats drift for two months, surface to transmit data to a satellite, and descend again for another two months of data collection. They can repeat this process for up to five years. Other combinations of these techniques are under development.

## *Fixed Point Marine Observation Systems*

Fixed-point marine observation systems have been deployed globally, to make in situ sustained Eulerian observations of a variety of biogeochemical and physical variables. Various platforms have been deployed, including fixed-depth or profiling moorings, fixed piles, towers and seabed landers that employ instrumentation capable of long term, autonomous operation.

## *Remote sensing*

Remote sensors capture the response of the electromagnetic interaction with water. Absorption and scattering are inherent optical properties (IOP) of water; and variations in IOP change the reflectance of water which is captured by a remote sensing sensor, and this is known as the apparent optical properties (AOP) of water. Reflection, absorption, and transmittance of electromagnetic radiation are highly dependent on the concentrations, types, and presence of substances in water. Total absorption is the sum of absorption by phytoplankton (microalgae), non-algal pigments (NAP), colour dissolved organic matter (CDOM), and absorption by water, whereas light scattering by water is mainly controlled by suspended sediments (SS) present in water. There are several remote sensing platforms for monitoring water pollutants, and they can be categorized into two types: **airborne and spaceborne**.

An aircraft can fly at relatively low altitudes (a few hundred meters to a few kilometres above the surface); therefore, the acquired data always have higher levels of detail. Airborne data are particularly useful for **real-time monitoring of oil and chemical spills.** Four common airborne sensors used for spill surveillance are: Infrared/ultraviolet line scan (IR/UVLS), Side-looking airborne radar (SLAR), Microwave radiometer (MWR), Laser fluorosensor (LF).

Spaceborne sensors can cover extensive and remote areas for water quality monitoring. Optical spaceborne sensors used for marine monitoring are mostly in sun-synchronous orbit; only GOCI, designed specifically for marine monitoring, is placed in geostationary orbit. Many **algorithms have been developed to retrieve water quality information** such as **primary productivity, Chl-a variability, SS, total suspended solids (TSS), turbidity, total nitrogen, total phosphorus, CDOM, and SST**. The major application areas of active spaceborne sensors include, but are not limited to, sea surface currents, oil spills, biogenic films (algal blooms), and river plumes.

CleanSeaNet is a European satellite-based oil spill and vessel detection service which offers assistance to participating States for the following activities:

- identifying and tracing oil pollution on the sea surface,
- monitoring accidental pollution during emergencies,

- contributing to the identification of polluters.

The CleanSeaNet service is based on the regular ordering of Synthetic Aperture Radar (SAR) satellite images, providing night and day worldwide coverage of maritime areas independent of fog and cloud cover. Data from these satellites is processed into images and analysed for oil spill, vessel detection and meteorological variables. The information retrieved includes among others: spill location, spill area and length, confidence level of the detection and supporting information on the potential source of the spill (i.e., detection of vessels and oil and gas installations).

## 4.2 Underwater robotics

According to Zereik et al (2018), marine robotics has steadily emerged as a **key enabling technology for the execution of increasingly complex and challenging missions at sea**. Intensive research and development in this field have led to major advances and shown the effectiveness and reliability of marine robotics solutions in several domains. Increasingly intelligent control and trajectory planning systems, high manoeuvrability, sophisticated anti-collision systems, as well as high data collection and processing capabilities have made robotic vehicles particularly well suited for industrial and scientific uses, including detection, monitoring and prevention of various types of pollution. **Marine robotics has been steadily expanding researchers' possibilities to study and monitor the underwater environment**. Robots' capability of operating and exploring challenging and hazardous scenarios has made these technologies essential tools for field specialists (Ridolfi et al, 2021).

Some of advantages of underwater robotic tools are **transportation ease and straightforward deployment without special equipment** (from a ship deck and from the shore). The high autonomy that limits the required human inputs greatly simplifies the monitoring operation logistics. Underwater robots come in a variety of shapes and sizes and **can be outfitted with numerous sensors and tools to collect extensive amounts of data from deep-sea environments**. Robots can explore areas of the ocean that are too dangerous or too difficult for humans to go. They can also represent a valuable complementary alternative to the traditional monitoring techniques. In the last decade, vehicles have become compact, robust and highly autonomous. They are now capable of performing frequent and rapid surveys and enhancing the acquired data coverage and resolution thanks to optimized survey strategies. For all those reasons, marine robots have the potential to **capture data that were previously difficult to acquire and, thus, integrate with existing models and databases.**

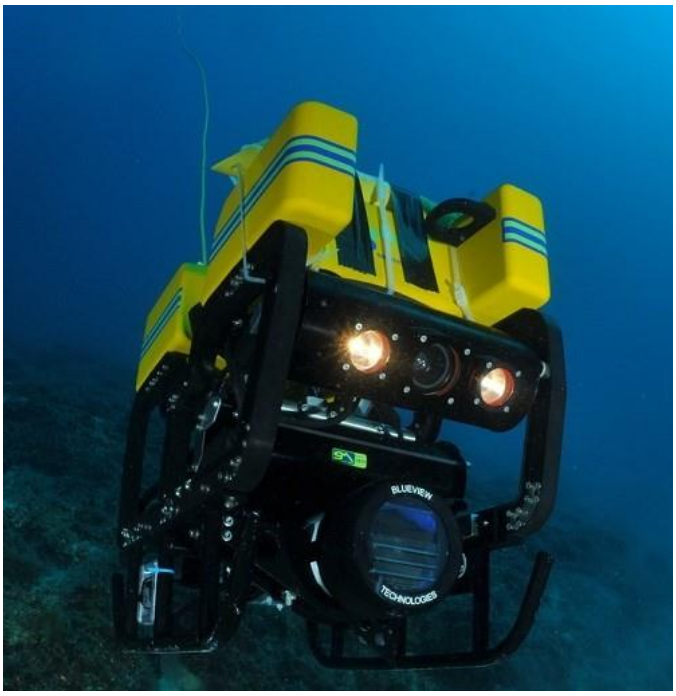
Autonomy of robotic vehicles can be categorized into two broad classes: human-in-the-loop (HITL) and human-on-the-loop (HOTL). Machines that carry out a task for a period of time, then stop and wait for human commands before continuing are known as HITL systems, while machines that can execute a task completely and independently but have a human in a monitoring or supervisory role, with the ability to interfere if the machine fails, are known as HOTL systems. Trends in robotics and automated systems are going in direction where HITL is increasingly being replaced by HOTL.

Robotic vehicles ban be remotely controlled or autonomous and most common types in the field of marine robotics are:

### *Remotely Operated Vehicles (ROV)*

ROVs are usually **tethered to a ship or a generic external control station**. The tether streams data and images from the vehicle, allowing a human operator to real-time control the robot; therefore, the operator can organize data acquisition campaigns and close-up investigations in new and demanding environments. The tether generally also delivers power to the vehicle enabling long-time missions. However, it limits the ROVs working range, and it must be carefully and closely monitored to avoid bending, abrasion, or possible breakages. Teleoperation allows for the exploitation of all the human pilot's creativity and dexterity and is currently preferred for delicate operations such as underwater manipulation. As much as the use of this technology offers greater safety than recruiting technical underwater operators to explore particularly hazardous environments, it still needs direct human intervention and, hence, is associated with an inevitable cost of personnel.

**Figure 11 SeaMor 300F ROV used by project partner LABUST**



*Source: LABUST (2022), available at: [https://labust.fer.hr/labust/about/equipment/seamor_300f_-_rov](https://labust.fer.hr/labust/about/equipment/seamor_300f_-_rov)*

### *Autonomous Underwater Vehicles (AUV)*

AUVs are **unmanned robots provided with their own power and control systems** allowing them for highly independent mobility. They usually conduct pre-programmed missions for a few hours up to several days, depending on the power systems and sensor set. AUV is an untethered vehicle which requires much less complicated logistics and has significantly larger area coverage than a Remotely Operated Vehicle (ROV). Its capabilities make AUV ideal underwater tool for environmental monitoring application requiring in-situ water sampling. AUVs ability to follow and control their trajectory together with the possibility to provide the platform with a **wide variety of instrumentation and sensors make them well suited to collect different types of data**. AUVs can also be used as Autonomous Surface Vehicles (ASV) as they are usually equipped with GPS antenna and can thus be employed also in very shallow water.

Figure 12 AUV Buddy designed and developed by project partner LABUST

*Source: LABUST (2022), available at: https://labust.fer.hr/labust/about/equipment/auv_buddy*

### *Gliders*

Submarine or buoyancy gliders are a relatively recently developed instrument platform for measuring the internal ocean. Gliders are a subclass of AUVs and they don't use thrusters or propellers for their movement. By shifting their internal mass and adjusting their buoyancy, gliders navigate rather than simply drift with the current. They operate independently but communicate via satellite enabling data upload, mission planning and updating. The design of gliders facilitates very low power consumption allowing them to be deployed for months at a time. Gliders may be equipped with a wide variety of sensors. While there are many glider designs that use different techniques to move through the water, all gliders share the ability to travel far distances over long periods, without servicing. Unmanned gliders sample the ocean in places where it is impractical to send people, and at low cost.

Compared to ROVs, AUVs are more expensive due to the cost of the underwater sensors required for the navigation and localization algorithms, which must guarantee high localization accuracy in a GPS-denied environment. AUVs can also be equipped with GPS navigation, however, because radio waves cannot travel through water, an AUV can only acquire a GPS signal while at the surface. **AUVs can autonomously perform large-area mapping activities and underwater surveys without requiring continuous monitoring** of an active operator, i.e., not requiring the support vessel to be located nearby, they significantly reduce the cost of the intervention and are suitable for frequent monitoring campaigns. AUVs can be deployed from shores or port's quays, drastically reducing the campaign costs by skipping the ship's logistic support. AUV operations are generally risky. For coastal AUV operations carried out from small boats in shallow waters, with possible uncharted obstacles or intense surface traffic, the probability of losing an AUV could be as high as 0.3 to 1.9%. Therefore, all modifications related to the operation and control of an AUV must be handled with great care (Zereik et al, 2018).

Robot's size determines the maximum reachable depth, the minimum depth for operation, the sensor payloads it can carry and the mission time. Large dimensions usually are related to long autonomy, coverage of large areas, sophisticated payloads and great reachable depths. However, bulk vehicles have the drawbacks of requiring a fully crewed ship equipped with a crane for their deployment which raises the costs. Therefore, the purposes of marine-coastal environment monitoring may ask for **more modular and compact robots characterized by low logistic requirements** and capable of performing frequent surveys in very shallow water (Ridolfi et al, 2021). Modular vehicles are composed of several modules each of which is usually dedicated to a specific task, allowing easy customization of the carried payload according to the mission to perform. The robot modularity also simplifies the logistic complexity since they can be carried dismantled and then assembled in situ. **AUVs can carry a variety of sensors.** Sensor packages can include video or still cameras, sonar, magnetometers, fluorometers, dissolved oxygen sensors, conductivity, temperature, and depth sensors (CTDs), pH sensors, and turbidity (suspended sediment concentration) sensors. AUVs can also be equipped with GPS/GNSS navigation, however, an AUV can only acquire a GPS signal while at the surface. When underwater, the AUV uses its last known GPS position and calculates its movement using an on-board inertial navigation system, which measures the AUVs velocity, acceleration, and rotation (Trembanis et al, 2021). Despite great results so far, the optimization of AUVs performances at sea remains a challenging task, and the potential for further innovation is still wide-ranging.

According to Zereik et al (2018) the **ocean environment places challenges to the development of autonomous and/or persistent systems for exploration and sampling**. Engineers and scientists must strive to meet the extremely tight design constraints imposed by the harsh conditions that both surface and underwater platforms must face. Among these, the following are worth stressing:

1. high pressures and low temperatures related to extremely deep or harsh environments (e.g., abyssal and polar areas) require suitable components and water-tight containers and equipment.

2. underwater communications mandate the use of acoustic devices that in challenging operational scenarios are plagued with intermittent communication losses and multi-path effects and exhibit reduced bandwidth and low reliability,
3. long range missions require that the vehicles be equipped with proper power supply systems (also relying on alternative technologies such as fuel cells, biological batteries, solar panels, etc.) and efficient energy management systems.

The use of autonomous vehicles also requires the design and implementation of advanced guidance, navigation, motion control, and mission control systems, together with acoustics-based communication networks in order to afford vehicles acting in isolation or in a group the high level of reliability required to accomplish complex missions.

Europe leads in many aspects of maritime technology, and the marine-robotics industry is proliferating. It is a crucial high-value/high-cost sector with considerable entry barriers to research and development. This industry’s full growth potential will be significantly enhanced with access to shared robotic research infrastructure. EUMarineRobots (EUMR) proposes an access-infrastructure for the deployment of a full-range of aerial, surface and sub-surface marine robotic assets. EUMR aims to open transnational access to significant national marine robotics R&D assets across Europe. The main objective of the EUMR project is to open up key national and regional marine robotics research infrastructures (RIs) to all European researchers, from both academia and industry, ensuring their optimal use and joint development to establish a world-class marine robotics integrated infrastructure. Objectives that arise from main objective are:

1. The provision of access for researchers from academia and industry to state-of-the-art infrastructures,
2. The provision of access for researchers from academia and industry to large-scale sea experiments,
3. The provision of opportunities for researchers from academia and industry to develop and evaluate operating concepts for high added-value applications,
4. The provision of access for researchers from academia and industry to dana,
5. Provide uniform access to RIs to facilitate distributed experimentation and testing and to contribute to standardization,
6. Provide uniform training for users of the infrastructures,
7. Enhance the utilization of marine robotic infrastructures,
8. Contribute to address current and future societal marine challenges,
9. Develop business plans with the goal of ensuring sustainability of the proposed infrastructures,
10. Contribute to the extension of the “robotics revolution” to marine robotics,
11. Contribute to the cross-fertilization of ideas, tools, technologies, and methods,

12. Contribute to the efficient and effective utilization of infrastructures in Europe.

Priority research areas in marine robotics according to Institute of IEEE Robotics and Automation Society are:

- actuation and sensing systems,
- communication,
- manipulation,
- interaction,
- guidance, navigation and control,
- mission control systems,
- localization,
- multi-vehicle coordination,
- networked vehicles,
- outreach and engagement,
- grand challenges,
- planning,
- persistent monitoring.

## 4.3 Sensors

A sensor is a device that produces a response to a change in a physical condition, or to a change in chemical concentration. There is a wide range of sensors available for marine monitoring including **chemical, biogeochemical, physical and biological parameters**. Sensors are particularly suited for making in situ measurements in the marine environment. Their use can overcome some of the problems of the under-sampling (in both space and time) of coastal waters and the ocean. Many engineering platforms are available on which sensors can be deployed in the environment and include buoys, floats, autonomous underwater vehicles (AUVs), gliders, benthic landers and moorings (Mills et al, 2012).

In situ sensors have been used for a few years to measure physical-based parameters. The majority of these are available commercially, particularly in sensor packages such as conductivity, temperature and depth (CTD) profiling instruments. CTD is often used today to describe a package that includes the CTD as well as auxiliary sensors to measure other parameters. Some of most common variables, which marine sensors detect, or measure are:

- dissolved oxygen,
- pH,
- turbidity,
- $CO_2$,

- chlorophyll a,
- ammonia and nitrate,
- phosphorus,
- metals,
- blue-green algae,
- dissolved inorganic carbon (DIC).

Arrays of sensors can be deployed so that multiple parameters can be measured simultaneously, and these systems can be fully automated. These can either be deployed from a ship in the profiling mode or can be deployed on a mooring for long-term monitoring as part of an observation system.

Engineering and manufacturing of sensors must consider important instruments requirements (Schroeder, Prien, 2020):

- accuracy - deviation of the measured value from the true value,
- precision - deviation of a measured value from another measured value of the same quantity,
- resolution - smallest change in the measured quantity that can be detected by the instrument,
- measurement rate - number of measurements that can be carried out per unit time (e.g., measurements/hour),
- power consumption - mean of electrical power uptake during deployment (usually measured in Watts [W]),
- deployment time - period of time for which the instrument can be deployed free from fouling problems (biological, physical, and chemical).

Operational lifetimes of remotely deployed instruments are often limited by the available power supplies. Cabled observatories can provide the power to operate sensor networks for extended periods; however, the establishment the infrastructure is expensive and therefore limited in scope. Other renewal energy options include use of methane hydrate fuel cells, microbial fuel cells and sea-surface photovoltaic cells. The use of energy harvesting could be important in future development. This makes use of energy that is derived from external sources (e.g., solar power, thermal and wind energy and salinity gradients) and that can be captured and stored to power (usually low energy) small wireless autonomous devices such as remote marine sensors.

Recent trends in microfabrication, microfluidics, and integrated microelectro-mechanical systems optics in many areas of instrumental analytical chemistry are being applied in the development of in situ monitoring devices. Lab-on-a-chip and nano technologies have advantages of a small size and limited reagent and power requirements. The challenge is to ensure that these systems can attain the sensitivity needed for many marine applications where analytes are present at only trace concentrations. However, as the overall cost of the sensing system is reduced this would potentially enable the deployment of larger numbers of devices and thereby improve the spatial and temporal resolution and extent of offshore monitoring activities.

The new generation of sensors will be able to share data and as smart units will be able to operate as a standalone solution or managed by a data sensor platform. They include a processor unit for transducer management, a communication interface and data conversion, and can operate autonomously.

Many AUVs and ROVs provide flexible sampling platforms, and are often equipped with a robust power supply, data loggers, and telemetry for real time data transmission. Combined with the flexibility of deployment scenarios, they can be equipped variety of sensors. In the field of robotic vehicles there is a need for development of sensors for: 1. function and navigation of the vehicles 2. sensors in the payload, i.e., sensors, which are used for measuring various parameters of the sea water. Payload can be modular and equipped with different sensors, depending on the type of data, which is collected. Some sensor instruments are designed to be used in payload of robotic vehicles, but also as an independent real-time instrument via conducting cable.

The challenges of sensor interface interoperability currently result in proprietary solutions for sensor integration, data acquisition, and data flow within and beyond marine observing systems. To achieve a maximum level of interoperability, it is important to establish application profiles for data exchange standards.

During the past couple of decades, advanced information and communication technologies have been applied to the development of various marine environment monitoring systems. Among others, the Internet of Things (IoT) has been playing an important role in this area. In an IoT-based marine environment monitoring system, different sensors are deployed to measure and monitor various physical and chemical parameters like water temperature and pressure, wind direction and speed, salinity, turbidity, pH, oxygen density, and chlorophyll levels. An advanced IoT-based marine environment monitoring and protection system would also be able to control some objects, devices, or equipment within the monitored marine environment, in order to adjust some physical and chemical parameters so as to improve the marine environment (Xu et al 2018).

While the design, development, and deployment of an IoT-based marine environment monitoring and protection system is needed to address some critical issues including autonomy, adaptability, scalability, simplicity, there are requirements specific to the harsh marine environments that should be considered:

1. sensor and actuator nodes need to have very high levels of water resistance,
2. strong robustness in hardware due to aggressive and complex marine environment with currents, waves, tides, etc.,

3. low energy consumption and energy harvesting; energy conservation and harvesting measures need to be considered due to long communication distances and an environment in constant motion,
4. stability of radio signal should be ensured since the oscillation of the radio antenna can cause an unstable line-of-sight between transmitters and receivers and bad weather conditions can also affect the stability of radio signals,
5. other issues: devices and sensor nodes should be highly reliable because of the difficult deployment and maintenance; the need for buoy and mooring devices; sensor coverage needs to be carefully calculated because of large areas.

# 5 Future demand

## 5.1 Key challenges and opportunities in Blue economy

Demand for underwater robotics and sensors (for use in tackling pollution problem in marine environment and Blue economy) is observed, first and foremost, in the context of established and emerging Blue economy sectors, important for the European Union. This approach is used as research and development activities in the fields of underwater robotics and sensors will be greatly driven by trends and policies in Blue economy sectors in EU. Furthermore, these trends and policies have direct impact on availability of funding sources for R&D&I projects, performed by business subjects, public research institutes and higher education institutions (including InnovaMare project stakeholders).

### 5.1.1 Demand in established sectors

EU Blue economy has a number of established sectors, and in this section is given overview, trends, figures and expected demand for underwater robotics and sensors broadly based on The EU Blue Economy Report 2022. Demand is presented in terms of impact of those sectors on environmental pollution, as well as possible influence of pollution to activities in these sectors. Established EU Blue economy sectors are:

- Marine living resources
- Marine non-living resources
- Marine renewable energy (offshore wind)
- Port activities
- Maritime transport
- Shipbuilding and repair
- Coastal tourism

***Marine living resources***

The Marine living resources sector comprises out of three components: the harvesting of renewable biological resources (primary sector), their conversion into food, feed, bio-based products and bioenergy (processing) and their distribution to consumers along the supply chain. The processing and distribution of seafood products are heavily dependent on the supply of raw materials from the primary sector. While consumption and general demand for seafood products increases, stagnation in the primary sector is evident. Better management of fish and shellfish stocks has contributed to a decrease in fishing pressure in the North-east Atlantic Ocean and the Baltic Sea, while the situation in the Mediterranean Sea and the Black Sea is highly unfavourable in this regard; 87% of the assessed stocks are overfished.

Marine living resources generated a gross value added (GVA) of about EUR 19.3 billion in 2019, which was a 31% increase compared to 2009. In 2019, the sector contributed to 10.5% of the EU Blue economy GVA (established sectors), which represents increase from 9.6% in 2009. The activities included in the sector directly employed over 538,700 persons in 2019, representing 12% of the EU blue jobs (established sectors). Within the primary sector, capture fisheries represent about the 80% of the EU production. European Union is the sixth largest producer of fishery and aquaculture products (behind China, Indonesia, India, Vietnam and Peru) and has a share of 3% in global production.

The sustainable development of aquaculture is one of the main objectives of the common fisheries policy. Aquaculture production is also recognised by the European Green Deal as a source of “low carbon” protein for food and feed. EU aquaculture production in volume has stagnated in volume over the last decades, but its value has increased. Mussels, as the main species produced in the EU aquaculture (in weight), have decreased in recent years due to environmental factors (algae blooms, lack of seed, diseases). The production of species, such as seabream and seabass, where farmers have higher degree of control on the production factors, has increased. Considering the increasing demand of seafood products and the opportunity to establish new farms partly due to Maritime Spatial Planning, a growth of the EU aquaculture products can be expected, in particular of species with a high degree of control (Blue Economy report, 2022). Furthermore, certain forms of aquaculture (e.g. mollusc farming, farming of algae and other invertebrates) can contribute to health of the ecosystems through absorption of excess nutrients and organic matter from the environment or the conservation and restoration of ecosystems and biodiversity. The Commission’s Strategic guidelines for a more sustainable and competitive EU aquaculture highlight the future relevance of low trophic level aquaculture to sustainably produce marine food for a growing global demand (EC, 2021).

Pollution, climate change and destruction of habitats represent threats to primary production, on which depend other activities in the value chain. Environmental impacts of fishing activities should be reduced, especially impact on seabed habitats, which are under significant pressure across Europe from the impacts of bottom fishing, offshore energy facilities, coastal developments, and pollution from land-based sources (nutrients, chemicals, plastics and debris). In the field of aquaculture, it is necessary to put effort in creating favourable conditions for its development in regard to climate change and pollution, but also mitigate its negative impacts on the surrounding environment in terms of nutrients and organic matter discharge from aquaculture farms in waters, feed ingredients for carnivorous fish (implementation of alternatives to wild fish), management of diseases and use of veterinary medicines and other substances (EC, 2022).

### *Marine non-living resources*

Sector includes extraction of crude oil, natural gas, as well as other minerals (extraction of gravel and sand, mining of clays and kaolin, extraction of salt). Despite decreasing crude oil production and consumption in the EU in recent years, crude oil and its derived products still remain the largest contributors to energy consumption (Eurostat, 2022). European Union imports more than 50% of the fossil fuel energy it consumes each year and has high dependency for imported crude oil and natural gas. Recent developments in Ukraine, which created insecurities in supply, emphasized importance of achieving higher level of energy production independence. The EU aims to be climate neutral by 2050 and to achieve this target, significant investments will be made in new low-carbon technologies, renewable energy, energy efficiency, and grid infrastructure. Transition will be long and entire paradigm of energy production and consumption will change across the EU. Natural gas should play most important role in achieving this transition until renewable energy becomes the main source production.

Most oil and gas production in Europe takes place offshore. There are currently around 193 installations in EU 27 waters. Given the EU’s high energy demand, these operations help ensure a secure supply of energy. The exploitation of Europe’s seas and oceans for non-living marine resources has increased over the last decade and is projected to continue growing, but mature offshore oil and gas sector is decreasing for years.

In 2019, the GVA generated by the sector amounted to almost EUR 4.7 billion, which was a 58% decrease compared to 2009. Gross profits, at EUR 3.7 billion, decreased by 61% in comparison to 2009 (EUR 9.7 billion). Reported turnover was EUR 13.1 billion (80% decrease on the turnover in 2009).

The demand for resources such as sand and gravel, used for construction purposes and production of concrete, is likely to increase in the future. Furthermore, coastal communities will have to adapt to new pressures caused by climate change, thus activities such as dredging, beach nourishment and sand reclamation could intensify. Environmental concerns of such operations are evident and should be considered in planning and legislation.

Accidents at offshore facilities, followed by massive pollution (such as the 2010 Deepwater Horizon in the Gulf of Mexico), implicate the need for comprehensive safety measures. While safety is the primary responsibility of operators and individual countries, EU rules are important because large scale accident can create environmental and economic damage to other countries in proximity.

Decommissioning of oil and gas facilities is expected to accelerate in the coming years due to the shift from fossil fuels to renewable and low-carbon energy sources. Decommissioning in the EU is expected at the earliest in 2050. The costs are currently high, and it is estimated that EUR 4.8 billion will be spent in the EU 27 on decommissioning of oil and gas infrastructure over the period 2020-2030.

Oil and gas offshore facilities require constant monitoring. Prevention of pollution from such facilities is a priority, due to possible accidents, which can range from small spills to catastrophic events. Robots and sensors should become common tools in detection and monitoring of pollution from these facilities. Robots also can be utilized for inspection as well as performing maintenance tasks, which are too dangerous for human workers to do.

### *Marine renewable energy (offshore wind)*

Although seas and oceans offer many possibilities for energy production, offshore wind energy is currently the only widely used form of marine renewable energy. Various ocean energy technologies are currently in the development and testing (wave energy, tidal energy, salinity gradient energy and ocean thermal energy conversion (OTEC)), and they are not yet commercially available. Broader description of these technologies in the context of environment, pollution and demand for underwater robots and sensors is given in the chapter Demand in emerging sectors.

At the end of 2021, European sea basins are leading in terms of installed offshore wind energy, with over 65% of the world's total installed capacity. The EU offshore wind energy sector has grown to a capacity of 16.3 GW by the end of 2021, with an increase of 1.8 GW (7%) in the 2021 only (Wind Europe, 2021). Most of the EU installed capacity is in the North Sea (84%) and Baltic Sea (15%).

In 2019, the GVA generated by the production and transmission of offshore wind energy was more than €1.9 billion, 46 times more than in 2009 (€41 million). Countries with highest contribution to GVA are Germany (EUR 1.22 billion), Denmark (EUR 585 million) and Belgium (EUR 118 million). Net investments in tangible goods reached EUR 938 million in 2019, which was more than 10 times more in comparison to 2009. New investments are being channelled into innovation, development, exploration and production units further offshore and in deeper waters. Presented numbers illustrate strength and strong potential of this sector.

The EU Offshore Renewable Energy Strategy aims for an installed capacity of at least 60 GW of offshore wind and at least 1 GW of ocean energy by 2030. By 2050, installed capacity should further increase to 300 GW of offshore wind and 40 GW of ocean energy, respectively (EC, 2020). Although, these actions should accelerate due to current situation in Ukraine, which revealed vulnerabilities of European countries, caused by high dependence on import of oil and gas from Russia. As a response to this crisis **REPowerEU Plan** was announced by the European Commission. Massive scaling-up and speeding-up of renewable energy in power generation, industry, buildings and transport in EU was announced due to geopolitical reasons, importance of the green transition, and reduction of prices over time. Within the Plan, the European Commission proposed to increase the headline 2030 target for renewables from 40% to 45%, which will have a strong impact on instalment of offshore wind facilities and development of other marine energy technologies.

Although renewables are viewed as "clean energy", they also have an impact on the environment. Regarding offshore wind facilities, some environmental considerations are important to address. Habitats' disturbance and degradation, increased underwater noise, disruption of seabed integrity, decreased water quality and leaks and debris are examples of the negative impacts on the marine environment in the context of demand for underwater robots and sensors (EC, 2021).

### *Port activities*

Port activities play a key role in trade, economic development and job creation in Europe. They represent essential important commercial as well as strategic infrastructures which activities support the free movement of goods and people in Europe. This Blue economy sector it is still growing, by serving the needs of various sectors of economy. Ports, as multi-activity transport and logistic nodes, also play a crucial role in the development of established and emerging maritime sectors. EU ports enable maritime transport to handle 77% of the EU's external trade and 35% of all intra-EU trade.

Port activities generated added value grew by 21% from 2009 to 2019, reaching EUR 27.9 billion. Gross profit, at EUR 11.8 billion, was 20% higher than in 2009. Turnover amounted to €68.5 billion, a 24% rise on 2009. Port activities accounted for 9% of the jobs, 15% of the GVA and 16% of the profits in the EU Blue economy in 2019. The sector has grown since 2009 in terms of jobs and GVA. Recent COVID-19 pandemic and its influence on disruption of the supply chains, had a strong impact on port activities regarding both cargo and passengers. Although this is a strong established sector, according to Deloitte (2021) the European market for port activities is still evolving as a result of several key drivers:

1. environmental, such as climate change impacts, resource and energy footprint,
2. technological, such as digitalisation, logistics, automation,
3. geopolitical; international trade developments, foreign investments, competition,
4. demographic, such as global population growth and urbanization.

These drivers are contributing to reinforce a number of trends in port activities that are actively enticed by EU policies:

- transition towards more sustainable port activities, which include reduction of negative port externalities, increasing environmental performance, improving safety and security, and promoting sustainable investment in line with the Regulation (EU) 2020/852,
- increased focus on technological innovation (especially in maritime service activities, cargo handling and logistics industry), such as increased use of AI, connectivity, automation, and robotics.

- supporting changing trade patterns as a result of the structurally increasing international demand, evolving consumption patterns, and resulting global integration and consolidation in the logistic industry.

Climate change has impacts on the port industry, port infrastructure and port activities. To protect from sea levels and extreme weather events, ports need to invest in new resilience and mitigation port infrastructure. At the same time, ports are expected to play an active role in climate change mitigation by shifting from conventional fossil fuels to renewable sources of energy and green fuels, as well as by making circular economy efforts to reduce and recycle waste through sustainable waste management approaches (Deloitte, 2021).

Port activities come with challenges, as they can cause local and global environmental impacts such as air pollution, greenhouse gases emissions, waste generation, noise, ship waste, local community impacts, sediment impacts, dust, water pollution, and use of land (EEA-EMSA, 2021). Due to many possible sources of environmental degradation from port activities, detecting, prevention and monitoring of pollution in ports and their surroundings represents necessary activity. Considering high importance of European ports for overall economic development, efforts should be invested to mitigate their environmental impacts and make their activities greener.

### *Shipbuilding and repair*

The European shipbuilding industry is important from both an economic and social perspective. It is also linked to other sectors including transport, security, energy, research, and the environment. Shipbuilding is an important and strategic industry in a number of EU countries. Shipyards contribute significantly to regional industrial infrastructure and national security interests (Blue economy report, 2022).

The European Shipbuilding industry currently comprises out of 300 shipyards specialised in building and repairing complex and technologically advanced civilian and naval ships and platforms and other equipment for application in maritime surroundings. Shipyards are focal point of the industry, but usually they are closely connected to many SMEs, who are often suppliers, contractors or providers of services. Demand for new ships, equipment and technologies for all Blue economy sectors is expected to increase in the next decade. In order to deliver more cost-effective, safer, competitive, and environmentally friendly ships, other vessels and offshore structures, the shipbuilding industry should apply technological innovations from other sectors, such as advanced materials, digitisation, automation, advanced design and production technology. Considering strong competition in the global market (mainly from China and South Korea), Europe should put efforts to maintain its leadership but also strengthen its position in the design, engineering, construction and maintenance of highly integrated complex systems in high value products (ships, equipment and machinery) (USWE, 2020).

In 2019, the GVA in the sector was valued at EUR 15.6 billion, which was increase by 39% compared to 2009. Gross profit, at EUR 3.3 billion, was 89% higher than the 2009 figure (EUR 1.8 billion). Reported turnover was EUR 57.9 billion, a 23% rise in 2009. Increasingly strict environmental regulations, driven by societal and policy influence on shipping to reduce its environmental footprint will continue to be key drivers for fleet replacement investments. Germany leads Shipbuilding and repair with 17% of the jobs and 25% of the GVA, followed by France and Italy with 14% of the jobs each and 21% and 19% of the GVA, respectively.

Main causes of environmental pressures and pollution, originating from the shipbuilding sector, are hazardous waste, wastewater, stormwater, and air emissions generated by vessel construction, maintenance, repair and dismantling activities (EBDR) in shipbuilding and recycling activities. Shipyards are mostly situated near and on water, thus the potential impact of pollution emissions from shipbuilding operations on surrounding environment is very significant. Shipyards are often situated near significant pools of workforce, such as cities, which emphasizes necessity for pollution prevention and reduction. Increased likelihood of hazardous emissions represents a threat for human health, environment and performance of other sectors, such as marine living resources and tourism.

### *Maritime transport*

Maritime transport plays a key role in the globalised economy. It has a crucial contribution in decarbonisation and climate change mitigation, being the most efficient mode of transportation in terms of lowest carbon dioxide emissions per distance and weight carried. Due to the expected growth of the world economy and associated transport demand from world trade, maritime transport must continue to improve energy efficiency of ships and conduct transition to alternative fuels. Besides the introduction of alternative marine fuels, efforts are made under the Zero-pollution action plan to drastically reduce further emissions to air and water. In that way environmental footprint from the maritime transport sector will decrease, from which will benefit sea basins, as well as coastal areas and ports across Europe and globally.

In the European Union, maritime transport carries 77% of external trade and 35% of internal EU trade. Overall, Maritime transport accounted for 9% of the jobs, 19% of the GVA and 25% of the profits in the EU Blue economy in 2019. Germany leads maritime transport, contributing with 34% of the jobs and 36% of the GVA, followed by Italy with 18% of the jobs and 14% of the GVA; while Denmark has only the 7% of the jobs, but 18% of the GVA. The sector seems to have recovered from the drop in 2016. The sector generated a GVA of EUR 34.3 billion in 2019, which was 27% higher compared to 2009. Gross profit, at EUR 18.2 billion, increased by 30% in comparison to 2009.

Marine habitats most affected by maritime transport related pressures are areas, which are identified as favourable locations for ports, since they are sheltered from waves and wind. These include estuaries, large shallow inlets and bays, sandbanks. Contaminants, originating from maritime transport negatively affect marine environment. Pollution events, such as oil spills, can also serious consequences on the economy of the affected areas. Other types of pollution, such as marine litter and underwater noise can impact marine animals. Maritime transport also accounts for the largest proportion of Non-Indigenous Species (NIS) introductions in seas around the European Union. NIS and aquatic pathogens can create a threat to local biodiversity, human health and damage to coastal economies if they adapt to new environment in the absence of their natural predators.

### *Coastal tourism*

Coastal tourism is the biggest mature and growing sector across the Blue economy in terms of GVA and employment. Blue Growth strategy emphasises that coastal and maritime tourism has large potential to promote a smart, sustainable and inclusive Europe. Tourism can be a powerful tool in economic progress, but also faces a series of challenges, ranging from greening its activities to reducing impacts on the marine environment.

In recent years, the increasing number of tourists have led to concerns around the environmental impacts of tourism on marine ecosystems and the sustainable development of coastal areas, especially those characterised by construction development. Over half of the EU's tourist accommodation establishments are in coastal areas (EC, 2012).

GVA generated by the sector in 2019 amounted to slightly more than EUR 80 billion, a 21% rise compared to 2009 (estimation due adjustment to changes in methodology). Gross operating surplus was valued at EUR 27.4 billion (+42% compared to 2009). Turnover amounted to almost EUR 230 billion, 20% more than in 2009. More than 2.8 million people were directly employed in the sector in 2019.

Coastal and maritime tourism depends highly on good environmental conditions and, especially, on good water quality. Any maritime or land-based activity deteriorating the environmental can negatively affect tourism. Besides competition for space with other sectors, impacts arise from land-sea interactions, such as oil spills from ships (Ecorys, 2016), nutrients from agriculture, urban wastewater, and industrial discharges. All these activities can have direct and indirect effects on both marine and terrestrial ecosystems and on the economic activities depending on them.

The natural resources, beauty and diversity of landscapes, flora and fauna are key reasons why coastal areas are popular destinations for visitors. Clean and healthy natural environment represents a valuable asset and any type of pollution represent a threat to this sector, especially large scale pollution events with years-long consequences. On the other hand, tourism also generates many pressures on local environment and ecosystems, such as higher water use, increased waste generation and emissions from transport in peak seasons. Therefore, to achieve best economic, environmental and social results, environmental protection and monitoring are important in sustainable tourism. In this way the sector can benefit from natural resources, without creating negative impacts and threats to its sustainability as well as profitability.

### 5.1.2 Demand in emerging sectors

The Blue Economy Report 2022 brings a view on a future demand in the emerging and innovative sectors of the Blue economy that include the following areas and activities linked to the marine environment:

- Marine renewable energy,
- Blue biotechnology,
- Maritime defence, security and surveillance,
- Marine infrastructure.

#### *Marine renewable energy*

Emerging marine renewable energy sector includes various types of renewable energy:

- floating offshore wind,
- wave and tidal energy,
- floating solar photovoltaic energy (FPV),
- offshore hydrogen generation.

The offshore wind represents the most advanced sector, while the other technologies are at an earlier stage of development.

In 2020, the European Commission published the **Offshore Renewable Energy Strategy** which outlines the expected contribution of the marine renewable energy sector to the EU ambitions to net zero emission by 2050. The goal is to increase Europe’s offshore wind capacity from its current level of 12 GW to at least 60 GW by 2030 and to 300 GW by 2050. Offshore wind deployment is complemented with 40 GW of ocean energy and other emerging technologies such as floating wind and solar by 2050. In addition, offshore renewable is expected to contribute significantly to another EU strategy: the EU Hydrogen Strategy that aims to have 40GW of renewables linked electrolysis capacity in the EU by 2030 (Blue Economy Report, 2022).

Floating wind technology opens the possibility to harvest the most resourceful wind energy sites in Europe. Nearly 80% of the wind in Europe blows in waters that are at least 60 meters deep, where it is too expensive to fix structures to the bottom of the sea. JRC (2019) estimates the technical potential for floating offshore wind in Europe with about 4 540 GW, of which 3,000 GW would be in deep sea (water depth between 100m and 1000m). Moreover, due to its specific geological condition and the specific stage of offshore renewable energy development, every sea basin has different potential.

Floating offshore wind is a growing sector that is strengthening Europe’s leadership in renewable energy. The technology for floating offshore wind in deep waters and harsh environments is progressing steadily towards commercial viability (UNEP & BloombergNEF, 2019). Floating applications seem to become a viable option for EU countries and regions with deep waters (depths between 50-1,000 metres) and could open up new markets such as the Atlantic Ocean, the Mediterranean Sea and potentially the Black Sea. The global market for floating offshore wind represents a considerable market opportunity for EU companies. Latest announcements of national floating offshore wind targets (particularly in Europe and Asia) suggest a substantial increase in the deployed capacity in the mid-term. In total about 12.2 GW to 16.5 GW of floating offshore wind energy is expected by 2030, with significant capacities in some Asian countries (South Korea and Japan) besides the European markets (France, Norway, Italy, Greece, Spain, the United Kingdom).

**Floating offshore wind** is one of the **EU's R&I priorities**. The FP7 programme funded seven research projects on floating offshore wind. Some projects such as FLOATGEN and DEMOWFLOAT demonstrated different floating concepts at pre-commercial scale in operational environment. H2020 allocated funding to 21 research projects on floating offshore wind since 2014. Floating offshore wind R&I received significant boost in 2019 and 2020 when total of 11 projects spread across the EU were awarded funds through H2020: projects COREWIND, FLOTANT, PivotBuoy, SeaTwirl, SATH, EDOWE, ASSO, FLOAWER, STEP4WIND, FLAGSHIP and SEAFLOWER.

Ocean energy is a largely untapped renewable energy source, although it has significant potential to unlock further decarbonisation of the EU energy system. Tidal and wave energy technologies are the **most advanced among the ocean energy technologies**, with significant potential located in different Member States and regions. For tidal energy, there is significant potential in France, Ireland and Spain, and for wave energy, high potential is to be found in the Atlantic.

Tidal technologies can be considered to be at the **pre-commercial stage**, benefitting from design convergence, significant electricity generation (over 60 GWh since 2016) and a number of projects and prototypes deployed across Europe and worldwide (Ocean Energy Europe, 2021). Instead, most of the wave energy technological approaches are at R&D stage. Over the past 5 years significant technology progress has been achieved thanks to the successful deployment of demonstration and first-of-a-kind farms; with the sector showing particular resilience in overcoming the setbacks (European Commission, 2017) that have hindered the industry in 2014/15. The variety in ocean resource and location requires different technological concepts and solutions. Given the resources available in the EU, and the advancement of the technologies, it is expected that in the short-to-medium term (up to 2030), ocean energy development in the EU will be largely dependent on the deployment of tidal and wave energy converters. In the EU, the highest resource potential for ocean energy exists along the Atlantic coast, with further localised exploitable potential in the Baltic and Mediterranean seas and in overseas regions (e.g., Reunion, Curacao). The theoretical potential of wave energy in Europe is about 2800 TWh annually, whilst the potential for tidal current was estimated to be about 50 TWh per year. OTEC offers potential only for the EU overseas islands since its deployment is basically only possible in tropical seas (JRC, 2014). The total installed capacity of ocean energy worldwide amounts for 574 MW, including 494 MW of tidal range projects. Excluding tidal range, the total cumulative installed capacity of ocean energy worldwide reached 46MW by the end of 2021 (Ocean Energy Europe, 2021).

In the EU-28, 51% of the ocean energy inventions patented are for wave energy technology, 43% for tidal energy, 2.7% on Oscillating Water Column (OWC, this represents a subset of wave energy technology), and 3% for Ocean Thermal Energy Conversion (OTEC). The patent filings indicate that the EU is a net exporter of Ocean energy technology and innovation, and that European Ocean energy developers are well positioned to exploit the growth of the sector globally.

Although the development of ocean energy technologies is still mostly at R&D stage, some technologies (tidal) have already made progress towards first-of-a-kind demonstration and pre-commercial projects. The necessity of reducing the cost of ocean energy technology, also through economies of scale, implies that the presence of Original Equipment Manufacturers (OEMs) with access to large manufacturing facilities could be seen as an indicator of the consolidation of the supply chain. Whilst the highest concentration of wave and tidal energy developers occurs within the EU and Europe (63% of the global ocean energy capacity) many developers are looking to deploy their technologies outside of Europe thanks availability of market instruments available elsewhere, such has the high feed-in-tariffs in Canada (JRC, 2020). Developing a strong internal market will be fundamental for the EU in order to build on and maintain its current leadership position in the market. As seen for other renewable energy sources first-mover advantage and strong internal markets are key to maintain a competitive position. Another challenge facing the ocean energy sector is identifying ways to support the deployment of wave and tidal energy farms through innovative support schemes. An increasing number of developers are exploring the use of crowdfunding either for the fabrication of their new device, to support R&D activities, or to reach the required capital for deployment. The impact of crowdfunding is comparable with public funding for projects, and it is likely to have limited impact, especially in terms of deployment of projects (Hume, 2018). However, it points to the challenges that technology developers are facing with.

A new emerging trend in the offshore renewable energy sector is the development of FPVs. While the current installed capacity is limited, the Offshore Renewable Energy Strategy recognises the potential of these technologies, and the potential for fast technology progression based on the results of ongoing demonstration projects. Global installed capacity has increased from less than 1 MW in 2007 to 1 314 MW in 2018 and is projected to reach approximately 13 000 MW by 2022 (Lee et al., 2020). While most of existing capacity and projected growth is expected in Asia, it has been estimated that FPV installations on hydropower reservoirs in Europe could generate up to 729 GW, in addition to energy gains in terms of evaporation reduction (Quaranta et al., 2021).

Deploying FPVs at sea requires overcoming numerous challenges related to the survivability of the structure at sea, costs, integration in the gird system, the development of substations, as well understanding the influence of the marine environment such as of algae growth, pollution, and salt deposits on the conversion system. One of the technological challenges to overcome is the interaction with waves, which has larger impacts than FPV installed on hydropower reservoirs. A key step required for the commercialisation of FPV at sea is the assessment of its potential contribution to the EU Green Deal, and the interaction with other maritime uses to identify ideal sites for deployment.

**FPV installations are expected to provide additional value** to different sectors of the Blue economy such as aquaculture and to help remote coastal communities offset diesel generators, by providing direct access to electricity offsite. Multiple projects that combine FPV with other ocean renewables sources of energy or other ocean activities are currently being developed, among which the project EU-SCORES is most distinguished.

Regarding offshore hydrogen generation, the production of offshore electricity is confronted with many **challenges related to the grid stability and variability** due to the temporal mismatch between the supply and the demand. The production of renewable hydrogen by electrolysis can help overcome several of those challenges and provide alternative for storing excess electricity generated at sea that is not immediately delivered to the grid. Once produced hydrogen could be employed for energy carrier (in fuel cells) or as fuel heavy transport by water, road and eventually by air. The generation of hydrogen offshore as a number of advantages, both hydrogen transportation and storage can be done at **large scale and relatively low cost**. Furthermore, offshore oil and gas platforms could be re-purposed for renewable hydrogen production. This offers the advantage for upstream oil company to transform their operation and to exploit the know-how of operating in harsh marine environments.

Overall, **the Hydrogen Strategy** estimates that from now to 2030, investments in electrolysers could range between EUR 24 and EUR 42 billion. In addition, over the same period, EUR 220-340 billion would be required to scale up and directly connect 80-120 GW of solar and wind energy production capacity to the electrolysers to provide the necessary electricity (Blue Economy Report, 2022).

The biggest technical challenge for producing renewable hydrogen offshore is the development of an electrolyser module, which is compatible with the ocean environment, able to operate effectively when coupled with intermittent renewable power and is sufficiently compact to achieve very high rates of hydrogen production per platform or per device. The technical viability in this harsh and remote environment and the potential for competitive hydrogen production costs still needs to be demonstrated.

Several projects (e.g., 3P2GO, PosHydon, Deep Purple, ITEG) are already exploring the possibility of specific options for the coupling of offshore energy and green hydrogen production: coupling wind energy, ocean energy and floating PV with electrolisers. The mentioned projects demonstrate the need for upscaling the installation of FPVs in Europe and worldwide.

All in all, the marine renewable energy sector has huge potential and can provide the possibility to solve this problem between **essential endurance and finite energy in marine robots**. The important significance of improving ocean robots' endurance introducing marine renewable energy is required. The autonomous technologies, especially aerial and underwater vehicles can play a crucial role in supporting and maintaining sustainable marine environment. Robots that **use non-contact methods of sensing**, such as radar and sonar, can interact with ocean infrastructure and its surrounding environment **without causing any damage or polluting the marine environment**. Miniature underwater gliders (MUG) move using very little energy. Therefore, they can operate for a very long time, monitor the environment and collect a lot of data. They are usually deployed and retrieved by drones in the ocean, and their batteries are charged on unmanned surface vessels using electricity from solar panels. MUGs can be equipped with important measuring instruments, e.g., optical fluorometers that are a type of underwater sensors that measure chlorophyll, among other things, and can map toxic algal blooms. Furthermore, an instrument can be added to the MUGs enabling it to find oil spills through UV radiation and thus help to solve the problem of the pollution. With the AUVs we can also help avoid issues like biofouling, where microorganisms, plants, algae or small animals accumulate on surfaces of cables. A bio-fouled cable can grow heavy, potentially distorting its outer protective layers and decreasing its useful life span. AUVs can monitor and clean these cables safely. Additionally, robots can provide **help with overeater offshore energy infrastructure**. When wind turbine blades reach the end of their useful lives, they are often burned or thrown into landfills which directly counteracts the circular economy approach. Instead of the latter practice, robots can be used to **repair, repurpose or recycle** degrading blades, reducing unnecessary waste. Furthermore, using drones fitted with advanced radar sensing technology can help see defects in the turbines as they begin to develop. Besides financial and carbon cost of turbine maintenance, robots can **minimise the inherent risks to humans working** in the unpredictable marine environments while also working more symbiotically with the environment. By deploying resident robots to inspect and maintain offshore renewable infrastructure, energy companies could initially reduce the number of people working in dangerous offshore roles. Eventually, a point of autonomous operation-where human operators remain onshore and connect remotely to offshore robotics systems, could be reached.

### *Blue biotechnology*

The blue biotechnology is a growing sector in Europe that includes any economic activity related to the use of renewable aquatic biological biomass (e.g., food additives, animal feeds, pharmaceuticals, cosmetics, energy, etc.). Bio-based alternatives to conventional fossil technologies offer **possible solutions for decarbonising chemical activities while protecting other environmental benefits** (Spekreijse et al., 2021). The potential of renewable bio-based materials is especially underlined in the context of bio-based plastics.

**The algae production** in Europe is still a **prominent branch of the industry** within the blue biotechnology sector. It is considered an emerging and booming sector of the Blue economy that continues to evolve and offer new business opportunities and sustainable products, while making a major contribution to the ocean regeneration. With that in mind, the European Commission adopted a new approach in order to make the blue economy sector more sustainable. It is expected that the implementation of the European Green Deal goals will contribute to climate change mitigation through algae production at sea, development of offshore renewable energy, decarbonization of maritime transport and ports greening. Furthermore, the Blue economy agenda should help develop green infrastructure in coastal areas that will help preserve biodiversity and landscapes, while the renewal of the standards for fishing gear design, ship recycling and the decommissioning of offshore platforms should contribute to the circular economy objectives. Apart from the European Green Deal, various initiatives such as the Farm to Fork Strategy, Bioeconomy Strategy and the Renewable Energy Directive recognized the algae production potential for a sustainable and safe food system, as well as the important role of algae in the carbon sequestration (Blue Economy Report, 2022).

According to a study conducted by Araújo et al. (2021) the number of companies producing algae in Europe has increased significantly (150%) in the last decade. The European algae sector relies on more than a 200 algae production companies (with a share of 67% of macroalgae and 33% of microalgae producers) and around 200 spirulina companies. Spain, France, Ireland and Norway stand out as countries with the largest number of macroalgae companies in Europe. The activities related with the macroalgae industry accounts for an important part of the cultural heritage and represent a major income source for some coastal and rural communities. Most European producers harvest the biomass by hand and only 15% of them, with mechanical means because that requires a fleet of vessels. Germany, France and Spain are the largest microalgae producers in Europe while France controls the spirulina production landscape with 65% of the mapped production units in Europe. Microalgae are cultivated by different production methods, among which the most common and most widely used systems are photobioreactors (PBR) with fermenters for algae and open ponds for spirulina production. Along with algae, bacteria, fungi and invertebrates are also an important marine resource.

The algae production has different commercial scope including food and food supplements, feed, cosmetics, fertilisers, plant biostimulants and innovative commercial uses as biomaterials, bioremediation or biofuels. These groups of organisms and derived compounds are significant resources associated with the numerous EU priorities such as carbon neutrality, innovative, healthy and sustainable food systems and sustainable and circular bioeconomy. Hundreds of new compounds from the marine world are discovered every year which indicates the innovative character and potential of the sector (Carroll et al., 2019). At the same time, new technologies are being researched to increase the quality and reliability of the latter (EUMOFA, 2020). Aquaculture contributes largely to building a more sustainable and responsible food system, especially as a low-carbon footprint source of protein.

Although jelly fish are blooming due to increased food (plankton) availability and decreased fish numbers and in this respect, they pose a serious ecological threat, they could also be viewed as a potential market opportunity, as shown in the GoJelly Project (https://gojelly.eu/about/). The project goal was to develop, test and promote a gelatinous solution to microplastic pollution by developing microplastics filter made of jellyfish mucus. Researchers discovered that mucus of jellyfish can bind microplastic, which led to testing the wastewater treatment. The added value of the project was a new valuable resource for the food and feed industry, as well as agro-biological fertilizer for organic farming. The innovative approaches, such as in the GoJelly Project, can be used as an efficient solution for reducing plastic in the ocean while ensuring sustainable and economically viable use of renewable resources. Additionally, a **new generation of autonomous pollution-fighting robots** that eat microplastics and digest pollution is being developed in order to help solve the pollution problems (Wang et al., 2022; Rossiter, 2016).

As for other activities in Blue bioeconomy and biotechnology, **the algae biofactory** is currently being researched for the use, extraction and valorisation of algae biomass value-added products (Zhang & Thomsen, 2019; Bak et al., 2018). Some researchers see the algae biofactory as a potential approach to increase the environmental sustainability (by optimising resources and minimising waste) and economic feasibility (by maximising profits) of existing conventional industrial processes. In addition to algae biofactory, the production of macroalgae biomass by offshore aquaculture could also be improved. Current projects are searching for a technological solution to improve the profitability of offshore aquaculture and to combine multipurpose activities-e.g., wind farms with algae facilities (van den Burg et al., 2020).

Since the marine biotechnology market is expected to expand, the ongoing **screening and cultivation approaches of marine organisms** for biotechnological applications needs to be optimized. High-throughput techniques produce a massive amount of data and can discover the potential of marine organisms. Therefore, knowledge on data management and analysis needs to be advanced and the experts from various fields need to create transdisciplinary networks and work on knowledge transfer and dissemination of best practices among. The use of underwater robotics and sensors could help upscale this type of production and overcome current technological constraints and knowledge limitations. In this way, infrastructural and logistics costs could be reduced, and at the same time, biomass yields could be increased.

### *Maritime defence, security and surveillance*

The maritime security and surveillance sectors are becoming more important and rising rapidly with an increased number of technological innovations and applications for both military and civilian uses. In terms of sustainability, the European Defence Agency (EDA) significantly contributes to the EU green agenda and the relevant activities for the maritime sector. EDA´s task is also to support Ministries of Defence in addressing energy, environmental and climate change related challenges. Besides EDA, the European Maritime Security Agency (EMSA) also plays an important role in providing a high, consistent, and effective level of maritime security, as well as preventing the pollution caused by ships, oil and gas installations.

In addition to the agencies, it is also important to mention the programmes, technological developments and investments that are implemented in Europe. **The Copernicus Maritime Surveillance system (CMS)** is a programme that provides access to satellite surveillance information to all EU Member States' bodies with tasks at sea (https://www.copernicus.eu/en/use-cases/cmems-support-copernicus-maritime-surveillance-service). **EMSA´s integrated maritime services (IMS)** provides the Member States authorities with a vast array of data and information on terrestrial and satellite vessel position data, satellite optical imagery, drones and met-ocean data, allowing for large areas of the sea to be monitored (https://www.emsa.europa.eu/newsroom/infographics/item/3941-integrated-maritime-services-users-types.html). In terms of maritime domain awareness, the EUROSUR Fusion Services (EFS) provide the Member States with value-added information services from vessel tracking and detection capabilities to software functionalities that allow complex calculations for detecting anomalies and predicting vessel positions, as well as precise weather and oceanographic forecasts.

As regard to the relevant areas for the maritime security and surveillance sectors, project OCEAN2020 should be mentioned. The project demonstrated the integration of new unmanned assets with existing military vessels to give a unique, well documented maritime situation for high level decision makers and the demonstration of autonomous coordination of multiple unmanned systems for a specific task, like underwater search for mines. These achievements have opened the way for follow-on future research activities in the areas like swarming of unmanned systems, sufficient communication links between underwater assets and their mother ships for big data transfer or application of AI to process big data coming from multiple sensors to generate clear maritime situational awareness.

Since the port operations are vital to the world economy and the challenges associated with providing successful maritime surveillance are complex, the interest in maritime security is rising and furthermore, requires a global approach. For this reason, researchers have been exploring different technologies in order to improve maritime security in which the robotics, plays a significant role. The involvement of unmanned vehicles within a surveillance system helps in replacing human low-level activities, giving to the human operator a high value information for higher decision level. The relevance of the robotics impact also arises from the unmanned vehicles possibility to host onboard various sensors, e.g., sonars, hydrophones, magnetometers and optical or infrared cameras. With the help of sensors, the vehicles can conduct a rapid search task of identifying and localizing underwater objects (e. g. underwater mines) in confined areas, such as piers, within harbour areas or specific regions of interest.

The current main scientific challenge in identifying potential threats in maritime defence and security concerns the **enhancement of autonomy and swarm mission capabilities** by improving interoperability among robotic vehicles and providing communication networking capabilities. The difficulty of obtaining precisely geo-referenced images collected by a sensor and subsequently locating found objects is another considerable problem according to Paull et al. (2018). Additionally, the robotic surveillance systems need to be indefinitely persistent, regardless of the sea state, while maintaining a high level of effectiveness which requires the development of innovative launch and recovery systems (LARS) and docking stations able to harvest energy 24 hours a day at sea. In case of longer missions, Wang et al. (2012) indicate that the vehicle energy consumption and more efficient power supply and propulsion systems will be essential. Since most surveillance systems rely on the use of high-frequency active sonar with detection ranges of less than 1 km, the further development of more advanced (longer range, smaller, lower power consumption) sensors can be a game-changer for the maritime security sector.

### *Marine infrastructure*

Marine infrastructure has a crucial rule for the sustainability transition and the European Digital Twin Ocean (DTO). The latter refers to the computing environment, which allows the assessment of different situational scenarios, providing knowledge-based input for informed decision-making. In 2020 the underwater robotics market was valued a, USD 2,2685 billion and forecasted to reach USD 6,719 billion by 2028 (Blue Economy Report, 2022). With the production of almost a third of all robots in the world, **Europe is a prominent leader in robotics**. Together with Artificial Intelligence (AI), robotics technologies are central to **the digital**

**transformation** of our societies and economies, with the **potential to create new jobs and increase productivity** (Charisi et al., 2021).

Submarine cable networks are a critical infrastructure which ensures that data, telecommunication and power transmission connections are possible within the EU and between the EU and third countries. According to estimations, there are more than 400 submarine cables around the world in 2021, covering around 1.3 kilometres around the world, with 45 more cables expected to be added by 2025 (https://www2.telegeography.com/submarine-cable-faqs-frequently-asked-questions). In comparison with satellites, cables can carry far more data at far less cost. With the massive demand for internet traffic further increasing, construction of new submarine cables might continue to be necessary to avoid service disruption, degradation and slower speeds.

Digitalisation and technological innovation have been developing and transforming the maritime sector in nearly every aspect of its operations, from underwater to air equipment. Technological progress is taking place at an accelerated rate in the following four areas:

- ocean sensing and imaging instruments (by using AI and machine to machine communication),
- the expanding spatial coverage of float arrays and fixed observation platforms,
- the increasing autonomy in mobile platforms,
- new complex systems integration schemes (OECD, 2021).

The maritime robots are used for different purposes in various spheres of Blue economy activities: surveys, scientific research, oil and gas exploration, border surveillance, infrastructure inspection and farming. Underwater systems are rising and becoming one of the most valuable sectors within the robotics market.

Since the underwater robots facilitate ocean or underwater exploration in challenging environmental situations, they are frequently used for industrial, commercial and scientific purposes, explorations, surveillance, defence and military use. Additionally, more countries are using bots to navigate inside the water for surveillance and defence, monitoring naval movements in the water. The usage for security purposes is increasing the demand. Risks of cyber threats and technological breach require more investments in research and innovation.

Underwater robotics sector is **high-value/high-cost sector** with significant entry barriers related to R&D. Currently, most countries are trying to find alternative resources of oil and gas that can meet their need which leads to exploring the water bodies in their region. As regards the unmanned water vehicles, ROVs and AUVs continue to be vital part of e rising offshore deep-sea oil and drilling industry due to its need to perform undersea operations, such as equipment assembling, drilling, underwater repair, and maintenance. AUVs are used in executing simple activities with little or no human supervision, often serving as survey platforms to map the seafloor or characterise physical, chemical or biological properties of the water.

Europe leads in many aspects of maritime technology but lacks well integrated and coordinated oceanic robotic infrastructure. The underwater environment is harsh and under constant influence of disturbances such as sea currents, winds and waves. However, the oceans and the seas are home for a myriad of species, many of which have yet to be discovered, and a great source of resources.

Advances in sensors, small embedded processors and miniaturized actuators have increased interest in study and development of multi-robot systems. The use of multiple autonomous robotic vehicles acting in cooperation drastically increase the performance, reliability, and effectiveness of automated systems at sea. With expanding research into more remote and inaccessible areas, the underwater robots and sensors will play a crucial role in the future in modern exploration of marine environments and adaption to the challenges presented by climate change. Recommendations for future action include continuing development and early adoption of newly emerging smaller, cheaper autonomous technologies and further investment in human potential and support facilities at all levels.

# 6 Delphi survey

## 6.1 Methodology

Delphi survey on future trends and technologies in the field of maritime technologies for detection, monitoring and prevention of marine pollution is a part of a larger Technology foresight study within the InnovaMare project that aims to identify the key challenges and opportunities in Blue economy, as well as future trends and innovative technologies in the field of maritime technologies, using a modified Delphi method. The main objective of this Delphi survey was to gather experts´ opinions and build consensus on a set of statements related to underwater robotics and sensors within the 10 to 20 years' time horizon.

The Delphi is based on principle that forecasts from a structured group of individuals are more accurate than those from unstructured groups. The experts answer questionnaires in two or more rounds, after which a facilitator provides an anonymised summary of the expert´s forecasts. Thus, experts are encouraged to revise their earlier answers in light of the replies of other members of their panel. The process is stopped after a predefined stop criterion (e. g. achievement of consensus, number of rounds). The mean or median scores of the final rounds determine the results. This method maximizes the benefits of using a large number of individuals across diverse locations and expertise while minimizing and/or avoiding potential disadvantages (powerful personalities and dominance by one individual, group pressure, effects of status) by implementing anonymity (Dalkey, 1972; Williams & Webb, 1994). The methods have been used extensively for programme planning and the development of research priorities in various areas.

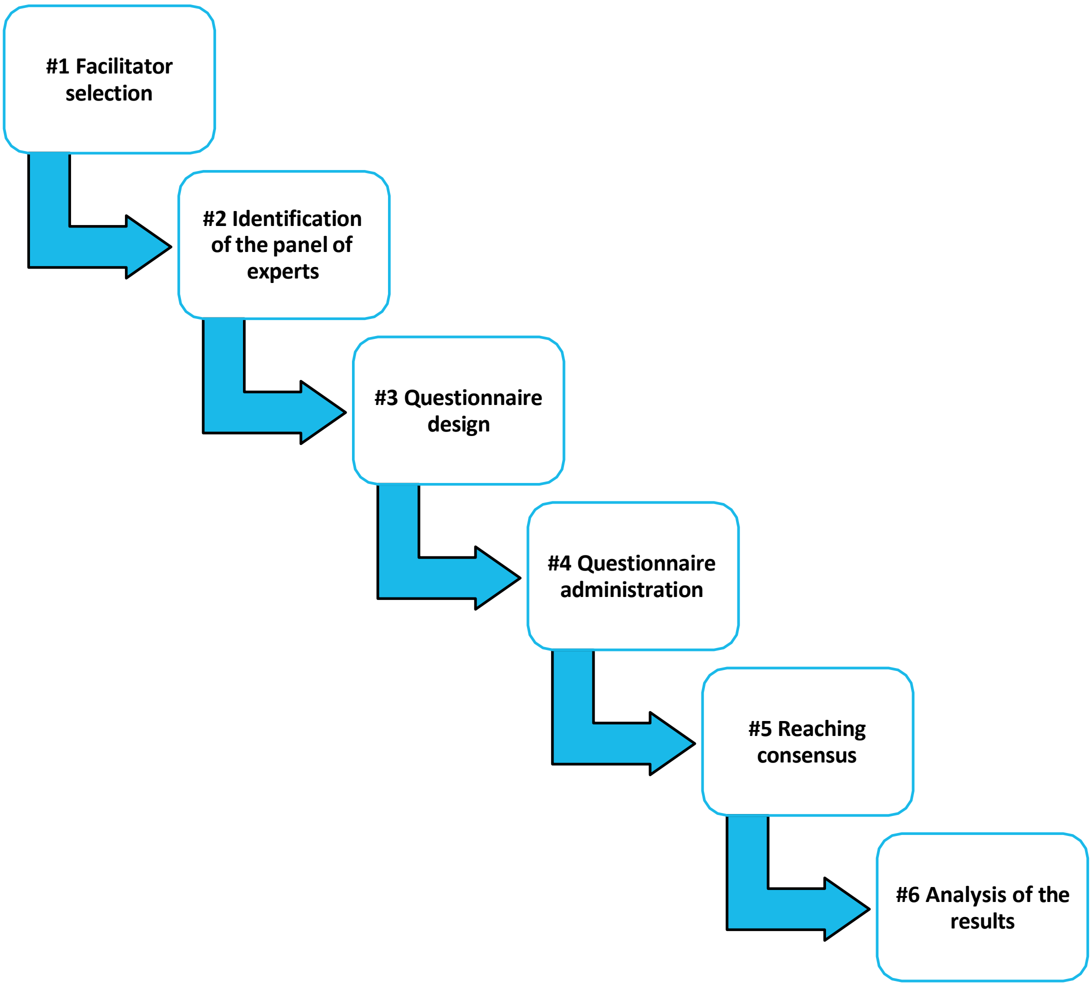
In comparison to conventional Delphi, the modified Delphi method is a group consensus strategy that systematically uses literature review, opinion of stakeholders and the judgment of experts, and involves controlled feedback and statistical group response within a certain field to reach agreement. The difference between these two methods is that usually in the first round of conventional Delphi, the facilitator asks the experts to rate and propose additional outcomes or issues and then combines them into questions or statement to test with the wider group in the next round, while the modified Delphi has the initial alternatives already selected before presenting them to the panel of experts. Studies have demonstrated that the modified Delphi method can be superior to the original Delphi method and perceived as highly cooperative and effective (Graefe et al., 2016).

In this survey, a modified Delphi was chosen as a suitable method for the following reasons:

- there was no need for a physical meeting of experts,
- there was no requirement for a large number of experts, but for a small number of the most specialized ones,

- economic approach in terms of research organization´s time and funding, and facilitated rapid communications between the experts from different geographical locations,
- appropriate method to rank the key challenges and trends in maritime technologies,
- the method allowed members of the panel to provide further clarification on some matters and present arguments in order to justify their viewpoints.

Figure 13 Implementation steps



Source: Created by the author.

The first step in the implementation of the Delphi method is to choose a facilitator within the research organization (Mreža znanja d.o.o. / Knowledge Network Ltd.) who is experienced in research and data collection. Facilitator´s duties include overseeing the designing the questionnaire, making decision on its format and question structure, selecting participants (panel of experts), setting the consensus and executing and analysing all phases of the questionnaire.

The next step is to identify a panel of experts who are knowledgeable about a certain topic so they can forecast the outcome of future scenarios, predict the likelihood of an event, or reach consensus about a particular topic. Panel sizes are usually guided by practicality or question scope, typically between 15 and 60 experts (Hasson et al., 2000). Sample sizes in this range are typical for the Delphi method and have been shown to be effective and reliable (Alkins et al., 2005). However, there is some evidence that 15-30 participants are ideal as more than 30 are not seen to improve the results (Keeney, Hasson & McKenna, 2011). Participants are not sampled for representativeness but are viewed as experts drawn from different stakeholder groups to allow comparison and consideration of different perspectives. To ensure that the selected experts met some pre-defined desirable characteristics, purposive sampling was used. The inclusion criteria for the experts invited to take part in the survey included area of expertise and years of professional experience. Apart from a list of experts compiled by the research organization itself, potential panellists were suggested by the project coordinator and other panellist. They were then invited by email to take part in the study and asked to consent to participation. The survey was distributed to a diverse and balanced group comprised of 40 EU and global experts in varying employment sectors (researchers from the academia and the industry, private sector entrepreneurs/managers), areas of expertise (maritime technologies, underwater robotics, sensors, remote sensing, underwater acoustic comms and sensing, underwater wireless communications and networks, environmental science, marine research, autonomous systems, data analysis and AI), organizations (research organisations, private and public bodies, SMEs) and career stages (from 5 to over 20 years of experience). Panel members' selection was heterogeneous, given that the literature demonstrates that decision-making groups perform better when they are heterogeneous (Bantel, 1993; Okoli and Pawlowski, 2004). This panel of experts has been designed and manned in a very meticulous way, in order to increase the validity and the reliability of the survey responses. Out of the 40 experts to whom the survey was sent in the first round, 25 of them agreed to participate in both survey rounds. They were requested to provide an email address through which all communications would take place. All data provided by them was accessed only by the facilitator and the team conducting the survey. The panel replied in a satisfactory way and provided valuable comments. During the implementation, the experts anonymously replied to questionnaires and subsequently received feedback in the form of a statistical representation of the group response from the facilitator. The experts at each round had a full record of what forecasts other experts made, but they didn´t know who made which forecast. Anonymity and confidentiality in the Delphi allow the experts to express their opinions freely, encourages openness and avoids admitting errors by revising earlier forecasts.

The selection of both facilitator and the experts is followed by the questionnaire design. The questionnaire as created using a commercially available online survey tool Google Forms (https://docs.google.com/forms). All data provided by the experts was treated with full confidentiality and anonymity. However, the respondents were requested to volunteer their email addresses for inclusion in subsequent rounds and for sending them the overall survey results afterward. An email was sent to 40 chosen experts requesting them to provide their feedback on the key challenges and trends in Blue economy, as well as future trends and innovative maritime technologies within the 10-20 years' time horizon.

As regards the administration process, the statements in the pilot questionnaire were carefully formulated. For the development of statements, the information was identified by the extensive search and analysis of the existing literature and compiled from various on-line sources (articles, reports, textbooks). Then, the reference list of those publications was checked to identify other relevant studies. Furthermore, the pilot questionnaire was pre-tested and initially e-mailed to chosen experts' accounts, asking for their views and insights on carefully selected statements regarding emerging technologies for detection, monitoring and prevention of marine pollution within the next 10 to 20 years. Following this, based on the comments of the pilot questionnaire, a modified „ranking and closed-ended questions type" version of the Delphi questionnaire was sent to the chosen panel of experts to rate the level of agreement or disagreement regarding the influence of underwater robotics and sensors on key challenges and opportunities in the sustainable Blue economy, as well as trends and expanding possibilities for the development of innovative underwater robotics and sensors for detection, monitoring and prevention of marine pollution. In all stages of the survey, the statements were grouped in three thematic areas: Blue economy, Underwater robotics and Sensors. The number of rounds or iterations in Delphi studies usually ranges from two to four. Ideally, the facilitator should continue until he reaches a consensus or 'point of diminishing returns', but it´s important to keep in mind that stopping too early may lead to invalid results and too many rounds may induce participant fatigue and cause them to drop out. In the present questionnaire, it was agreed at the start that the employed methodology would consist of the pilot and the two rounds of the questionnaire.

The level of consensus is usually set prior to conducting the survey and is influenced by the objectives of the study and the implications for practice (Keeney et al. 2006; Hasson et al. 2000). Delphi consensus typically ranges between 55% to 100%, with 70% considered to be the standard (Vernon, 2009). In this survey, a cut-off consensus level was set on 60% agreements.

The results of the analysis were presented statistically, using mean values and standard deviation scores for each statement. Statements not meeting 60% agreement were redistributed to the panellists for the second round, alongside the group agreement levels and the panellists' individual ratings. Then they were asked to review their opinion in light of the group consensus. In the first round, 46 statements related to the sustainable Blue economy trends and innovative maritime technologies were distributed to the panel of experts for the first round of voting. Panel members were asked to mark the level of agreement or disagreement beside each statement and provide additional comments. The same voting method was again used for the second round, but this time, on only 15 statements on which the experts had high differences in opinions since the consensus was reached on most statements from the first round. In total, 37 statements representing three thematic areas reached a consensus during the two rounds of questionnaire.

## 6.2 Delphi pilot survey

The draft survey containing the list of statements grouped in three thematic areas was circulated by email to several experts and accompanied by a clear explanation of the objectives of the Delphi survey and specific instructions for member participation. The pilot survey intended to clarify any redundancy or issues regarding comprehension or syntax of each statement. Experts were also allowed to provide comments and suggest additional items that may not have been included when developing the initial list of statements. Some statements were modified according to feedback provided by the experts and redistributed to the panellists for the first round of the Delphi survey.

## 6.3 Delphi survey - round 1

The first round consisted of a structured questionnaire and closed-ended questions. The participants were asked to vote by marking “agree” or “disagree” beside each statement on a 9-point Likert scale. Within the 9-point scale, score 1 represented ‘very strongly agree’ and 9 ‘very strongly disagree´.

For each statement, panellists were given the option to provide free-text comments to further elaborate their opinions and provide additional information or explanation regarding each statement. We then conducted the analysis of free-text responses to the closed-ended questions by manually reviewing the comments for all three thematic areas.

Consensus was set a priori as 60% of participants agreeing (1-very strongly agreeing, 2-strongly agreeing, 3-agreeing) or disagreeing (7-disagreeing, 8-strongly disagreeing, 9-very strongly disagreeing) with each statement.

Responses to the first round of the questionnaire were analysed by the research team during a one-week period. Agreement with statements was calculated and summarized using mean values and standard deviation scores. The data was then entered into a database by a facilitator. Statements required 60% agreement from the panel (i.e., agreement among greater than or equal to 15 of 25 experts) to be accepted. In other words, if 15 or more experts agreed on a statement, that meant the end of data collection for a particular statement.

Statements not meeting 60% agreement were redistributed to the panellists for the second round, alongside the group agreement levels and the panellists’ individual ratings. Then they were asked to reconsider their rating using the same scale as in the first round.

Out of a total of 46 statements, 31 statements met consensus in the first round. The list of statements that did not meet consensus was emailed to all 25 members in the second round.

## 6.4 Delphi survey - round 2

The second round of survey proceeded towards consensus-building by focusing only on the statements on which the experts have expressed significantly different opinions. Once again, the experts were emailed a questionnaire asking them to vote by marking “agree” or “disagree” beside each statement on a 9-point Likert scale, but this time, each statement was accompanied by the expert´s response in the first round, as well as by the average (mean) and the standard deviation values of the responses received. In the light of the group responses, the participants could reflect on their score, re-evaluate statements and possibly change their minds, while preserving the anonymity of their responses.

Once more, the experts' final responses were analysed as described for the first round (i.e., calculating mean and standard deviation values). Out of a total of 15 statements, 9 statements reached consensus.

After the first round of voting, expert´s opinions and comments were collated and summarized. In total 31 statements reached a consensus after the first round. The remaining 15 statements were returned to respondents for re-rating in the second round. After the second round of voting, panel members reached a consensus on 6 statements that initially did not receive consensus in the first round. In total, 37 statements representing three thematic areas reached a consensus.

## 6.5 Statistical results of Delphi survey

Total of 46 statements were identified by the research organization that would be relevant in reviewing the potential challenges and opportunities for the Blue economy sector, as well as future trends and innovative maritime technologies. The statements were divided in three thematic areas: Blue economy, Underwater robotics and Sensors.

The analysis of the results of both rounds showed that consensus was reached on many of the statements in all three thematic areas.  In the following table are listed individual statements across three fields of survey.

- **Statements in Delphi survey**

| Statement | Consensus (Y/N) |
|---|---|
| **Blue economy** | |
| STM1: Underwater robotics and sensors will have significant impact in resolving challenge of pollution in Blue economy. | Y |
| STM2: Underwater robotics and sensors will have major role in cleaning seas and oceans from microplastics. | Y |
| STM3: Underwater robotics and sensors will have major role in cleaning seas and oceans from macroplastics. | Y |
| STM4: Underwater robotics and sensors will become the most important tools in prevention and detection of small-scale pollution events (small oil spills, chemical or nutrients pollution). | Y |
| STM5: Remediation of marine pollution by marine (micro)organisms will be increased by underwater robotics and sensors. | Y |
| STM6: Use of underwater robotics and sensors will play an important role in climate change mitigation. | Y |
| STM7: Underwater robotics and sensors will significantly contribute to development of sustainable fisheries and aquaculture. | Y |
| STM8: Underwater robotics and sensors will be used in different aspects of blue biotechnology. | Y |
| STM9: Underwater robotics and sensors will be used for stopping and preventing biodiversity loss. | Y |
| STM10: With the use of underwater robotics and sensors, negative environmental impacts of emerging “green” sectors will be prevented and detected (e.g., disrupting seabed habitats for renewable energy production, or bycatch in the removal of marine litter and plastics). | Y |
| STM11: Underwater robotics and sensors will improve efficiency of marine renewable energy technologies (eg. offshore wind, tidal and wave energy technologies, floating solar photovoltaic energy, hydrogen generation offshore). | Y |
| STM12: Underwater robotics and sensors will significantly contribute to sustainable shipbuilding and sustainable maritime transport. | N |
| STM13: Development of sustainable coastal tourism will be significantly influenced by underwater robotics and sensors. | Y |
| STM14: Underwater robotics and sensors will significantly contribute to the sustainability of port activities. | Y |
| STM15: Underwater robotics and sensors will play a crucial role in the field of sustainable maritime defence, security and surveillance. | Y |
| **Underwater robotics** | |
| STM1: Human input in operation of robotic vehicles will decrease. | Y |
| STM2: Development of AI will enable fully autonomous operation of robotic vehicles. | Y |
| STM3: AI will be used in mission planning. | Y |
| STM4: Use of remotely operated robotic vehicles will decrease in favour of autonomous robotic vehicles. | Y |
| STM5: Development of AI will enable detecting and removing plastic waste and debris. | Y |
| STM6: Development of underwater communication technologies for autonomous robotic vehicles will enable reliable navigation and data transmission, regardless of the depth. | Y |
| STM7: Development of underwater communication technologies will enable groups of coordinated robotic vehicles to cover large areas. | Y |
| STM8: Autonomous robotic vehicles will be able to find oil, chemical and nutrient pollution source in sea water by following increase in pollutant concentration. | N |
| STM9: Development of advanced materials and micro- and nanoelectronics will improve sensors needed for autonomous operation of robotic vehicles. | Y |
| STM10: Use of robotic vehicles will eliminate the need for use of human-operated research ships. | N |

| | |
|---|---|
| STM11: Development of advanced materials and micro- and nanoelectronics will enable miniaturisation of robotic vehicles and sensor payloads. | Y |
| STM12: Advancements in battery technology, alternative power supply systems and energy efficient propulsion systems will at least double the operation time of untethered robotic vehicles. | Y |
| STM13: In design and engineering will be applied solutions which imitate nature, i.e., features of some marine organisms. | Y |
| STM14: Development of renewable energy will decrease the number of offshore oil and gas platforms, reducing the need for monitoring and detection of pollution from these sources. | Y |
| STM15: Docking and deployment of robotic vehicles from ships or fixed stations will be completely automated with the need for human assistance only in case of malfunctions. | Y |
| STM16: Ships for deployment of robotic vehicles in open sea will be fully autonomous, without human crew. | N |
| STM17: Some robotic vehicles will be widely available as “off the shelf” products, similar to current situation with air drones. | Y |
| **Sensors** | |
| STM1: Development of advanced materials will decrease maintenance and replacement costs (e.g., increased durability to environmental conditions and resistance to fouling). | Y |
| STM2: Development of advanced materials and micro- and nanoelectronics will increase research and development cost of sensor instruments. | Y |
| STM3: Research and development in advanced materials and micro- and nanoelectronics will significantly increase use of Lab-on-a-chip solutions. | Y |
| STM4: Production cost of sensor instruments will decrease due to demand for monitoring and larger volume of production. | Y |
| STM5: Number of deployed autonomous sensor instruments and sensor arrays will significantly increase. | Y |
| STM6: Cabled observatories will steadily decrease. | Y |
| STM7: Development of satellite technology for remote sensing will decrease the need for in situ sensors. | N |
| STM8: Autonomous sensors and arrays will decrease the need for use of human-operated research ships. | N |
| STM9: Remote sensor management will be based on IoT technologies. | Y |
| STM10: Integration of IoT technologies in sensors will become prevalent solution for collection and transmission of pollution data. | Y |
| STM11: Use of Big Data technologies will become standard in interpretation of collected data. | Y |
| STM12: Energy harvesting technologies (e.g., solar power, thermal and wind energy and salinity gradients) will become main power supply source for autonomous sensor instruments. | Y |
| STM13: Increase in offshore renewable energy facilities (wind and solar farms) will create favourable opportunities for sensor instruments installation. | Y |
| STM14: Increase in offshore renewable energy facilities will create demand for monitoring and detection of small-scale pollution. | Y |

In the table below, the experts' rating results for each one of the statements (STM) for Blue economy (BE), Underwater robotics (UR) and Sensors (S) during the first and second round can be seen. It summarizes the expert's valuation of the statements, expressed in mean values and standard deviations, as well as the level of agreement. As can be seen from the table below, the agreement level for most of the statements is strong and the consensus was reached on 67% of statements after the first round.

- **Rating results for the Delphi first and second round**

| Statements | First round´s results | | | | Second round´s results | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Standard deviation | Level of agreement | Consensus (Yes/No) | Mean | Standard deviation | Level of agreement | Consensus (Yes/No) |
| **Blue economy** | | | | | | | | |
| STM1 BE | 2.20 | 1.04 | 2 | Y | - | - | - | - |
| STM2 BE | 2.88 | 2.06 | 3 | N | 2.68 | 1.14 | 3 | Y |
| STM3 BE | 2.80 | 1.41 | 3 | Y | - | - | - | - |
| STM4 BE | 2.72 | 1.36 | 3 | Y | - | - | - | - |
| STM5 BE | 3.76 | 1.66 | 4 | Y | - | - | - | - |
| STM6 BE | 3.12 | 1.66 | 3 | N | 3.00 | 1.63 | 3 | Y |
| STM7 BE | 2.40 | 1.29 | 2 | Y | - | - | - | - |
| STM8 BE | 2.72 | 1.59 | 3 | N | 2.48 | 1.39 | 2 | Y |
| STM9 BE | 3.12 | 1.42 | 3 | N | 2.72 | 1.36 | 3 | Y |
| STM10 BE | 2.76 | 1.26 | 3 | Y | - | - | - | - |
| STM11 BE | 2.88 | 1.58 | 3 | Y | - | - | - | - |
| STM12 BE | 2.88 | 1.64 | 3 | N | 2.96 | 1.81 | 3 | N |
| STM13 BE | 3.60 | 1.80 | 4 | N | 3.68 | 1.49 | 4 | Y |
| STM14 BE | 2.60 | 1.19 | 3 | Y | - | - | - | - |
| STM15 BE | 2.44 | 1.52 | 2 | Y | - | - | - | - |
| **Underwater robotics** | | | | | | | | |
| STM1 UR | 3.24 | 1.78 | 3 | Y | - | - | - | - |
| STM2 UR | 2.76 | 1.16 | 3 | Y | - | - | - | - |
| STM3 UR | 2.60 | 1.04 | 3 | Y | - | - | - | - |
| STM4 UR | 3.16 | 1.21 | 3 | Y | - | - | - | - |
| STM5 UR | 2.88 | 1.53 | 3 | Y | - | - | - | - |
| STM6 UR | 2.92 | 1.49 | 3 | Y | - | - | - | - |
| STM7 UR | 2.56 | 1.22 | 3 | Y | - | - | - | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| STM8 UR | 2.76 | 1.33 | 3 | N | 2.60 | 1.32 | 3 | N |
| STM9 UR | 2.76 | 1.39 | 3 | Y | - | - | - | - |
| STM10 UR | 5.28 | 2.42 | 5 | N | 5.12 | 2.28 | 5 | N |
| STM11 UR | 3.36 | 1.49 | 3 | Y | - | - | - | - |
| STM12 UR | 2.56 | 1.39 | 3 | N | 2.44 | 1.29 | 2 | Y |
| STM13 UR | 3.80 | 1.22 | 4 | Y | - | - | - | - |
| STM14 UR | 3.88 | 1.67 | 4 | N | 3.60 | 1.41 | 4 | Y |
| STM15 UR | 3.16 | 1.49 | 3 | Y | - | - | - | - |
| STM16 UR | 4.12 | 2.03 | 4 | N | 3.96 | 1.86 | 4 | N |
| STM17 UR | 3.32 | 1.52 | 3 | Y | - | - | - | - |
| **Sensors** | | | | | | | | |
| STM1 S | 2.84 | 1.18 | 3 | Y | - | - | - | - |
| STM2 S | 3.80 | 1.63 | 4 | Y | - | - | - | - |
| STM3 S | 3.40 | 1.38 | 3 | Y | - | - | - | - |
| STM4 S | 3.20 | 1.32 | 3 | Y | - | - | - | - |
| STM5 S | 2.88 | 1.27 | 3 | Y | - | - | - | - |
| STM6 S | 4.40 | 1.73 | 4 | N | 4.28 | 1.62 | 4 | Y |
| STM7 S | 5.36 | 2.10 | 5 | N | 5.40 | 2.10 | 5 | N |
| STM8 S | 4.52 | 2.04 | 5 | N | 4.08 | 1.98 | 4 | N |
| STM9 S | 3.28 | 1.34 | 3 | Y | - | - | - | - |
| STM10 S | 3.44 | 1.39 | 3 | Y | - | - | - | - |
| STM11 S | 2.48 | 1.16 | 2 | Y | - | - | - | - |
| STM12 S | 3.56 | 1.36 | 4 | Y | - | - | - | - |
| STM13 S | 2.96 | 1.43 | 3 | N | 2.96 | 1.59 | 3 | Y |
| STM14 S | 3.16 | 1.34 | 3 | Y | - | - | - | - |

## 6.6 Conclusions of Delphi survey

The overall goal of this survey was to identify and anticipate emerging maritime technologies with emphasis on underwater robotics and sensors, which will meet the societal needs and market demands of other participants in the Blue economy sector. The selected method was a modified Delphi that relies on a panel of experts to forecast the future outcome. This survey was distributed to a diverse and balanced group comprised of 40 EU and global experts in varying employment sectors, areas of expertise and career stages. Out of the 40 experts to whom the survey was sent in the first round, 25 of them agreed to participate in both survey rounds and provide their feedback on the key challenges and trends in Blue economy, as well as future trends and innovative maritime technologies within the 10-20 years' time horizon. The questionnaire was created using survey tool Google Forms, and all data provided by the experts was treated with full confidentiality and anonymity. The implementation phase included pilot and two rounds of the questionnaire. The pilot questionnaire was pre-tested and initially e-mailed to chosen experts' accounts. Based on the comments of the pilot questionnaire, a modified „ranking and closed-ended questions type“ version of the Delphi questionnaire was sent to the chosen panel of experts to rate the level of agreement or disagreement regarding the influence of underwater robotics and sensors on key challenges and opportunities in the sustainable Blue economy, as well as trends and expanding possibilities for the development of innovative underwater robotics and sensors for detection, monitoring and prevention of marine pollution. In all stages of the survey, the statements were grouped in three thematic areas: Blue economy, Underwater robotics and Sensors. In this survey, a cut-off consensus level was set on 60% agreements. After the first round of voting, expert´s opinions and comments were collated and summarized. In total 31 statements reached a consensus after the first round. The remaining 15 statements not meeting 60% agreement were returned to respondents for re-rating in the second round. After the second round of voting, panel members reached a consensus on additional 6 statements. The results of the analysis were presented statistically, using mean values and standard deviation scores for each statement. In total, 37 statements representing three thematic areas reached a consensus during the two rounds of questionnaire.

# 7 Future offer

## 7.1 Future role of underwater robotics and sensors in Blue economy

"Underwater robotics and sensors will have significant impact in resolving challenge of pollution in Blue economy". This statement, strongly confirmed by respondents in the Delphi survey, is rather general, but indicates belief that pollution problem in marine environment and related socio-economic activities can be resolved or at least minimized, through implementation of advanced technology, which will complement other changes and measures on the path towards healthy environment and sustainable development. The role of underwater robots and sensors will be further elaborated in this chapter across sectors and components of Blue economy based on expert opinions.

Robots will represent a viable solution for cleaning the oceans and seas from macroplastics, as one of the most prevalent pollutants in seas and oceans and threat to marine animals. This pollutant is also a source of microplastics, which slowly becomes ubiquitous and its long-term influence on environment, health of marine life and human health is in increased focus of research activities. Robots will be able to distinguish macroplastics and other litter from natural objects and living organisms and mechanically remove them from marine environment. Robots and sensors will also be able to detect microplastics in water and contribute to the process of cleaning.

Small scale pollution (small oil spills, chemical or nutrients pollution events) occurs constantly in maritime activities or originates from inland activities. Due to its limited scope, often is not in focus of the public interest, but its effects cannot be underestimated, especially in small areas with high concentration of possible pollution sources. By increased deployment of sensors, which will monitor offshore and coastal facilities (energy facilities, ports, aquaculture farms), as well as other locations where pollution may occur (river deltas, coastal cities), detection and response will be quicker. Robots will be engaged in detection, but also prevention activities, as tools for facilities inspection.

Climate change mitigation is currently one of the most important and complex global topics, which requires actions in multiple social and economic fields. Underwater robotics and sensors will contribute on their part to climate change mitigation in following ways: through tackling the problem of pollution; as tools in environmental research and protection; as a sources of data in decision making process; through support activities at renewable energy facilities (inspection, monitoring); as option for decrease of resource-intensive maritime activities.

Fisheries and aquaculture represent primary sector in exploitation of living marine organisms for food. Pollution, destruction of seabed habitats and overfishing represent threats for this sector and can be mitigated by use of underwater robotics and sensors. Besides their role in dealing with pollution, robots and sensors represent research tools and sources of data, from which primary sector can benefit. In aquaculture, robots and sensors should also be used to prevent negative effects on surrounding environment. Robots and sensors will be involved in emerging “green” sectors such as new offshore renewables and blue biotechnology. Offshore wind is currently only broadly accepted technology in this sector, but other renewables are in development or experimental phase. Robots and sensors will be used in operation and management of marine renewable energy facilities. Foreseen involvement includes detection of small-scale pollution, monitoring underwater noise pollution, seabed habitats protection, monitoring and inspection of facilities. General contribution of robots and sensors in blue biotechnology is reduction of marine pollution. Clean marine environment is important for farming products (such as algae), which are intended to be used as food, feed or fertilizers. Blue biotechnology benefits from healthy and biodiverse environment, which is primary source of compounds and biomass for development of products for further use (food additives, animal feeds, pharmaceuticals, cosmetics). Robots and sensors will be engaged in prevention of biodiversity loss caused by seabed habitat destruction, pollution and climate change.

Shipbuilding and port activities in Europe represent economically important coastal areas. Robots and sensors will have a role in detection and prevention of pollution, originating from shipyards, which are usual situated on or near the sea shore. Monitoring and detection of hazardous materials and other possible discharges, which are used in shipbuilding as materials or in production processes, is important for clean environment and mitigation of pollution. Ports are both entry and exit points for trade of goods and transport of people and often are complex systems which require intensive monitoring. Making ports greener will be possible through use of robots and sensors in monitoring influence of port activities on the environment, detecting pollution in due time (small fuel spills, hazardous materials discharge) and use of this technologies in port management.

Coastal tourism, as important source of income for entire communities across Europe and globally, will benefit from application of underwater robots and sensors technology through preservation of environment (especially water quality), which is often most valuable resource in this sector. Technology will also contribute to sustainability of coastal tourism through monitoring, detecting and decreasing the environmental pressures which tourist activities cause (garbage, transport pollution, wastewater).

Although maritime defence, security and surveillance are not closely related to environmental issues, they are a part of Blue economy, and as such, can utilize robots and sensors for the purpose of keeping European maritime countries safe from external threats. Recent developments in Ukraine emphasize importance of new technology, which can be used for safety of people and infrastructure.

Overall results of Delphi survey indicate that underwater robotics and sensors will have a major role in sustainable development of Blue economy in the time period of 10-20 years across most of the sectors.

## 7.2 Future technology in underwater robotics based on TF results

Trends on the demand side outline the direction in which field of underwater robotics should develop in terms of Blue economy and detecting, monitoring and prevention of pollution. Continuous advancement of technology and its application in underwater robotics should result in more advanced features across the field. Based on opinions of expert panel, forecast of trends and technologies in a timeframe of 10-20 years is given.

Trends in overall robotics and automation are moving towards decrease of human involvement and that is also a case in underwater robotics. Most of the respondents agreed that the human impact in use of underwater robotic vehicles would be reduced, but human supervision and monitoring would still be needed. Robotic vehicles will be significantly more autonomous due to development of artificial intelligence (AI), which will have a major role in mission planning and operation of vehicles. Role of AI is also important in removing macroplastics and other debris thus helping in cleaning the seas and oceans and making them less polluted. It should be emphasized that a significant factor remains human perception and willingness to work on fully autonomous vehicles that require new procedures and rules of operation. Some processes will be automated, such as deployment and docking, which will significantly ease the use and manipulation of robotic vehicles on ships or fixed stations. This should also create favourable opportunities for installing docking stations on various points of interest such as research and monitoring stations or possible pollution sources (ports, offshore energy facilities, aquaculture farms, river estuaries). However, views are divided on whether docking ships will be fully autonomous; it is considered to be potentially possible in the time span of 10-20 years, but significant level of consensus on this matter was not achieved. Autonomous robotic vehicles will not replace the need for offshore research work, performed by scientists and experts aboard the research ships, although robotic vehicles should decrease the use of such ships in some scenarios, depending on the type of required missions. Nevertheless, they represent useful asset, which can be used to complement and extend research activities of the human operated ships, including monitoring, detecting and remediation of pollution.

Advancement of technology will provide machines with better performance, due to developments in engineering, advanced materials, batteries, propulsion systems, micro- and nanoelectronics, manufacturing processes and communication technology. This means that robots will have improved sensors needed for autonomous control, higher operation time (at least double) and will be able to go to greater depths. Overall trend of electrification, especially in transport sector should bring benefits, due to increased investments in research and development of battery technologies and propulsion components, which results should trickle down to underwater robotics. The development of communication technologies would contribute to the coordinated work of robotic vehicles that would cover a wider area of the sea thanks to increasing the communication range or in cooperation with different media that would enable much better connectivity and better joint action. Technological development will also be visible in design, which could (based on specific needs) seek miniaturisation; according to most respondents, the development of more advanced materials and micro- and nanotechnology should lead to the creation of miniature robotic vehicles and sensor payloads. Although sensors and batteries are already being produced in microform, the key challenge is the miniaturization of energy sources. Design process will also implement the best solutions from nature in order to increase performance or adapt to specific type of operation and surroundings, but all vehicles will not be biomimetic.

Underwater robotics will still have a role in managing offshore non-renewable energy facilities but will have to follow transition to renewable energy sources, offshore wind being the most important. The experts agreed that there would be a reduction in offshore oil and gas platforms, which will reduce the need to monitor and detect pollution from these sources, but demand will not decrease because offshore renewables need to be monitored for small scale pollution, underwater noise and seabed habitat health.

Commercialization of underwater robots, similar to current situation with air drones, is expected to some degree and some types of robots should be increasingly available for purchase by end users. This implies that robots could be more accessible to operate for average user and will require less expert knowledge. Commercialization would benefit users from various sectors (environment, transport, security and defence, fisheries, aquaculture) for their specific needs. When underwater robots become common commercial tools, the need for legislative regulation could be implemented, due to safety, security, and environmental concerns.

## 7.3 Future technology in sensors based on TF results

Development in the field of advanced materials will make sensors more durable and resistant to environmental conditions, which will reduce maintenance and replacement costs. This should entice increased implementation of sensors in pollution detection and monitoring. It is believed that the development of advanced materials and micro- and nanoelectronics would contribute to higher cost of research and development, although the increase in cost is expected in initial application of novel technologies and over the time it would gradually decrease. Research and development in aforementioned fields would also contribute to increased use of lab-on-chip devices, but additional comments of some experts show scepticism that this would happen in the time span of 10-20 years.

High demand and larger production volume of sensor instruments will lower production prices and significantly increase the number of sensor instruments in use. Demand should arise from increased awareness about importance of healthy and clean marine environment, on which depend coastal societies and various sectors in economy.

It is believed that the number of cabled observatories would decrease, although this will highly depend on the development of the wireless communication technology. Cable observatories currently can provide accurate real online data, while autonomous sensors should take over that role in the future. Experts could not reach a consensus whether advancements in satellite technology for remote sensing will lead to a reduction in the need for in situ sensors. From the comments of experts it can be concluded that these two methods are rather complementary and that developments in both fields will contribute to research and monitoring of seas and oceans. These types of sensing should work together, as satellite sensors can cover a broader area, closer to the surface, while in situ sensors provide data from depth and measure the concentration of chemicals and pollutants.

Autonomous sensors and arrays should reduce the need for human-operated research vessels over a period of 10-20 years, with the prerequisite of an intelligent sensor network setup. Fulfilment of this condition relies on implementation of new technologies; in that regard, the respondents agreed that remote sensor management would be based on IoT technology, enabling connectivity and real-time access, which should enhance the role of sensors in marine research and environment protection. The integration of IoT into the field of sensors will become a prevalent solution for the collection and transmission of pollution data. Current main obstacle for IoT in sensors is identified in the field of wireless communication technology, and IoT solutions will be implemented after communication solutions are developed. Furthermore, respondents strongly agreed with the statement that the use of Big Data technology would become the standard in the interpretation of collected data. For users, IoT and Big data will enable access to high amount of structured information, as well as provide better insight to current situation in monitored areas of the sea. This will result in more efficient and precise monitoring process, which will enable faster response to pollution occurrences and enhance research activities.

The energy harvesting technologies (e.g., solar power, thermal and wind energy and salinity gradients) will become important power sources, although not the main ones. Implementation of these technologies depends on type of sensors and their energy consumption. As problems in this field experts stated the lack of available energy for harvesting in some marine environments and the reliability of harvester technologies in the marine surroundings. Nevertheless, efforts in development should be made to enable higher level of autonomy for sensor instruments and their installation in remote areas.

Most respondents agreed that increase of offshore renewable energy facilities would create favourable conditions for the sensor instruments installation. In this way there will be no issues with the power supply and offshore facilities would be also under monitoring. Due to specific operation properties of renewable sources (primary wind turbines) measurements of underwater noise pollution will become increasingly important, as well as research of its influence on marine ecosystems.

# 8 Conclusions

Protection and sustainable management of oceans and seas is a necessity for the future development of humankind. The problem of marine pollution on the global scale primarily represents the threat to sustainable economic and social development of coastal areas, but also inlands, as they are, in one form or another, connected to activities in seas and oceans. Furthermore, inland territories are often sources of pollution, which ends up in marine environment. Besides marine pollution there is a problem of air and land pollution which originates from maritime sectors and activities. In the context of climate change mitigation, efforts which make seas and oceans cleaner and healthier, are among most important priorities.

Economic and social development of the globalized world will be increasingly more dependent on the application of advanced technologies, which are resource-efficient, zero-emission and environmentally friendly. Application of robots and sensors in marine environment falls in this description in the time frame of the next 10-20 years. **Underwater robotics and sensors represent promising technologies for detection, monitoring and prevention of marine pollution**, which is confirmed by panel of experts, who participated in the process of technology foresight for the purpose of this report.

The main objective of the survey was to gather experts´ opinions and build consensus on a set of statements related to the field of Blue economy and maritime technologies. The panel of experts consisted of 25 EU and global experts in varying employment sectors, areas of expertise and career stages. The implementation phase of the modified Delphi method included a pilot and two rounds of the questionnaire. The experts had to rate the level of agreement or disagreement regarding the influence of underwater robotics and sensors on key challenges and opportunities in the sustainable Blue economy, as well as trends and expanding possibilities for the development of innovative underwater robotics and sensors for detection, monitoring and prevention of marine pollution. In total, 37 out of 46 statements reached a consensus (agreement level higher than 60%) during the two rounds of questionnaire which helped to identify and anticipate the emerging maritime technologies for tackling and preventing marine pollution within the 10-20 years’ time horizon.

**Trends in Blue economy are moving in direction of pollution prevention and remediation, decarbonization, automation, sustainability and biodiversity preservation.** While some established sectors are at their limits (fisheries), and other (such as offshore oil and gas) in decline, there are new emerging sectors, which should significantly contribute to European and global economy in near future.

Progress in mechanical and electrical engineering, advanced materials, micro- and nano electronics, battery technology and communication technology will enable the development of components and systems which will significantly improve performance and capabilities of autonomous robotic vehicles. Development of technology (advanced materials, micro- and nanoelectronics, energy harvesting technologies) and its application will result in sensors with better technical properties, durability and lower cost. Continuous advancements in information and communication technologies (especially development of AI, big data and Internet of Things) will have a significant role in design, manufacturing and operation of underwater robots and sensors, as well as in collection and interpretation of acquired data.

**Overall technological advancements will enable a broader application of underwater robots and sensors for tackling marine pollution issues.** Their development and application of new technological solutions should make them important assets in environmental protection and research, as well as useful tools across established and emerging sectors in the Blue economy in the future.

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## Annexes

### Annex 1 Underwater robotics and sensors - FP7 and H2020 projects

### Annex 2 Delphi survey on future trends and technologies in the field of maritime technologies for detection, monitoring and prevention of marine pollution

### Annex 3 Scenario: “Robo” vs “Pirate” in Adriatic Sea

It is a calm night, the sky is full of stars and the full moon of the early spring of 2031. The ship “Pirate” sailed into the Adriatic Sea at full speed, carelessly consuming fuel and throwing out all the collected waste in the open sea, without fear that anyone would see what it was doing. The "Pirate" is on a sneaky night attack of illegal fishing in the Adriatic Sea, skilfully avoiding Croatian Navy Coast Guard ships. However, they did not know that our ship “Robo” is equipped with robots to hunts illegal fishing boats. Many of our robots can go on long, unmanned missions. They work by using sensors in remote marine locations, which open up expanses of the Adriatic see that were once inaccessible. Big data from the robots, plus satellite imagery and artificial intelligence, can pinpoint where illegal fishing may occur, allowing officials to stop it. That's how the "Pirate" was discovered, the information was sent, and the coast guard ships soon surrounded the "Pirate" and took it to the port of Split for further processing.

Our ship “Robo” is also equipped with sensors, cameras and communication devices to capture information about pollutants on the open sea and hunts exactly such pollutants. Our ship uses power from the sun and wind to travel for months without producing any of their own emissions. As the boat continuously collects data, using satellite and communication systems to send information to users in real-time. This process offers precise data related to weather conditions and forecasts. Everyone who is interested can then use this information to optimize ship routes that cut fuel costs and reduce greenhouse gases.

One of the tasks of our ship is to monitor what's going on at the seafloor. Biomimetic ocean robotics is changing that, as these machines cruise the ocean on surveillance missions. For example, robotic crabs collect new data on the seabed, and robo-jellyfish can monitor what's going on with specific environments. It doesn't stir up clouds of silt and debris, such as propeller-driven remotely operated underwater vehicles (ROVs). The robo-crab also has a doppler radar-based navigation system so that it can feel around in murky conditions. With its several cameras, including a tillable color HD camera, it can zoom in on essential objects and species to see what's happening at the deepest depths.

Robots on our ship are also helping pollution reduction because they clean up trash in the sea. It's solar-powered, too, so it doesn't introduce any additional greenhouse gas emissions. The robots have a collection conveyer belt to pick up floating debris. Once its bins are full of plastic, it will head back to shore to offload the collected trash. They also have sensors and pingers designed to ensure it stays away from marine life during the process.

Our robots are already protecting the sea, from improving ship efficiency to removing patches of garbage. Our robots are also very useful for the wastewater treatment industry. Water purification is also crucial, as wastewater gets discharged into lakes and the sea. Robots can ensure treatment plants increase their capacity while releasing clean fluids.

Our "Robo" ship continues its mission of protecting the Adriatic Sea from pollution, illegal fishing and monitoring and cleaning the sea and seabed and protecting living creatures in the beautiful Adriatic Sea.