Uptake of new technology for ocean observation

European Maritime and Fisheries Fund (EMFF)

Sander van den Burg, Maarten Visscher, Anne Sonneveld, Benoit Berges, Lara Jansen, Fraser Sharp, Jacob Steinmann, Gurvinder Arora, Marion Bogers

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E-mail: CINEA-EMFAF-CONTRACTS@ec.europa.eu

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Uptake of new technology for ocean observation

Final Report

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1. INTRODUCTION

This document is the final report of the study "Uptake of new technologies for ocean observation" (EASME/EMFF/2020/3.1.16/SI2.833154-SC08). The final report describes the activities undertaken in the study and presents the results. This study investigates the current state of the development of sensors and platforms to gain a better understanding of the uptake of new technology in ocean observation in Europe and outside Europe. Below the objectives of the study are presented as stated in the request for this study.

1.1 Objectives as formulated in the request for this study

The general objective of this assignment was: *to determine how new technologies can increase effectiveness and efficiency of sensors and platforms used for EU's ocean observation efforts*. Four specific objectives were formulated:

Specific objective 1: To summarise the present state of development of sensors and platforms for ocean observation.

Under this specific objective a list was established with ocean sensors and platforms. The list is in tabular form and uses a common nomenclature and classification where relevant. The list is machine readable and contains the following items:

- For sensors and platforms the following variables are listed: the owner and manufacturer, the technology readiness level (TRL), the effort that has gone into its development (time and money), price, the market in terms of volume and geographical coverage, the depth at which it can operate, power requirements and communication means.
- For sensors the following variables are listed: the parameter measured, the frequency of measurement, the maintenance requirements (time interval and costs).
- For sensors the trends are identified by type op sensor (physics, biology etc.).
- For platforms the following variables are listed: the type of propulsion, the autonomy (including range and speed), communication means, payload requirements (weight, power), maintenance requirements (time intervals, costs), intended market and type of sensors that have been used on the platform.

Specific objective 2: To examine how the ocean observation market operates.

- Under this specific objective, the marketing of the technology mentioned under objective 1 was examined. The following questions were addressed:
  - What is the size of the current market?
  - Is the technology:
    - Primarily used by private or public sectors?
    - Used outside of its country of origin?
    - Operated by the supplier or bought or leased from them?
    - Primarily used by the technology owner?
  - Is there an open market for equipment or services based on competitive tendering?

Specific objective 3: To investigate how enterprises offering ocean observation equipment and services finance their business.

- Under this objective the financing of the development and commercialisation of the technologies mentioned under objective 1 was examined - e.g. government grants, venture capital, large corporations, private foundations. The analysis highlights differences between practices in the United States and Europe and the reasons for these differences. The role of defence budgets was investigated.

Specific objective 4: To identify challenges and opportunities for a more widespread introduction of the new technologies for ocean observation in the EU.

- Under this objective, public and private efforts made to stimulate and accelerate development and deployment of new observation technology were evaluated on how well these have worked. The analysis includes circumstantiated proposals for further measures that could be taken up by the EU and national governments, including support to research, investment, definition of standards and the use of public procurement.

1.2 Background of the study

- Those analysing the seas and oceans always ask for more observations and for faster and more reliable delivery of relevant data. Yet, despite ample evidence that the value of observations is worth more than their cost, budgets are limited. Traditionally ocean observation has meant collecting samples from ships and analysing them on board or in the laboratory. Nowadays, buoys or platforms that relay information back to shore for analysis and dissemination are used, in addition to other ways to obtain more and better observations for the same money. Much research funding, including by the EU, has gone into technology for in-situ measuring rather than samples being brought back to the laboratory, or research funding for platforms that can carry the instruments deeper, further, and more autonomously into the seas and oceans at lower costs. Examples of such research projects include AtlantOS, which is aimed at a transition from a loosely coordinated set of existing ocean observing activities producing fragmented, often monodisciplinary data, to a sustainable, efficient, and fit-for-purpose Integrated Atlantic Ocean Observing System (IAOOS), and INTAROS, which is working on a Pan-Artic observation system by extending, improving and unifying existing and evolving systems in the different regions of the Arctic.

- The European Marine Board (EMB) has worked on the topic of ocean observation. Through its pan-European network, the European Marine Board provides expert advice from the European marine scientific community in the areas of ocean observation and Marine Research Infrastructures (MRIs) to inform marine research policy and strategic planning. It has advanced the development of an end-to-end European Ocean Observation System (EOOS), a joint initiative between EUROGoos and the EMB.

- GOOS (the Global Ocean Observing System) is a programme executed by the Intergovernmental Oceanographic Commission (IOC) of the UNESCO. Its success relies on the coordinated contributions of several people and organisations worldwide. GOOS coordinates observations around the global ocean for three critical themes: climate, operational services, and marine ecosystem health. Actions are executed through international collaboration of a diverse collection of scientific experts across the world. EuroGOOS is the European component of GOOS and identifies priorities, enhances cooperation and promotes the benefits of operational oceanography to ensure sustained observations are made in Europe's seas, underpinning a suite of fit-for-purpose products and services for marine and maritime end-users.

- At the request of DG MARE and EASME, this study investigates the current state of the development of sensors and platforms to gain an understanding of the uptake of new technology in ocean observation in Europe and outside Europe. This study will map ongoing (and finished) developments of sensors and platforms for ocean observation.

1.3 Reading guide

This reports consists of seven chapters. In the current chapter (Chapter 1), the background to and objectives of the study are introduced. Chapter 2 is the methodological chapter, describing which activities were undertaken in this study to collect data. Chapter 3 discusses the present state of the development of sensors and platforms, and Chapter 4 describes the current state of the market. The financing of development and employment of ocean observation technologies is discussed in Chapter 5. In Chapter 6 the role of public and private efforts to stimulate the development of ocean observation technology is discussed. Chapter 7 presents the conclusions of the rapport.

Added to this main report are the following Annexes:

- Annex 1: an Excel-based overview of sensors, platforms and manufacturers.
- Annex 2: the survey metadata
- Annex 3: the report of the interviews (confidential)

2 TASK 0 COMMON METHODOLOGICAL APPROACH

2.1 Purpose and overall approach

The purpose of task 0 was to create the questionnaire and interview guides and to structure the online survey and qualitative interviews, in support of data collection for this study. The online survey contributed to Task 1 to 3 and qualitative interviews contributed to Task 1 to 4 (see Figure 1).

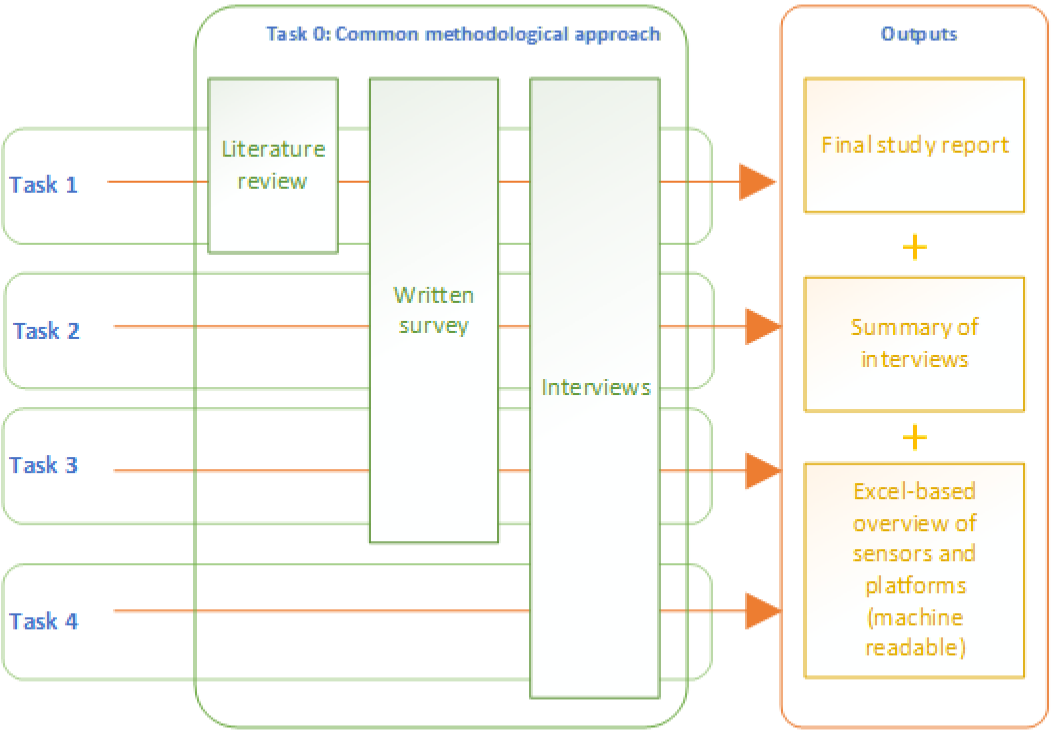

Figure 1 Overall approach

- Task 1: Specific objective 1: To summarise the present state of development of sensors and platforms for ocean observation.
- Task 2: Specific objective 2: To examine how the ocean observation market operates.
- Task 3: Specific objective 3: To investigate how enterprises offering ocean observation equipment and services finance their business.
- Task 4: Specific objective 4: To identify challenges and opportunities for a more widespread introduction of the new technologies for ocean observation in the EU.

2.2 Literature review

Under this task, the study team (a) searched for, and reviewed, the scientific literature on ocean observation to understand the state-of-the-art, and (b) reviewed documents and websites to populate the Excel-based overview of sensors and platforms.

To provide insight into the ocean observation markets and current trends therein, the existing body of literature on ocean observations was examined. Relevant literature was sought using Google Scholar. First, we performed searches on peer-reviewed papers and books within a 5-year period (2015-2020) with relevant keywords (e.g. ocean observation, monitoring, marine ecosystem monitoring). At this stage, only publications with a scope on reviewing a specific field were examined in depth (e.g. (Whitt et al. 2020) or (Lin and Yang 2020)). From this first round of literature search, further important publications, keywords and leads emerged, which were used in subsequent searches.

The desk research to populate the Excel-based overview of sensors and platforms has taken the following avenues:

- An investigation of Horizon 2020 projects featured on the project lists provided by EASME and DG MARE
- An investigation of all companies named in the 2016 Ocean Enterprise Study[1] and the continuously updated list US "Ocean Enterprise Study Companies"[2]
- An investigation of companies mentioned in the Hydro-International companies database[3]
- Additional sensors and platforms were identified, either through presentation at conferences, personal experiences of working with these technologies and social media.

In the case of the Horizon 2020 projects, the Cordis website[4] was used to check the purposes of the projects, and if necessary the website of the project was used as well. If projects developed new sensors or platforms, the project was further investigated and if identified, platforms and/or sensors were added to the Excel-based overview. In some cases the websites did not provide enough information on the state of development of sensors and platforms to fill in the proper detail in the Excel-based overview, in which case these were not added to the Excel-based overview.

To gain more information about turnover and research and development budgets the Orbis database of Bureau van Dijk[5] was used. In most cases the Orbis database provided information about turnover and number of employees, but little information about research and development budgets. The data on turnover and number of employees was

[1] https://ioos.noaa.gov/ocean-enterprise-study-companies/
[2] https://ioos.noaa.gov/ocean-enterprise-study-companies/
[3] https://www.hydro-international.com/companies
[4] https://cordis.europa.eu/
[5] https://www.bvdinfo.com/en-gb/

used to determine if the company is an SME and if so, under which label it can be categorised (micro, small or medium-sized). The following criteria were used in investigating companies by means of the Orbis database: the website or the headquarters address were used to assess if the company in question was the same as the one being searched; if a company had a maritime department this data was used; if a company had subsidiaries only the head data was used[6]; if it was unclear if the company in question was the one being searched (due to multiple companies having the same name), no data was used.

2.2.1 *Reflection on the method*

In carrying out this work, the following bottlenecks were encountered that influenced the Excel-based overview of sensors and platforms (included in Annex 1).

Collection and adding the details of all conventional (e.g. CTD) sensors to the Excel was time consuming and did not add much to answering the main questions of the project. In consultation with EASME/DG MARE it was decided that the Excel-based overview should focus on new sensors and trends.

It proved difficult to the find all the detailed information required to populate the Excel-based overview. As a solution to this bottleneck, the study team sent the survey (see next section) to producers of sensors and platforms to retrieve additional information. In addition to sending the survey we investigated the Orbis Database of Bureau van Dijk for usefulness. Data on companies in this database is not comparable between countries because the reporting requirements for companies vary per country. Furthermore, most companies are part of larger companies and the data presented is aggregated data; it is not only for the ocean observation activities but also for other sectors in which companies are active. This is not the case for smaller companies, but the problem here is that smaller companies are exempt from the obligation to deliver data due to their size. The cut-off point for which companies are obliged to provide data about their finances differs per country because countries have different regulations.

The focus of the investigation was on new and innovative sensors and platforms, with a specific focus on areas of ocean observation where a lot of progress can still be made. In the case when a company presented a product along with its successors, the newest product was given priority in the Excel-based overview. The Excel-based overview of sensors and platforms is not exhaustive. We cannot claim to have found all companies producing and developing sensors and platforms.

Where available, data on the type of sensors to be used with the platform is included. There is a trend in ocean observation technology for multi-sensor complex platforms to optimise the cost-benefit ratio and to have synchronised sensing. Still, little information on the compatibility of sensors and platforms is available.

[6] This due to the fact that for the majority of companies that have subsidiaries there was no data for the subsidiaries available.

2.3 Survey

A survey was created, which was verified and approved by the Commission. The survey was set up in English and based on the contractor's desk research in addition to the topics provided by the Commission.

The survey was conducted using Qualtrics™' survey tool[7] with the help of routing-enabled sections based on the four stakeholder groups (manufacturers of sensors, manufacturers of platforms, technology experts and market experts). However, the survey routing followed five categories, as desk research revealed the existence of organisations that manufacture both platforms and sensors. The five groups used for survey-routing were:

- Manufacturers of sensors to be deployed at sea
- Manufacturers of platforms to be deployed at sea
- Manufacturers of platforms and sensors to be deployed at sea
- Technology experts, including scientific researchers
- Market experts for sensor and platform technologies.

The survey was online from 2 December 2020 until 20 January 2021 and was distributed to targeted organisations, and published on the EMODnet[8] website. Over 100 organisations were contacted directly or through online channels for the survey. A total of 67 organisations initiated a response on the survey link, 43 organisations out of these managed to complete the survey in some capacity and provided information as requested in the survey. Figure 2 shows the reach-out summary of the survey, providing an overview of the sectors, geography and percentage distribution by expertise of the respondents. In addition, the size of the organisation, both in revenue (EUR) and number of employees is also included for respondents in the manufacturing category.

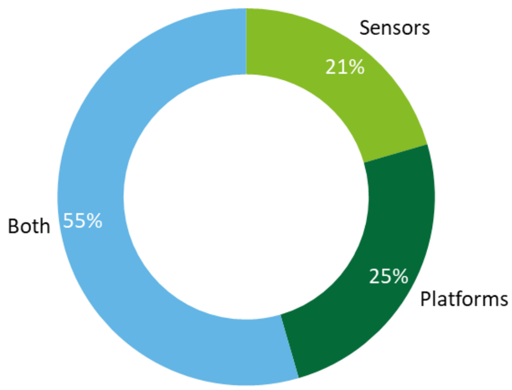

Figure 2 Survey respondents, by expertise

[7] https://www.qualtrics.com
[8] https://www.emodnet.eu/en

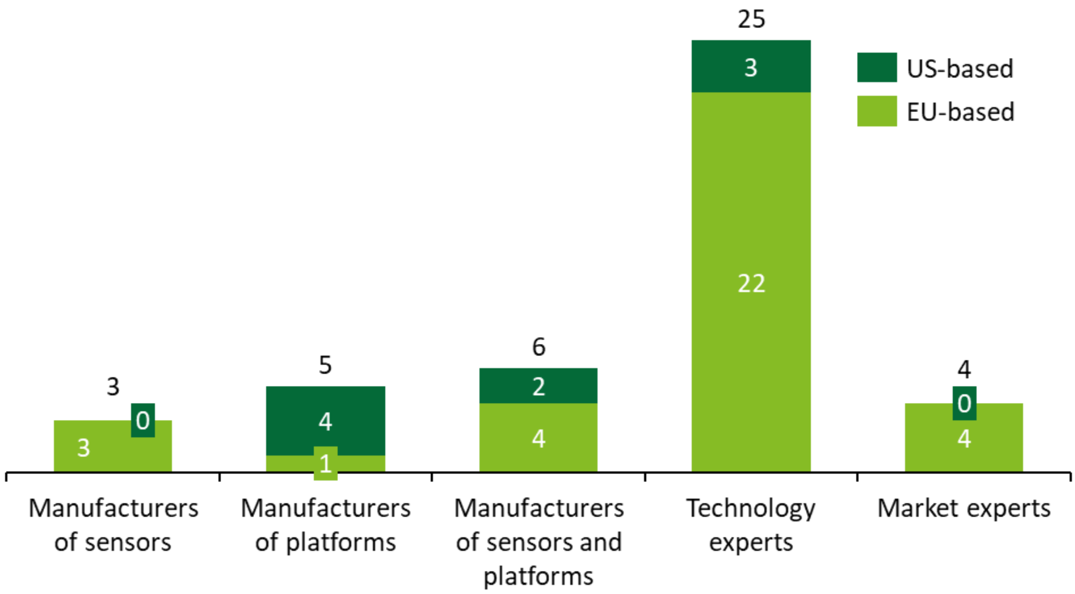

Figure 3 Survey respondents, by occupation and geography

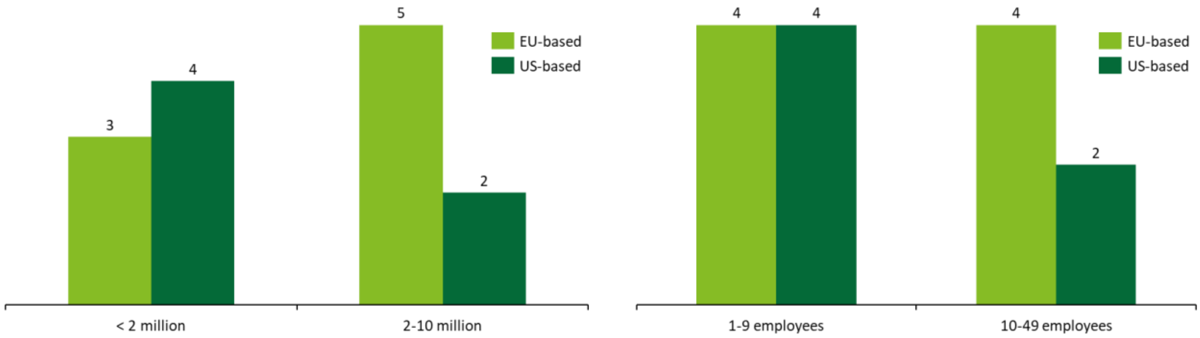

Figure 4 Manufacturers of ocean observation technologies by revenue (EUR) and number of employees

In addition to filling in the survey, many organisations attached their brochures and product catalogue documents. These documents were used to gain valuable product information to enrich sensor and platform level data in Task 1. A detailed reach-out summary has been added to the document as an Appendix 8.2.

2.3.1 *Reflection on the method*

The study team experienced difficulties with regards to response rates from the survey. Even after reaching out to stakeholders directly for the survey, the number of finished responses received is relatively low (43 respondents). The survey link was shared with industry associations, which can request their members to fill in the survey. Additionally, the link was hosted on EU platforms and social media platforms to increase the outreach. Bi-weekly reminders were sent to the participants that did not respond to the email with their willingness to participate.

2.4 Interviews

As stated in the inception stage of this study, two types of interviews were foreseen: exploratory interviews and structured interviews throughout the implementation period. The following sections present an overview from both categories of interviews.

2.4.1 *Exploratory interviews*

The exploratory interviews were conducted as part of the inception period to gain a deeper understanding of the most critical needs concerning ocean observation and the key technologies to conduct such activities, as well as the expectations for the study, and to identify relevant sources of evidence. In total four interviews were conducted, with:

- DG for Defence Industry and Space Unit C3 – Earth Observation (DEFIS.DDG.C.3)
- Representatives from ICES (International Council for the Exploration of the Sea) Advisory Committee
- Representatives from EuroGOOS
- Ifremer, Département Ressources Biologiques et Environnement (PDG-RBE).

2.4.2 *Structured interviews*

The main purpose of the structured interviews was to corroborate the findings of the literature review, and to collect supplementary evidence to fill any identified information gaps and feed into the answers to the study questions. During the implementation phase of the structured interviews, two methods were deployed to contact stakeholders; [1] interviewees were contacted thanks to contact details collected from EASME/the European Marine Board, and/or [2] people were contacted directly via email or telephone obtained from professional network mobilisation or snowballing.

Snowballing techniques involve asking a first respondent to name an organisation or person in a specific role within the organisation able to provide relevant answers for a defined stakeholder category and may be most useful at city-level. This method in particular has proved to be successful for private organisations outside of professional networks, while EU and national level contacts were obtained through from existing relationships and professional networks.

Initially a total of **50 structured interviews** were planned, covering all the key stakeholder groups involved in the development, marketing, financing and use of new technologies for ocean observation. As outlines, **38 interviews were conducted**. For more detailed information on the specific stakeholders which were contacted, see Section 8.1.

Table 1 Status of the interviews conducted

Stakeholder Category	Conducted
Public bodies: EU level	6
Public bodies: international level	4
Public bodies: national authorities	3
Research institutes (national level)	6
Hydrographic agencies	3
Research (EU/international level)	3
Environmental bodies & NGOs	2
Copernicus Marine Service Data Producers	1
Private sector: Technology providers and operators, including Small and Medium Enterprises (SMEs)	10
Totals	**38**

It is important to stress that if there was no initial response, two series of follow-up emails were sent to try and encourage participation. When this proved unfruitful, we tried to replace some of the initially foreseen interviewees with other interviews (first within their organisation, and otherwise beyond their organisation). Close collaboration with the Commission throughout this process enabled a number of additional interviewees to be contacted. As a result of these mitigation measures, **73 potential interviewees were contacted.**

The data gathered through interviews was summarised in individual interview reports after each interview. These are clearly labelled and follow the same format. The reports are placed into a zip file and sent alongside the final report rather than included in an Annex, because the interview notes are not to be published.

The data collected through interviews was analysed through pulling together findings from different stakeholders, highlighting trends and possible divergence between and within stakeholder groups. These results feed directly into the final study report, insofar as they provide evidence that is relevant for answering the study questions. As agreed during the kick-off meeting, summaries from the individual interviews will be shared with DG MARE/EASME (not for public use). Interviewees' names and organisations will be listed on these summaries as long as they have consented to the information being shared in writing, in line with GDPR requirements.

2.4.3 *Additional interviews with buyers of ocean observation technology*

Following feedback received in the meeting with the Steering Group (February 12, 2021), the study aimed to conduct additional interviews with buyers of ocean observation technologies, to get additional insight into some market-related questions. Questions included:

- What does your procurement process look like (incl. how is it published)?
- What motivated your choices for a particular platform and/or sensor?

- What is the origin of your suppliers?
- What is the origin of your funding?
- How do you assess new sensors/platforms upon market entry?

Following the suggestions provided by EASME/DG MARE, the study team reached out to various experts (see Table 2).

Table 2 Organisations approached for additional interviews

Organisation	Reply received	Relevance	Interview conducted
BODC	N	-	N
BSH	Y	Involved in MOCCA project	Y
Euro-Argo	Y	Late reply	N
Marine Institute Ireland	Y	High, buyer of technologies	Y
EMBRC	Y	Involved in biological monitoring, do not buy sensors	N
Atlantos	Y/N	Questions forwarded to colleague. No further response received.	N
Intaros	N	-	N
GEOMAR	Y	Coordinator of Eurosea project	Y

2.4.4 *Reflection on the method*

The study team experienced some difficulties with regards to the scheduling and conducting of interviews, but mitigating measures were taken, as described above.

The length of the interview guides also made it difficult (especially in the case of research organisations and data providers), to cover all relevant questions in the allotted time. At the scheduling stage, interviewees were given an indication of the time needed for the interview. When time was limited, the study team focused on a number of key questions. Interviewees were also sent the notes from their interview after the fact, giving them the opportunity to add any additional insights not covered as part of the interview itself.

3 TASK 1 PRESENT STATE OF DEVELOPMENT OF SENSORS AND PLATFORMS

The purpose of this task is to deliver an overview of the present state of development of sensors and platforms. The overview of ocean sensors and platforms is available in tabular form (see Annex 1). The initial review of scientific literature pointed out the background and context of the development state. This literature review is supplemented with information from the online surveys and interviews with key informants (both representatives from research institutes as well as significant operators in the private sector). The collected information provides insights into the background, context, and current situation of the development state of sensors and platforms, through (a) quantitative analysis of the Excel-based overview of sensors and platform and (b) qualitative analysis of the state-of-the-art and current challenges in ocean observation.

3.1 Quantitative analysis

The Excel-based overview of sensors, platforms and manufacturers is presented in Annex 1. In this section we provide an analysis of these overview of sensors, platforms and manufacturers.

3.1.1 *Sensors*

In this study a total of 119 sensors have been identified, produced across ten countries by 89 different manufacturers. Figure 5 visualises the number of sensors identified per country of manufacturer. Figure 6 shows the distribution of parameters measures across the sensors.

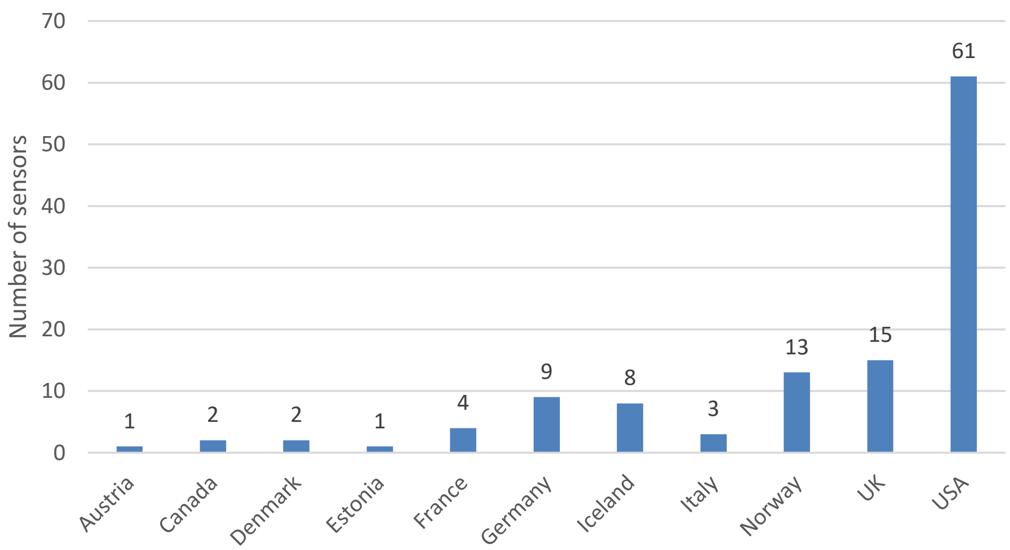

Figure 5 Manufacturers per country

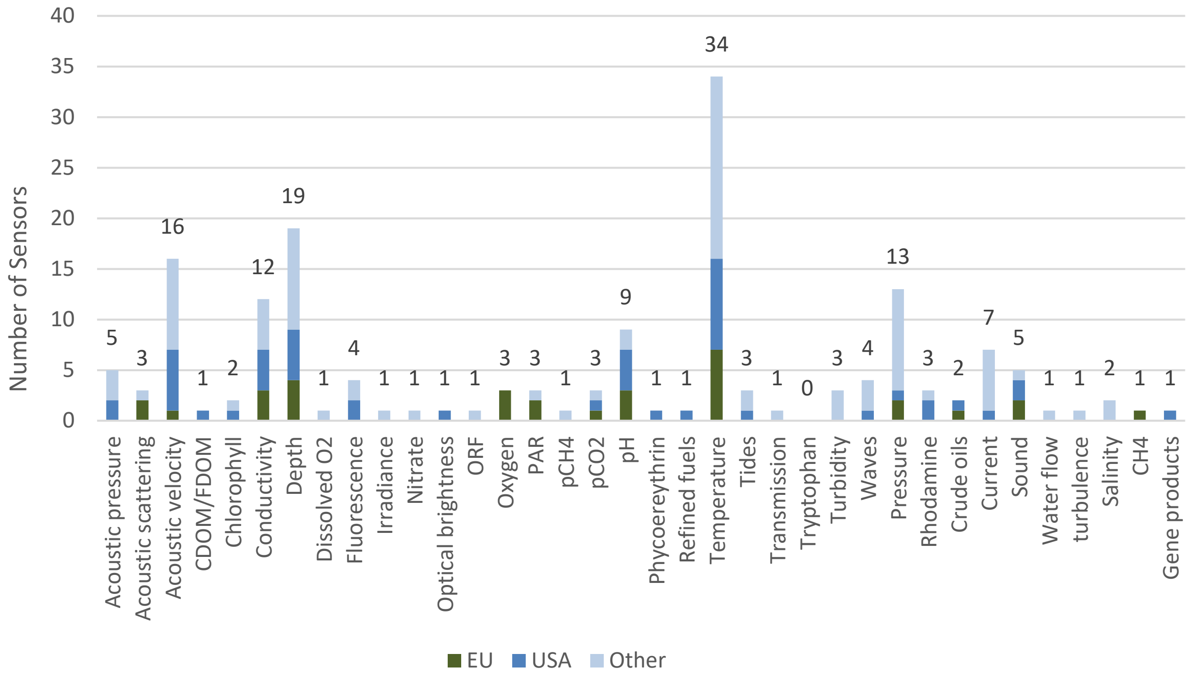

Figure 6 Parameter measured by amount of sensors, differences per region indicated

The data collected on other sensor characteristics is summarised in Table 3 below.

Table 3 Further analysis of sensors

Characteristics	Results	
Mounted or self-contained	Mounted	46
	Self-contained	32
	Unknown	41
TRL	TRL 6	1
	TRL 9	71
	Not specified	47
Place of deployment	Specified per in Excel-based overview if this information was available.	
Type of observation	Specified in Excel-based overview if this information was available. Categorised as: Physical, Biological, Meteorological and Chemical. Also see Figure 6 (Parameters measure).	
Time into development	Limited or no information was available	
Development costs	Limited or no information was available	
Price	Limited or no Information was available.	
Market volume	Limited or no Information was available.	
Operational Depth	Specified when information was available.	

Powering Type	Specified in Excel-based overview if this information was available. Categorised as: vessel powered, battery powered, cable powered, lithium-Ion battery,
Power Requirements	Specified in the Excel-based overview.
Frequency of measurement	Specified in Excel when information was available.
Maintenance	Limited or no information was available.

3.1.2 *Platforms*

In this study, a total of 116 different platforms have been identified, spanning various countries and types of platforms. Figure 7 shows the number of platforms identified per country of manufacturer.

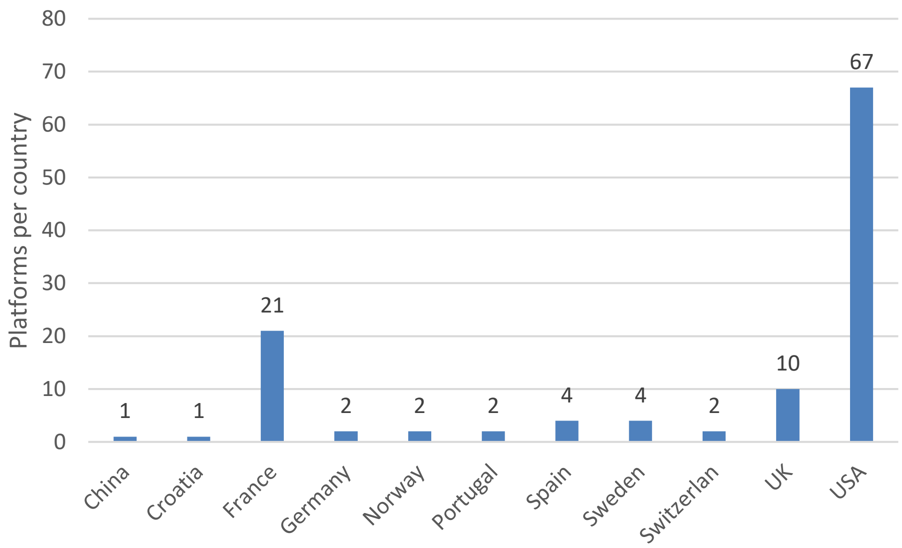

Figure 7 Distribution of platforms per country of manufacturer

Various types of platforms are identified, including probes, gliders, floats, drifters, autonomous surface vehicles, sleds, autonomous underwater vehicles and buoys. The distribution of identified platforms over these categories is shown in Figure 8.

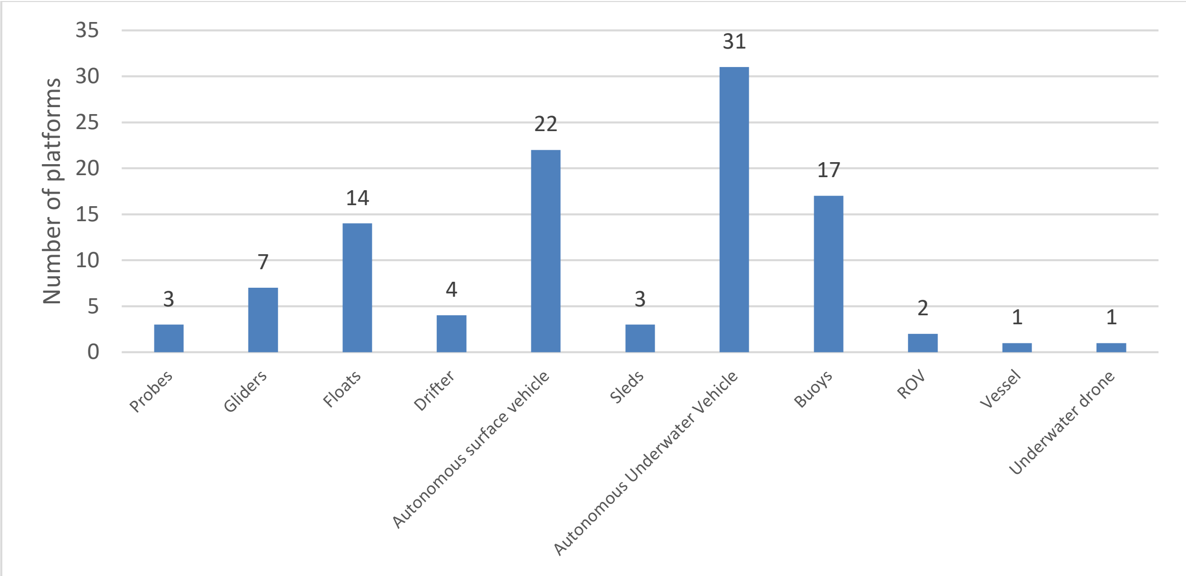

Figure 8 Types of platforms

The platforms identified are deployed from ships (42), ship or shore (8), shore (5) or airplane (1). See Figure 8.

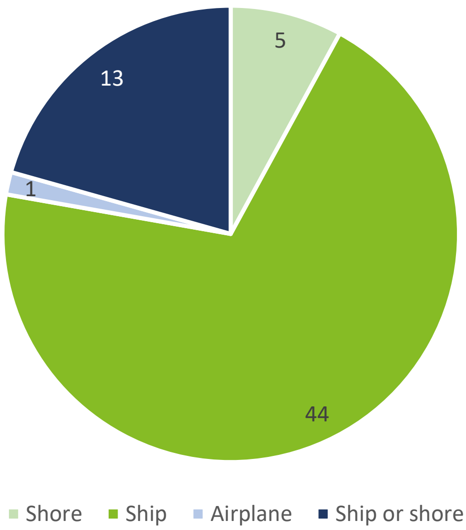

Figure 9 Means of deployment of platform

The platforms identified have different operational depths, as shown in Figure 9.

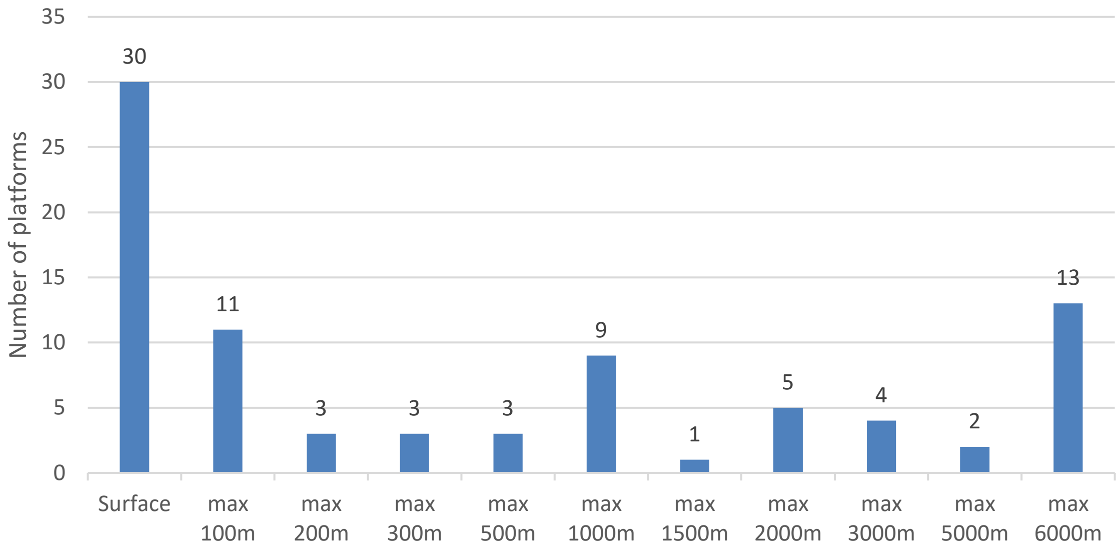

Figure 10 Operational depths of platforms identified

The Excel-based overview of platforms provides some additional information, characterising the development and functioning of these platforms. It must be noted that for various parameters, limited to no data was available from public data sources, nor was the info provided in survey responses. An analysis of data provided is presented below in Table 4.

Table 4 Further analysis of platforms

Characteristics	Results	
Fixed or movable	Fixed	15/116
	Movable	92/116
TRL	TRL2	1/116
	TRL5	5/116
	TRL9	88/116
Time into development	Limited to no data was available	
Development costs	Limited to no data was available	
Price	Limited to no data was available	
Sold/lease	Limited to no data was available	
Market volume	Limited to no data was available	
Geographical market coverage	Global market coverage	42/42
Powering type	Diversity of power types is reported	
Power requirements	Diversity of power requirements is reported	
Propulsion type	Diversity of propulsion types is reported	
Autonomy	Autonomy ranges from a few hours to 4 years.	

Range	Identified range varies from 20m to 72 km
Speed	Diverse speeds reported.
Communication means	Various communication means are used
Payload requirements (weight)	Varies from 4.5 kg to 150 kg
Payload required (power)	Limited data available
Maintenance interval	Ranging from 6-8 hours to 4.5 years
Maintenance costs per interval	No data available
Intended markets	Limited data available
Type of sensors used on platform	Detailed information is presented in Excel-based overview

3.1.3 *Manufacturers*

A total of 89 companies were identified. Figure 11 shows the number of companies with headquarters in the EU, the USA or other.

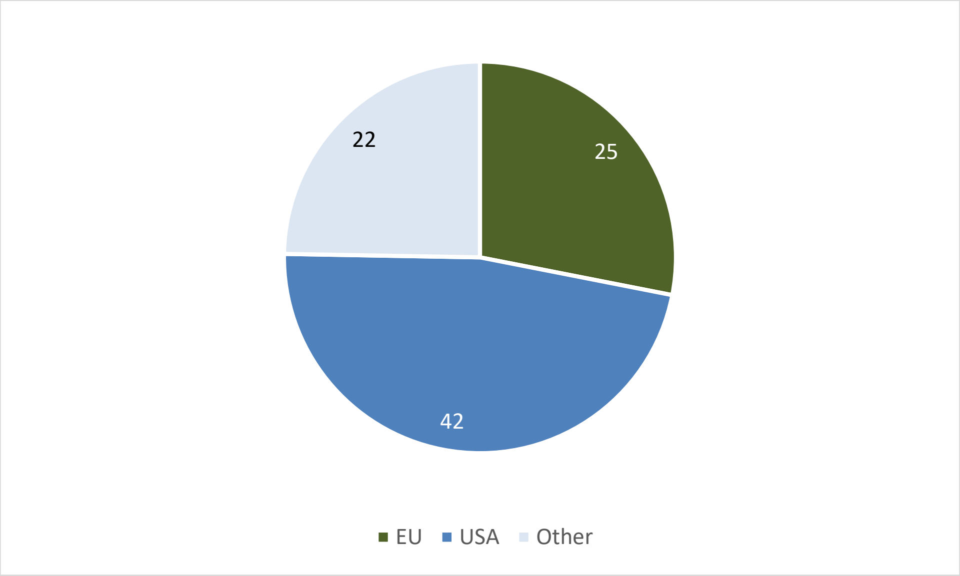

Figure 11 Country of headquarters

Figure 12 below specifies country of origin for the 24 companies from within the EU, indicating the amount of companies per country.

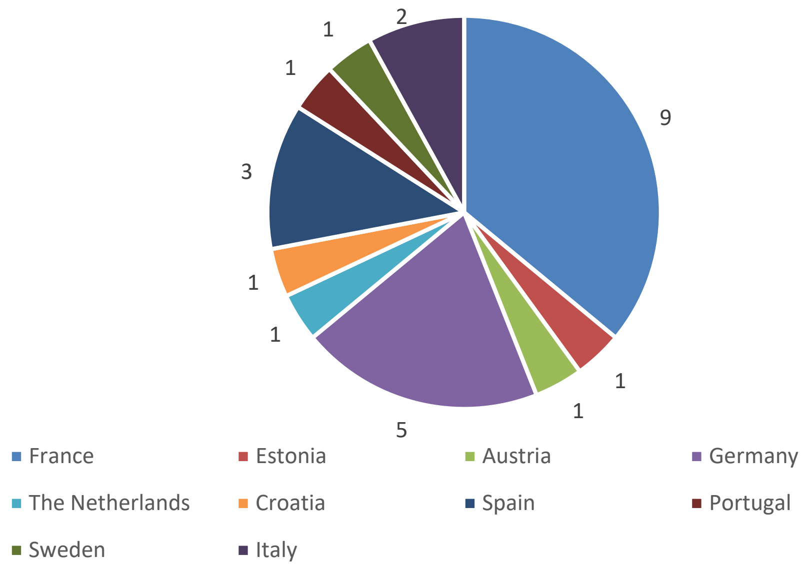

Figure 12 Country of headquarters of EU companies

3.2 Qualitative analysis of the state-of-the-art

3.2.1 *Overall developments in technology*

Ocean observations are paramount in the understanding of ocean dynamics but are expensive. Ocean observation takes place in the harsh and vast oceanic environment, posing challenges to the robustness of sensors and platforms. The technologies used are custom-made and require extensive testing. Furthermore, in this field, deployment of platforms and sensors can be resource demanding. Generally, technological development in the field of ocean observations has benefited from the development of large or lucrative markets but also champions bringing disruptive innovations (Curtin and Belcher 2008).

Observations consist of surface and sub-surface measurements that can be conducted in-situ (e.g. ships, drift buoys, gliders, drones, moorings) or remotely (e.g. satellite, aircraft, radar). The current study focuses solely on in-situ monitoring. Ocean observations can be classified based on the following variables (Venkatesan et al. 2018): physical, biological, meteorological and chemical. When considering ocean observations, there is the ability to record variables, i.e. sensors and the platforms on which they are embedded. Whilst both are intertwined, it is useful to consider them separately as there are challenges specific to each.

Across the range of ocean variables, monitoring at high temporal and spatial resolutions is generally a challenge in ocean observations for the different types of variables and platforms (Lin and Yang 2020). Whilst the need for temporal and spatial resolution is dictated by each individual monitoring, this is limited by allocated resources and factors such as turbulent weather regions/seasons, technical mortality of sensors or operating in depth. Even for well-established technologies like the global Argo float array, future prospects consist of expanding coverage to better understand ocean dynamics with larger and longer deployments (e.g. marginal seas or seasonal ice-zone), possibly at greater depths (Riser et al. 2016). Working at large depths (so called "depth sea") is particularly challenging and demands progress in research (Rogers et al. 2015), making it an important axis of development in ocean observation technologies in future years. The use of animal-borne instruments is also an interesting prospect for improved data resolution (March et al. 2020). It is important to note that the advances of existing observing systems have sometime been constrained by flat funding and limited cooperation among present users (Lin and Yang 2020).

Alongside the development of new technologies, there is a push towards the integration of a wide range of data sources for monitoring using networks of sensors as opposed to solitary measurements. This also includes the integration of past and existing data sets. The drive for more data integration should foster larger collaborations (Kaiser et al. 2019; Gawarkiewicz and Malek Mercer 2019). Moreover, with such an expansion in data volume, tools to handle large data flows and data management frameworks need to be in place. The European Commission strives for larger cooperation within the sector to build innovative, analytical frameworks and information services. The improved infrastructure should better handle the large data flows. Within the European Horizon 2020 programme, multiple projects are designed to tackle these issues.

Of the stakeholders contacted through the interviews that actively purchase and deploy ocean observation technologies[9] (25 stakeholders), the majority (19 out of 25) responded that overall progress has been made to date regarding the development and uptake of new technology. In particular, many of the stakeholders noted that in the past 10 years, there has been a sustained and exponential increase in technology development and use.

When asked what the key driving forces are behind this progress, multiple responses were provided. One of the most salient drivers was the increase in climate and environmental awareness in the past 10 years. In many respects, this driver has the greatest impact on the development of technologies as it has the potential to impact almost all parts of the technological value chain, from research through to commercialisation and data analysis. The rise in the climate change agenda at the societal level has on the one hand pushed researchers to try and answer greater questions regarding the natural changes in the oceans, while on the other hand provided more market opportunities for technology providers and operators. It is also important to note the impact at the governmental and political level, with greater societal awareness and pressure, providing a mandate for national governments to invest further in oceanographic research.

In addition to this, it was also emphasised that a key driver is the need for accurate and useful data. This driver was also said to have two key sub-drivers or needs that have also pushed development, namely the need for cheaper and reliable technologies. These two sub-drivers are crucial for the amount and accuracy of data being collected. For instance, cheaper technologies allowed the collection of data to be more accessible while the reliability of technologies further enables long time-series data to be collected.

To gain a better understanding of how EU projects funded through programmes like H2020 bring technological developments to the market, 20 finished projects that had aimed to develop new technology were contacted to ask if and how they had brought the developed technology to the market. Out of these 20 that were contacted, 2 projects responded.[10] Both projects cooperated with companies and end-users in their consortium: in one case the partners exited the market at the end of the projects and experienced lack of funding. The other project presented the technology to the commercial market place and in response to requests for quotes. No further comment was given in the responses as to how to ameliorate barriers and bottlenecks.

[9] This includes research institutes, hydrographic agencies, environmental bodies and private technology providers and operators (including SMEs). It should be noted that EU and international level stakeholders were not asked specific questions on the development of ocean observation technologies.

[10] This is a low response, but the query was made in response to questions posed during the final meeting between the contractor and DG MARE and EASME. Hence there was little time for project leaders to react.

3.2.2 *Key developments*

A by-product associated with the collection of data at increased temporal and spatial resolution is the increase in data volume. There are bottlenecks associated with relatively high costs of telecom but independent developments in this field will necessarily benefit ocean observations in the future. Another axis for development with communications is underwater communications, which is paramount in the context of increased use of network of sensors and platforms and coordinated surveys from autonomous systems such as AUVs and gliders (Ali et al. 2020). Also, the capacity for data analysis has not progressed comparatively and the growing discrepancy is becoming a major bottleneck for effective use of the available data, as well as an obstacle to scaling up data collection further. Moreover, large data volumes and the needs for scientific collaborations require adopting common frameworks for data management for open, secure and free data access (Crise et al. 2018; Wilkinson et al. 2016).

In that context, advances in Artificial Intelligence (AI) will be central to data processing (Malde et al. 2020) and data collection. Example uses of AI technologies include navigation and swarm collaboration for autonomous vehicles, big data processing (e.g. pattern recognition or automatic processing). With respect to the collection of data, it was further noted by interviewees from research organisations that one major expectation from AI technology will be its ability to reduce the need for the physical collection of data (i.e. through research vessels) and instead transmit data to a centralised data point. In addition, it was also noted that AI technology will be crucial in reducing the need for technology to be maintained, for example through self-recalibration and the cleaning of lenses. The European Commission identified the importance of AI as well. Within the European programme Horizon 2020, several projects focusing on AI, but also on machine learning, reinforcement learning, and Internet of Things (IoT), were launched over the last couple of years.

Autonomous vehicles (UAV, USV) and observatories have been used for decades to probe the ocean but their use is now widespread in ocean observations (Leonard 2016; Howe, Duennebier, and Lukas 2015; Chai et al. 2020; Whitt et al. 2020) but also environment assessment, e.g. in the field of oil and gas (Jones et al. 2019). One of the main future trends in autonomous vehicles is the cooperative network of platforms across a wide range of vehicle types. This will require development in guidance techniques and dealing with environmental disturbances (Liu et al. 2016), e.g. using future advances in AI methods. Technological advances in communication technologies (Ali et al. 2020) and docking technologies (Li et al. 2015) are also necessary for effectively building platform networks and operational coverage.

Similar to the literature review, results from the interviews with research institutes, hydrographic agencies, environmental bodies and private technology providers and operators highlighted that the most salient technological development was the area of autonomous observations with the use of gliders and autonomous surface vehicles. In terms of observing platforms, it was perceived that at the EU level it has been positive, but not widespread. However, many of the interviewees were of the view that it is an emerging field and were optimistic for future development.

The ease of use of autonomous platforms is dependent on the ocean variable that is being probed. Whilst physical variables can be measured effectively from autonomous platforms (Whitt et al. 2020; Daniel, Manley, and Trenaman 2011; Liu et al. 2016), the monitoring of biological and chemical variables is emerging (Chai et al. 2020; Meinig et al. 2019). This is partly due to the level of complexity of the probed variable. For example, the monitoring of biological variables such as fish biomass is most often performed using ship-borne surveys but the use of autonomous vehicles has shown great prospects (De Robertis et al. 2019; Meinig et al. 2019).

For the probing of biological variables, recent advances in environmental DNA (eDNA) yield very large potential for the understanding of ocean biodiversity. This technology consists of the DNA sequencing of environmental samples to potentially detect the presence of individual species. In the current technological state of eDNA, there is a need to improve and standardise sampling methods and instruments but also scale data handling and processing accordingly (Garlapati et al. 2019). Moreover, the use of eDNA is mostly limited to ex-situ analysis of samples. Only few studies have attempted autonomous monitoring of eDNA (Hansen et al. 2020). Such autonomous monitoring might expand in the future but will require further testing of autonomous samplers (Preston et al. 2011; Scholin et al. 2009) and advances in eDNA methodologies.

Alongside advances in sensors and methods such as eDNA monitoring, the more widespread use of autonomous vehicles will benefit the monitoring of chemical variables. For example, biochemical processes are difficult to sample in the ocean which affects both the observational sampling strategy and the representativeness of sparse measurements in data assimilation models (Stanev et al. 2017; Schaeffer et al. 2016).

3.2.3 *Key gaps in development*

The topic of the collection of biogeochemical data was raised by all interviewed stakeholders as an area that is developing at a slower rate compared to other comparable collection techniques. In particular, it was mentioned by one research institute that there is a general lag in being able to consistently measure variables such as temperature and salinity through water sampling. However, this was caveated as something which will continue to advance over time. Stakeholders also noted that there are many research programmes that are trying to make advances in this field, although they primarily rely on instrumentation that both works, and reliably collects data in-situ. Many of the stakeholders also acknowledged that while sensors that examine chemical and biological aspects are lagging behind, this lag is often due to these technologies being more expensive in comparison to other available sensors. Thus, the lack of available funding of this type of technology, data and analysis can be a major constraint to more widespread application.

The use of acoustic waves is the most effective monitoring means underwater and it is part of most ocean observations. There is ongoing development of new acoustics technologies for both passive and active acoustics. For active acoustics, this includes larger sampling of the water column through multi-beam and multi-frequency sensors (Chu 2011; Korneliussen et al. 2009). Passive acoustics is somewhat more established but reliable measurements of variables such as acoustic particle motion is still a growing field. More importantly, a driver of acoustic technological developments is the utilisation of these technologies, which is constantly evolving with the increasing need to sample larger portions of the water column at larger sampling rates to better understand complex ecosystems and biological variables (e.g. fisheries, gas seepage).

At a broader level, another key gap which was identified by stakeholders was the general reliability of technology and the quality of data it produces. In particular, several private technology providers and operators highlighted that sensor development remains a persistent gap in terms of reliability and flexibility to operate across different platforms.

Similarly, there is also a gap in the ability to transfer large amounts of data back to the platforms, along with a general lack of expertise to analyse and present the data in a meaningful way, thus undermining the significance of the data which has been collected.

While several technological gaps were raised, it is also important to highlight that all of the interviewed stakeholders noted that the lack of cooperation on the use and development of technologies is a major restraint. In particular, it was highlighted by several research institutions that there is no clear commonality across Member States as to what constitutes ocean observation. For example, in some Member States, the mapping of the seabed is listed as one of the key objectives, although this is not widely considered as "classical" ocean observation. Instead, other Member States are conducting more widespread tests using sampling vessels to monitor biological and chemical changes in the ocean. A major issue resulting from this uncoordinated approach is that it can create inefficiencies. For example, some institutes send out only one or two sensors into the ocean to measure just one parameter without measuring other important ocean parameters.

In many respects, a major factor limiting a more coordinated approach across Europe is the difference in the level of importance that national governments place on the need to push development in ocean observation technologies and the collection of data across a variety of parameters. In particular, stakeholders from countries in the south-eastern part of Europe (Greece and Bulgaria), noted that the lack of investment in marine research had a direct impact on their capacity to invest in new technologies and collect data efficiently. This is contrary to countries such as Germany, France, Denmark, the Netherlands, Norway and the UK, which were noted to have greater governmental mandates to gather data from ocean observations, thus pushing the development of new technologies. Despite this, however, all interviewees noted that irrespective of the national level funding that is available, the lack of international cooperation and the sharing of information and data is limiting the potential of both ocean observations technology and the data it gathers. Thus, it was highlighted that there needed to be more opportunities for there to be a continual dialogue between researchers and developers on what technology and data is readily available (see Section 6.1 for further analysis).

3.2.4 *Expectations for the next five years of development*

Similar to the recent developments highlighted in the literature review, the main capability that was expected in the next five years by stakeholders was the increase in autonomous technologies. Other key developments that were expected included a rise in the use of Artificial Intelligence (AI), AUVs (Autonomous Underwater Vehicles) and USVs (Unmanned Surface Vehicles), ROVs, multi-spectral sensors, swarm robotics systems,[11] bathymetry systems and biological sensors to monitor parameters such as eDNA, harmful algae bloom, fish populations and migration patterns.[12] With respect to the use of AI in technology, it was noted that AI could be particularly influential in swarm robotics systems, for example through micro-UAVs, or alternate fleets through seabed surveying or acoustic fisheries surveying.[13]

[11] For example: http://www.swarms.eu/ or https://marine.jacobs-university.de/j/index.php/projects/11-tic-auv
[12] For example also see: https://aquavitaeproject.eu/expected-results/
[13] For example: https://cordis.europa.eu/project/id/893089 (no project website yet)

In addition to the specific technological developments it was also anticipated by stakeholders that there would be improvements in the reliability of the technologies (particularly in battery life) and in the quality of data produced.

Moreover, investments of the European Commission will boost the technological development by European stakeholders. In the coming years, different H2020 projects are due to focus on newly developed data methodologies in which the availability and accessibility of data will be improved. An improved data infrastructure will create more synergy within the blue economy sector in the EU.

4 TASK 2. THE MARKET

4.1 What is the size of the current or present market?

Based on the literature review, the ocean observation market can be characterised as a diverse market, spanning annual observations to the benefit of global research efforts and local observation to the benefit of industries. The field of ocean observation includes both complex multi-annual programmes such as GOOS and IOOS, using newly developed sensors and platforms, as well as the application of widely-established CTD sensors. The study has identified a total of 89 manufacturers. Some companies are exclusively dedicated to ocean observation, for others ocean observation is part of their portfolio of maritime activities (see e.g. Fugro and Kongsberg).

A single number on the size of the ocean observation market cannot be given. However, two market studies have estimated the market for sensors, underwater drones and sonar. A brief summary of those reports is presented in Table 5.

Table 5 Key findings from market study reports on size of the market

Report	Main findings	References to ocean observation
Global Sensors Market (2020-2015) by Mordor Intelligence	The global sensor market was valued at USD 77.16 billion in 2019, and is expected to reach USD 128.56 billion by 2025, registering a CAGR of 8.86%, during the period of 2020-2025. By end-user industry, the consumer electronics segment accounted for the largest share of 48.2% in 2019. The demand in this segment has been augmented by wearable and mobile devices driving the market. The automotive segment followed as second largest market with a share of 19.6% in 2019. Healthcare is projected to grow at a CAGR of 10.0%, which is the fastest growth in the end-user segment.	Reference of Chinese deployment of a fleet of underwater drones in the Indian Ocean in December 2019. Sensors measured seawater salinity, temperature, turbidity, chlorophyll, and oxygen levels. In August 2019, MIT developed a new underwater sensor and communication system that neither requires batteries nor uses power. This could help set up an underwater IoT, which would allow for real-time sea temperature and marine life monitoring. Key vendor profiles include Sensata Technologies, active in the marine sector.
Underwater Drones Market (December 2020), Allies Market Research	The global underwater drone market was valued at USD 3,598.70 million in 2019, and is projected to reach USD 7,391.10 million by 2027, registering a CAGR of 11.7%.	Underwater drones are being increasingly used in offshore oil & gas exploration activities across the world. Offshore oil & gas production accounts for a major share in the

	North America was the highest revenue contributor, accounting for USD 1,227.88 million in 2019, and is estimated to reach USD 2,416.89 million by 2027, with a CAGR of 11.3%. Europe and Asia Pacific collectively accounted for around 55.8% share in 2019, with the former constituting around 30.6% share. Asia-Pacific and LAMEA are expected to witness considerable CAGRs of 12.8% and 11%, respectively, during the forecast period. The cumulative share of these two segments was 35.3% in 2019, and is anticipated to reach 36.5% by 2027.	overall oil & gas production, and underwater drones with the capability of diving thousands of meters underwater, equipped with cameras, sensors, manipulator arms, and other payloads offer great benefits over traditionally deployed human divers and ships. The significant factors impacting the growth of the global underwater drones market includes a rise in demand for underwater drones for defence and security applications and an increase in the adoption of underwater drones by developing countries. However, the global underwater drones market has also been affected by factors such as communication problems associated with AUVs, rising deep-water offshore oil & gas exploration and the advent of energy-efficient underwater drones.

A key market-related element covered in the survey was the potential growth in demand of the technology sectors in the next 5 years. Based on the responses received, Energy is considered the sector with highest growth potential by EU respondents, followed by Oceanography, Civil Engineering and Oil and gas with equal importance. The US-based respondents considered Oceanography as the sector with highest growth potential, followed by Defence, Fisheries and Energy sectors. Fisheries as a sector was not indicated by EU respondents and Oil and Gas was absent from the US-based firms as a potential growth area.

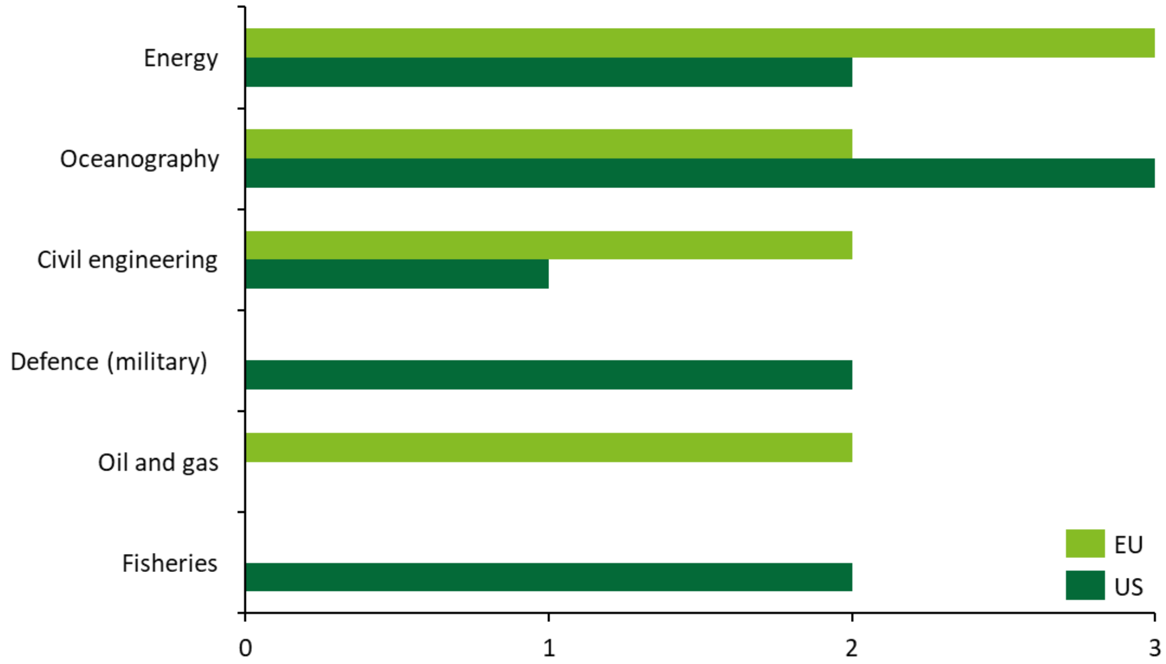

Figure 13 Sectors with increasing demand for ocean observation technologies, next 5 years

In addition to looking at the sectors, the survey also explored the growth potential of geographical regions in the next 5 years. Figure 14 shows the distribution of responses received. Both the EU and US respondents indicated that Europe, the Middle East and Africa (EMEA) are regions with one of the highest growth potentials. The EU-based respondents further indicated that North America (NA) and Asia Pacific (APAC) are high potential markets. Latin America (LATAM) is mentioned least often as potential growth market by EU-based respondents. The US-based respondents indicated that the domestic market has one of the highest growth potentials while APAC and LATAM were also indicated as having a high growth potential. This outcome shows a high perceived confidence in the respective domestic demand for the next 5 years.

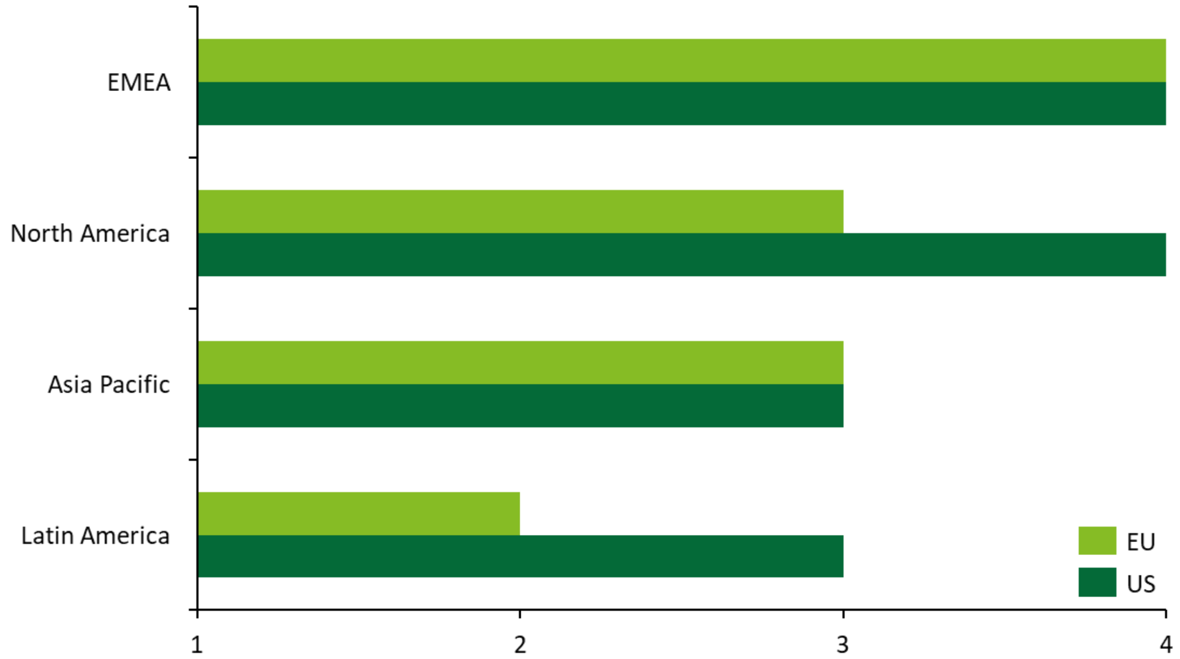

Figure 14 Regions with highest market growth potential, next 5 years

Apart from the areas of growth, looking at both sectors and geographies, the survey explored the topic of the rate of future growth of the Ocean Observation market with respect to its current pace. Of the few respondents that submitted their answers, the overall perception towards rate of growth was anticipated to be slower. Although the survey does not capture a clear reason for this sentiment, the impact of COVID-19 could likely be one of the reasons.

From the interviews, there was general agreement across all stakeholders that the current size of the market is growing, with a notable increase in the number of companies and services available. Over the past five to ten years, there have been a few very established companies that have developed a reputation which people rely on when purchasing technologies. In addition, there has been an increase in the market from the same technology types. For example, in the case of an ADCP current profiler, where there used to be only two to three different types on the market there are now around ten or fifteen different types.

A main reason the market has grown in the manner it has in the past 10 years is that the market has become increasingly global, with the number of technology providers increasing along with the growing demand for data. Interesting, however, is that while many of the stakeholders acknowledge that the market is growing, they also note that it is becoming increasingly polarised. This polarisation is observed between large and well-established companies and SMEs that are entering the market. In particular, it was noted by large private technology providers and operators that the market share for their businesses has grown, primarily due to buyers being more confident with well-established companies producing a wide variety of technologies. This is compared to emerging SMEs in the market which commonly produce very specific technologies. Therefore, smaller companies can have difficulties accessing the market.

More generally, despite the growth in the market, issues surrounding its size still persist. One issue that was highlighted was that although the number of players in the market has increased slightly, it is still far behind the needs of the sector. A further example was given with respect to gliders where there are two or three different types that you can purchase with only one or two companies to purchase from. So, in this respect, the market is not particularly big.

Indeed, this caveat was provided by a number of stakeholders who said that, historically, the size of the market for ocean observation technologically has never been large, thus giving rise to several companies that are able capture and meet the needs of the market.

Similar to projects for developments in technological development, the majority of interviewed stakeholders were also of the view that the market will continue to expand and mature over time. Some stakeholders noted in particular that this expansion of the market will be a result of increasing international engagement on ocean protection (for example from the UN sustainable development goals), the Green Deal in Europe and by the development of commercial activities (for example through marine renewable energy; aquaculture; green shipping).

4.2 How is technology used throughout the market?

The data from the review of sensors and platforms provides little insight into the envisioned use of the sensors and platforms. The foreseen market application of sensors is identifiable for 15 out of 119 sensors and includes fish surveys, coastal surveys, marine mammal monitoring, noise monitoring and environmental monitoring. The foreseen market application of platforms is only identifiable for 4/116 platforms.

The data collected through the survey shows the key geographical markets of the respondents' primary technology. It is important to note that the response below is based on the markets of operation of the products. In the results presented below, respondents indicated European, Middle East and Africa (EMEA) to be the primary market, followed closely by North America and Asia Pacific (APAC). It can be seen that APAC is seen as an important market by EU producers. Latin America (LATAM) as an important market has been highlighted by US producers, although it was mentioned by the fewest number of respondents as the current key market for their primary technology.

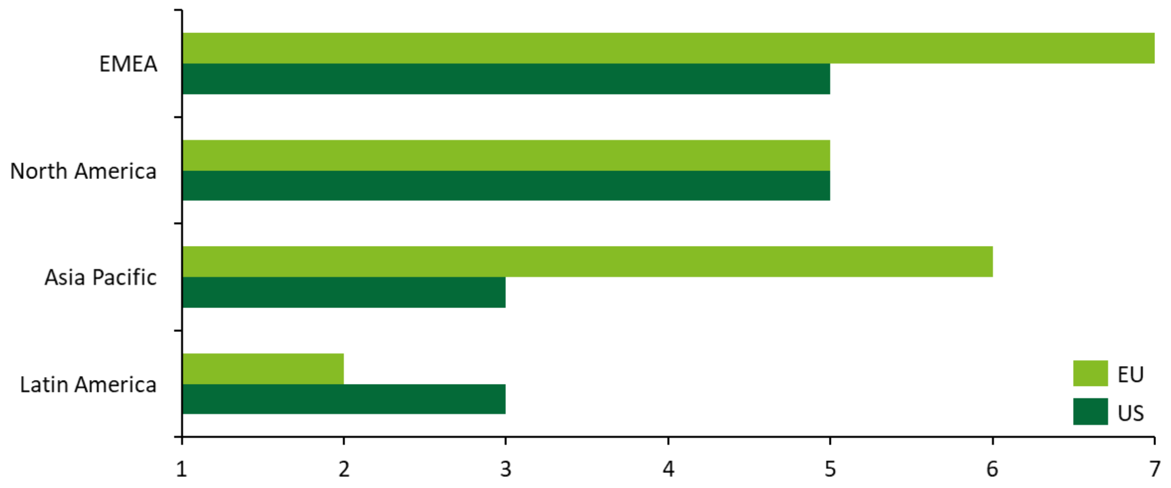

Figure 15 Key geographical markets for sensors and platform manufacturers

Based on the question on ownership and business case in the survey, a picture emerges of a sector where the technology is owned by private sectors with a key customer base in both public and private organisations. The survey captured the inputs of major buyers for both the platform and sensor technologies. As can be seen from the figures below, the predominant sales model indicated is Business to Business (B2B) with only one respondent indicating Direct to Consumer (D2C) services. The procurement model for both the sensors and platform technology is a pure sales model with no organisation indicating any kind of leasing services. This is true for both the EU and US respondents. More details on the procurement process is provided in the next section.

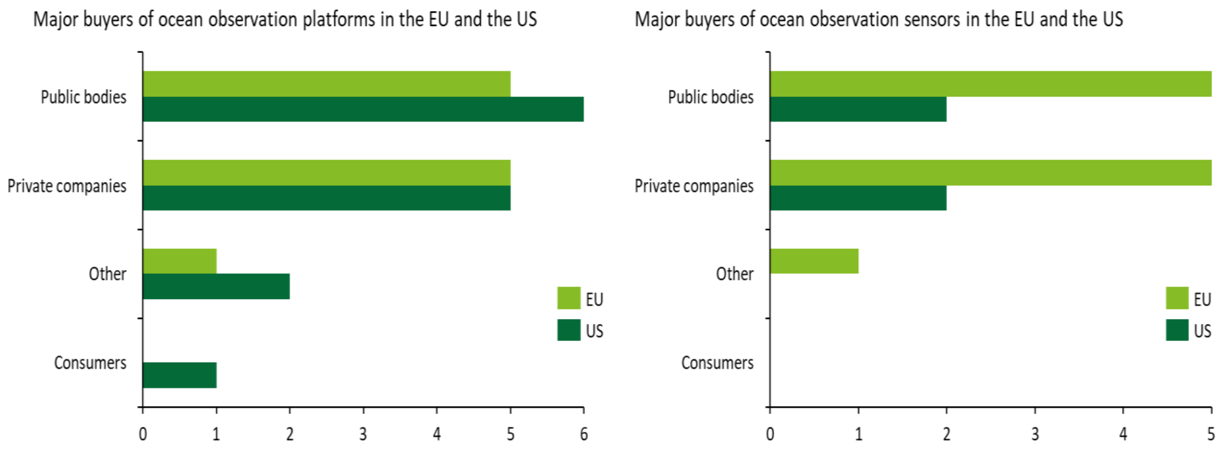

Figure 16 Major buyers for sensors and platform technologies

In addition to exploring the key customers and the procurement model, the survey was used to gain insights on the Technology Readiness Level (TRL). The TRL level helps to understand the stage of maturity of the technology. Since the survey explicitly asked for the TRL of the primary technology, it can be used as a predictor of the maturity of the organisation. A higher TRL number will indicate the primary technology is closer to implementation, and hence an established organisation, whereas a lower TRL number could potentially mean the organisation is in a start-up or concept phase.

Figure 16 indicates the summary of responses for manufacturers of platform technologies. The largest share of the respondents, both from US and EU, indicated TRL9; System proven in operational environment. This indicates that the technology is mature and proven. The majority of the responses are skewed towards the bottom of the figure with only one EU platform manufacturer indicating TRL1.

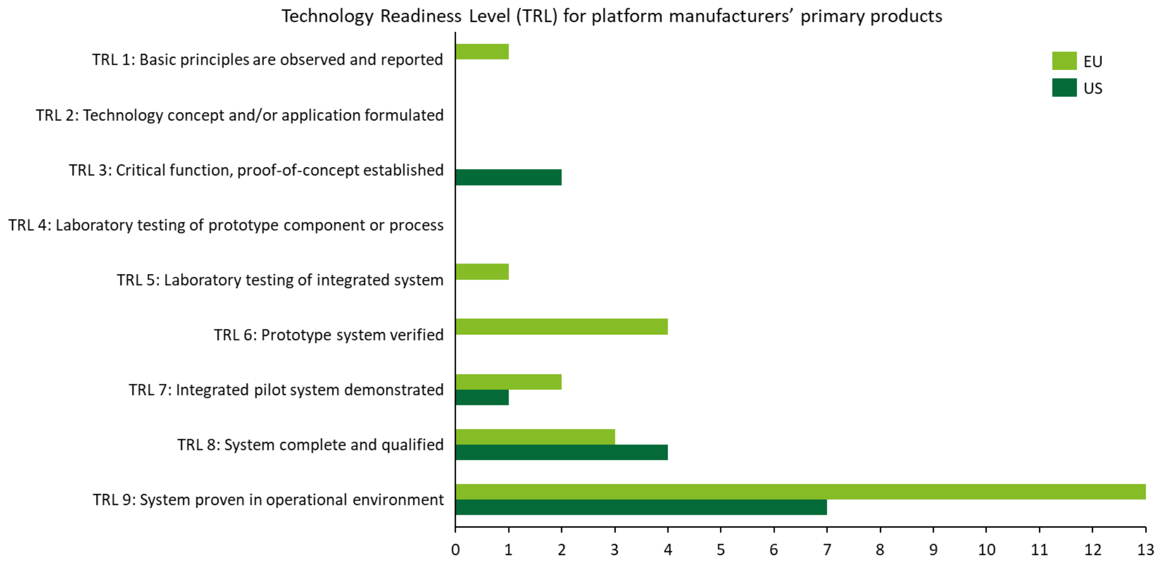

Figure 17 Technology Readiness Level (TRL) for platform manufacturer's primary technology

Similar to the platform technologies, the responses received from manufacturers of sensor technologies are also skewed towards the lower half of the figure, indicating a higher maturity level.

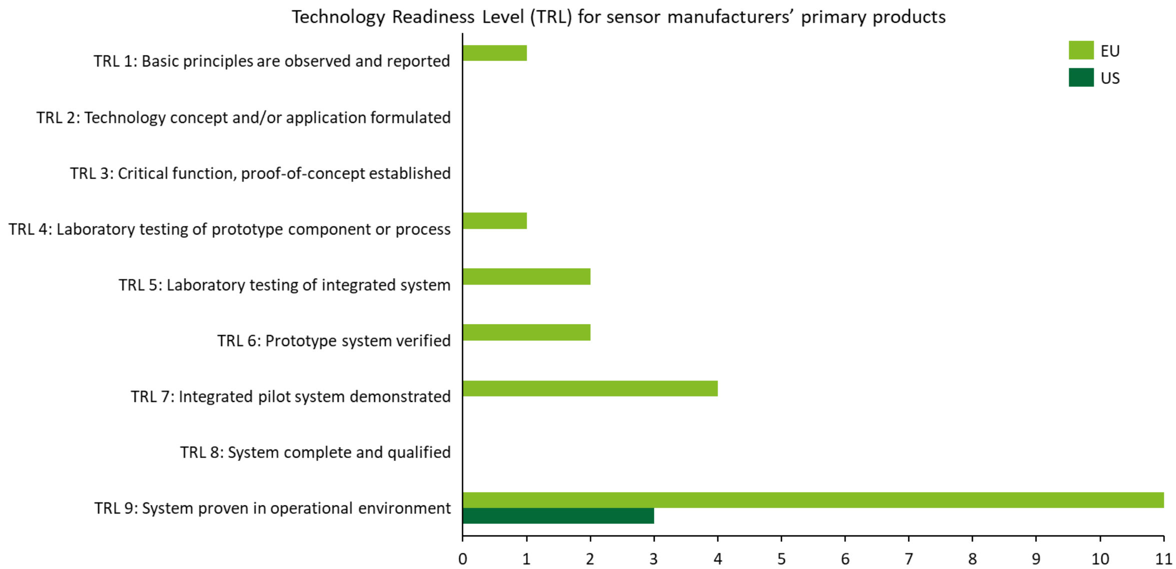

Figure 18 Technology Readiness Level (TRL) for sensor manufacturer's primary technology

Primary users of technology

Unsurprisingly, interviewees noted that some of the main end-users of ocean observation technologies were from the public sector. This included research institutions, federal and national government agencies, hydrographic and geological institutions and agencies, oceanography centres and universities. In particular, it was noted that universities, government and oceanographic centres are the biggest users due to labs not necessarily being driven by discovery science, but more to monitor the oceans and make sure that the environment is healthy. To a certain extent the research side could be expanded in the field of education, in terms of capacity building and educating for the next generation of oceanographers, but this was noted as being a rare case as it was not likely that technology would be bought just for education purposes, but rather would be used it in a combination of research and education.

The private (industry) sector was also named as a key user of ocean observation technology. This primarily involved offshore industries such as oil and gas exploration companies, renewable energy companies, sea-bed mining companies, fishing industry and shipping companies. In addition, private weather stations were also highlighted as key user of these technologies.

At a broader level, it was highlighted that the primary users of ocean observation technologies could be seen across three main groups, as shown in Figure 19. National and federal governments require a considerable amount of information to manage and monitor their national waters, thus requiring the use of a wide array of sensors and platforms. At the industry level, there is a need for technology in off-shore projects to produce accurate data, particularly in energy-related projects. Some interviewees from the private sector noted that the data gathered is often limited to set parameters compared to the research sector, which is more likely to require a broad range of parameters to answer research questions.

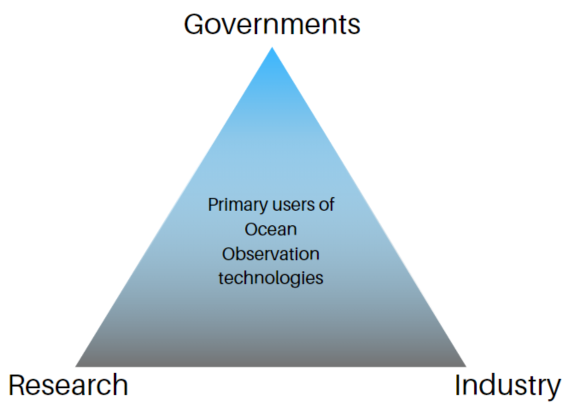

Figure 19. Triangle of primary users of technology

With regards to the technology being primarily used by the technology owner, it was highlighted that it depends on the business model. In addition, it was noted that technologies are either sold as a product or sold as a service, although it was caveated that there are very few companies providing data as a service in the current market. For those that still provide this service, it was mentioned by some private sector organisations that they operate on a data as a service model as a means to keep the costs for the client at a low.

Market differences between Europe and other geographic regions

Europe and USA

Overall, there was a broad consensus across all stakeholder groups that although there have been strong developments in the market in Europe, the market is still broadly dominated by well-established companies in the USA.

This dominance was further explained across a number of different levels. One of these levels includes the differences in the level of demand between the USA and Europe. In particular the level of demand was considered to be higher in the USA, especially for federal agencies and sectors such as defence and the Navy. From a technological point of view, interviewees often noted that there is a greater market in the USA particularly for sensors (e.g. CDC sensors) and gliders. This demand is seen to operate primarily at the federal level, thus giving greater incentive for close collaboration between the public and private sector to develop new technologies. This approach has meant that there is a concentrated market in the USA which can enable greater investment into specific technologies, allowing these technologies to not only be technologically advanced, but to also have the ability to 'break-through' the market into mass commercialisation. Indeed, it was noted by several stakeholders that this cycle enables greater uptake of new technologies.

While acknowledging the fact that Europe does not work under one federal state, many interviewees both in the public and private sector pointed out that Europe has a more scattered and fragmented approach, particularly in the area of procurement. These interviewees explained that while the market is moving in a positive direction in Europe, there is a lack of ambition, particularly on the scale at which products can be produced and sold. One USA technology provider noted that in Europe there is demand for technology, although the paths to commercialisation can often be very convoluted. This can often mean that the speed of uptake does not match the urgency of many challenges that are facing the oceans. Despite there being less of a centralised approach in Europe, with regards to development of new technologies, one initiative that was highlighted as being important was the work carried out by EMODnet.[14] In particular, it was noted that agencies such as NOAA looked to take inspiration from the approach adopted by EMODnet to try and pull data together in a way that can be easily viewed and accessed.

When asked if there is any variation in the purchase of technologies from either the EU or the USA, it was highlighted that there was no strict preference on where technologies came from. Rather, the preference is based on how well the technology has been developed and tested. Often when a technology is used for the first time, it is used in collaboration with the people that have developed it. So, in many cases it depends on the availability of professional networks.

Although it was noted by all interviewees that there is a market dominance from American companies, many interviews highlighted this isn't necessarily a problem. This dominance is due to the technology being reliable and accurate. One limitation, however, that was noted by stakeholders in Bulgaria and Greece was the costs in shipment of the

[14] Available at: https://emodnet.eu/en

technology to be refurbished or maintained, which can often disincentivise the purchase of goods from the USA.

Overall, however, in comparison to the USA, many stakeholders are of the view that the market in Europe is heading in a positive trajectory. In particular, countries such as Norway, France, UK, Spain, the Netherlands and Germany are seen as countries at the forefront of development and uptake of new technologies.

Other geographies

Interestingly, a small number of interviewees were of the view that market in Europe is generally on par with other major markets in the USA and China. In particular it was often noted that Europe has very strong development work, particularly in new innovations in technology. However, again the correlation between the level of national investment and the uptake of new technologies is still observed.

While the market in the USA was highlighted as being a dominant force in the global market, several interviewees also noted an entrance in the market from China and Latin American countries. For China, large investments in the development of new technology was observed with particular growth in unmanned platforms and ROVs. In comparison, only one interviewee noted that emergence of technology in Latin American countries, highlighting in particular the mass availability of affordable technology.

4.3 Is there an open market for equipment or services based on competitive tendering?

Figure 20 visualises responses to the questions on the tendering process. As can be seen, for platforms, the differences between EU and USA procedures are limited, except for the higher occurrence of restricted tenders in the EU. For the EU in particular, the distribution of respondents among direct sales, open tenders and restricted tenders is similar, which may indicate that both public and private companies are fairly similar in demand for Ocean observation products. This can be verified from the beginning of Section 4.2, where the key consumers are discussed. In case of respondents from the USA, direct sales have the highest responses followed by open tenders. For sensors, only two respondents from the USA answered this question and a comparison cannot be made.

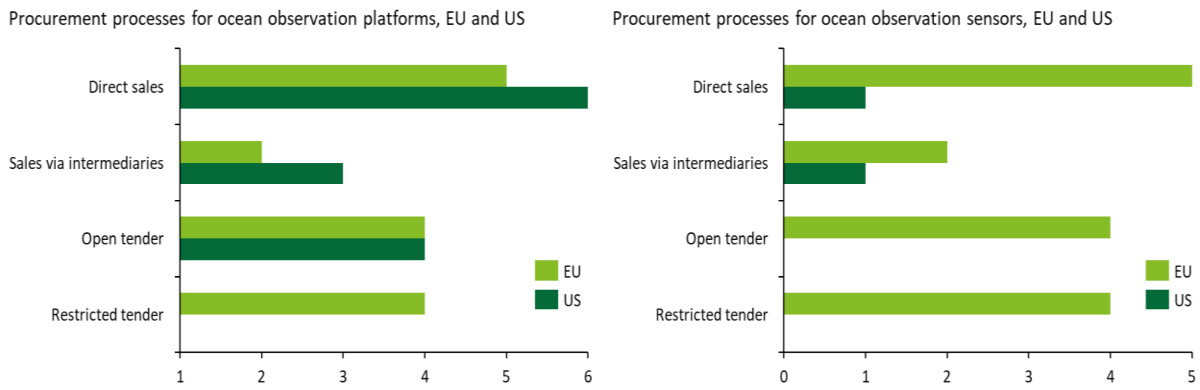

Figure 20 Procurement process for platforms and sensors in EU and USA

Findings from the interviews were similar. Overall, out of the 25 interviewees asked if there is an open market for equipment or services based on competitive tendering, the majority (15 out of 25), answered that the market was and remains open. In particular, there was a general view that competitive tendering for equipment and services work well across Europe. It was acknowledged by a minority of stakeholders however that there can be restrictions in the competitive tendering. For example, one research institute noted that in comparison to the progress in the past 10 years, it has become increasingly complicated and time consuming to tender for specific technologies with there being a lack of flexibility on choice. Here, the importance of the joint efforts between the public and private sectors at an early stage in tendering process is crucial.

In addition, it was noted that there is quite a lot of interaction between areas such as weather forecasting, shipping, renewable energy and science research. In particular, several research institutes noted that in calls for the development of new technologies, stakeholders are able to come together in a joint consortium, further boosting the ties between the public and private sector.

4.4 Insights from the interviews with buyers of ocean observation technologies

Three interviews with European buyers of ocean observation technologies were conducted to gain additional insights into the process of, and motivation behind, buying these technologies. Due to the limited number of interviews, the following section is explorative in nature.

All buyers use open tender procedures if required by regulation. In such a tender process, a strict procedure needs to be followed, which defined the technical requirements and balance between price and accuracy. The ocean observation sector is not that big, buyers know most producers in person and also know what they can ask for.

The manufacturers from the USA are credited for having better marketing, and they are more visible compared to the buyers from European counterparts. In terms of quality, no major differences are observed (the exception to this being the Seabird CTD sensor which outperforms other sensors). European manufacturers are reached more easily - if only because of the different time zones - which is seen as an advantage.

All respondents recognise the pivotal role of NOAA in the development of the USA ocean observation sector. Their purchasing power has helped manufacturers to produce larger volumes, reduce costs of production and improve their products. The EU market is considered to be more fragmented and those occasions (e.g. the MOCCA project) where European users bought technologies in larger volumes have supported the European manufactures.

European research projects have contributed to the development of new technologies, albeit often at the lower end of the TRL scale. Developed technologies run the risk on ending up in the 'Valley of Death'. New sensors have to be tested before they can replace previously bought technologies. It is argued that funding dedicated to such tests can help to ease the uptake of new technologies for ocean observation.

5 Task 3. Finance

The purpose of Task 3 was to examine how the development and commercialisation of the technology examined in objective 1 have been financed – e.g. government grants, venture capital, large corporations, private foundations. In the following, we present our findings for each of the questions defined. These findings are based on the literature review, the survey responses received so far and the interviews held.

5.1 How is it financed?

Before diving into the modes of finance for ocean observation, it is important to gain some insights into the level of investment needed to scale up the technologies. The survey was used to collect this information from manufacturers and technology experts by asking about the level of investment (range) required for their primary platform and sensor technologies. As can be seen from Figure 21, the majority of the investments for both sensors and platforms fall within 10 million euros for one technology. Responses indicate that the investment for most technologies developed were less than USD 0.5 million. Although the number of responses from USA-based companies is low, a similar trend can still be seen there. Additionally, investments higher than USD 10 million are observed only for platform technologies as the systems themselves can be complex to develop and deploy.

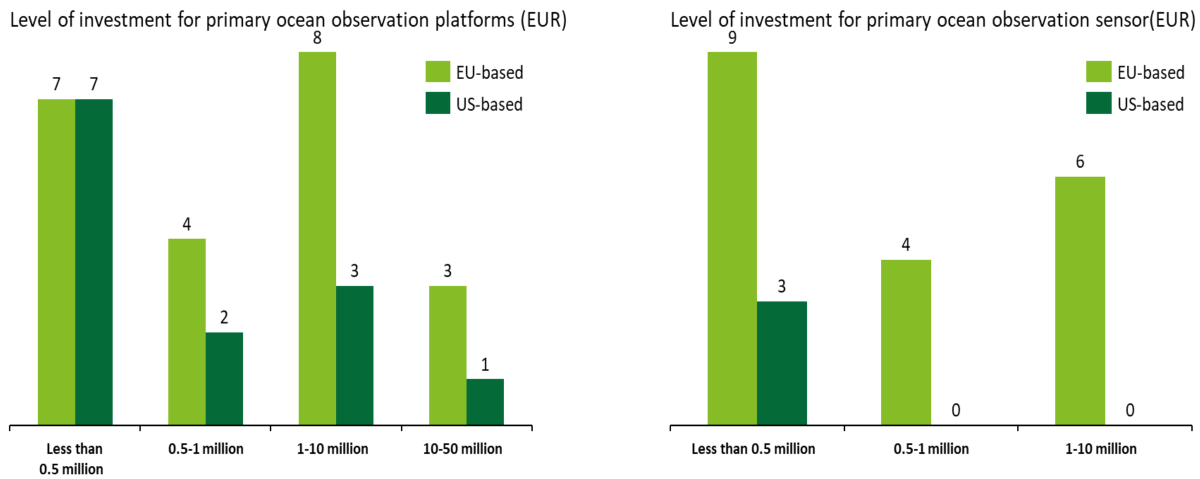

Figure 21 Level of investment (EUR) needed for primary ocean observation technologies

Additionally, the survey was used to collect information on the key investors that play a role in development and commercialisation of ocean observation technologies in both the EU and the USA. As can be seen from Figure 22, the majority of the respondents from the EU indicate that the government is by far the primary source of investment. This category includes both national governments as well as EU-level financing. While the other sources of investment include venture capital, private foundations (including individuals), corporate investors and national defence, this points to the importance of the role of governments in the EU in financial support to upcoming technologies. In case of the USA, the responses were equally distributed over all investor categories, other than the absence of any indication of defence-based spending. The category "other" for both the EU and the USA includes respondents that indicated self-funding.

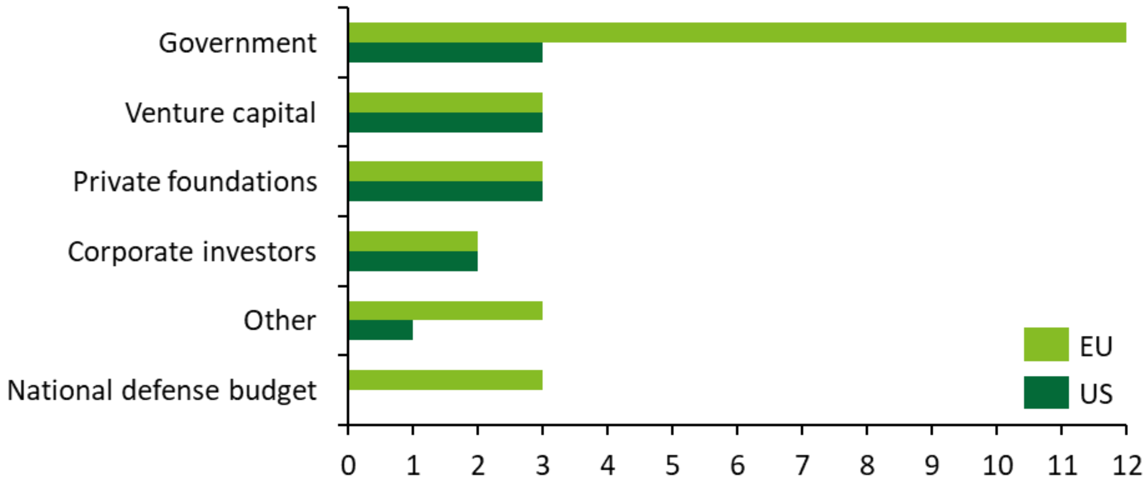

Figure 22 Key investors in the development and commercialisation of ocean observation technologies, EU and USA

Lastly, through the survey we tried to capture the different modes of investments that were made available to the technology developers by the key investors. As can be seen in Figure 23, it correlates with the type of investors. For the EU, as governments are indicated as the biggest investor, the primary financing is also provided in the form of grants and sponsorships. Apart from the grants, equity financing and debt financing is indicated as an important mode of finance. For the USA, the distribution of modes also reflects the key investors as seen from the equal distribution. This again underlines the pre-dominant role that public organisations play in the EU to fund upcoming technology. The funding both in the EU and the USA is made accessible in multiple rounds with respondents indicating up to 3 rounds of financing.

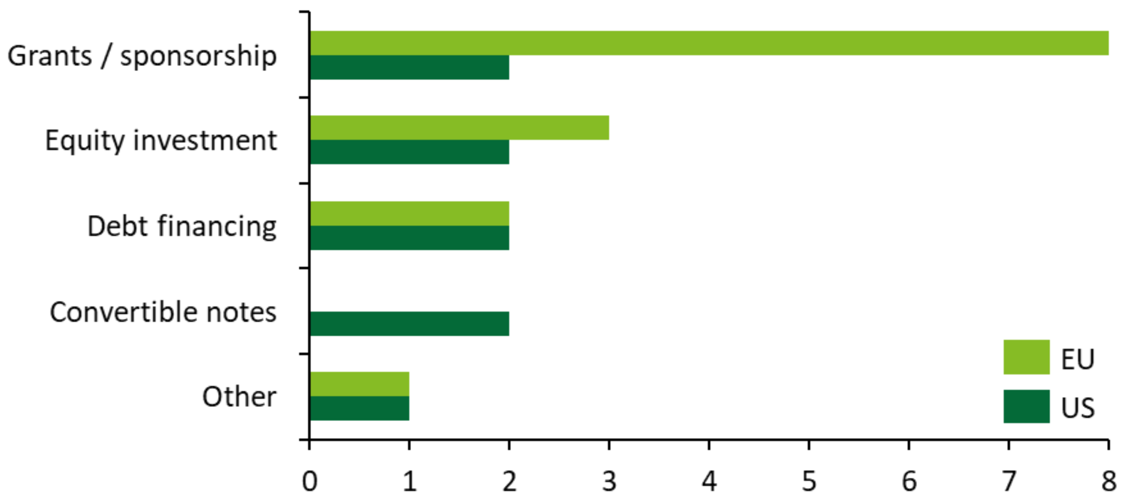

Figure 23 Key modes of financing for development and commercialisation of ocean observation technologies, EU and USA

Under Task 3, the following stakeholders were asked questions on the area of financing: National Ministries responsible for the collection/study of ocean data, research institutes, hydrographic agencies, environmental bodies, Copernicus Marine Service Data Producers and technology providers and operators (including SMEs). The following subsections will explore these questions according to the financing of development and commercialisation as well as for research.

Financing for development and commercialisation of ocean observation technologies

Out of the 25 stakeholders which were asked questions on financing, the majority (16) were of the view that funding for development and commercialisation primarily came from public sector funds (i.e. national level funding or EU level funding). For specific national level funding, it was noted that funding is often readily available for technologies that are of particular strategic importance for national government research. However, this view often came with the caveat that while novel techniques can be funded by national governments, they often require large and well-established companies to enable the technology to become widely available on the market. Thus, it is often perceived that there is a gap in funding, particularly for the development of specific technologies by smaller research organisations/ businesses.

In addition, many interviewees noted that funding for development and commercialisation seldom originates from a singular source and is rather a mixture of funds from national and international levels. This approach was often used due to the levels of funding that were available, with no particular fund being able to cover the full chain of development from conception to commercialisation and use.

When comparing responses geographically, there was a noticeable split between countries based in South-East Europe compared to North and Central Europe. In particular, interviews with stakeholders from Greece and Bulgaria noted that it is often the case that due to a lack of national level funding, there is more of a reliance put on EU structural funds. Examples of the most pertinent EU-level funds included the five main operational programmes[15] (in Bulgaria), Horizon 2020,[16] regional innovation programmes, and country specific cross border partnerships which are funded by the EU, such as the Black Sea Cross-Border Cooperation programme.[17]

An assessment of whether the level of funding for development and commercialisation was suitable across all levels led to a general consensus that while more funding is always welcomed, it is often the case that it does not target the key areas of technological development. In particular, one area of consensus between both the public and private sectors was that funding should focus on the data needs and requirements rather than technological innovation.

Crucially, the sustainability of funding over the entire duration of development of a technology should be funded in some form. For example, it was emphasised that while funding for the development of a technology is readily available, funding for the maintenance of the technology, the analysis and then sharing of data is seldom covered. This is particularly significant as these areas can often incur higher costs compared to the initial development costs.

In addition, there was a general perception that there can be barriers to accessing funding for SMEs. While interviewed SME stakeholders did not provide specific examples

[15] Available at: https://ec.europa.eu/regional_policy/en/atlas/programmes/2014-2020/bulgaria/2014bg16rfop002
[16] Available at: https://ec.europa.eu/programmes/horizon2020/en/area/oceans-and-seas
[17] Available at: https://blacksea-cbc.net/

of what barriers are present, it was noted that barriers do exist due to ocean observation not being fully considered as a topic of interest under SME programmes at both the national and EU level.

From the technology providers and operators' point of view, there was a general perception that funding can sometimes push the development of technology only for the sake of innovation. It was therefore suggested that funding should push technologies that not only fulfil specific data needs but are also more efficient and can be made affordable to encourage widespread use.

Financing for research

In the area of research financing, the most common method of funding was through national and EU-level funding. It was also commonly highlighted by research institutions that research on ocean observation at the national level would not be covered, and that instead the operational costs would be funded. For funding on specific research, it was more common to access funds by international grants or funding programmes, such as at the EU level, with programmes such as Horizon 2020. In particular, it was often the case that for national coastlines (which would be costly to fund from the EU), national governments provide funding for research of the coastal areas of their country. EU funds are seen on the other hand to be directed at the interconnection between ocean observatories to provide an EU-level service. At a more global level, it is more common to collaborate with other countries or institutes on one big question, after which each institute applies for their own national funding to work on the project.

From the point of view of technology providers and operators, it was caveated that it is important to take into account the existing levels of infrastructure. For both private and public organisations, if infrastructure is strong (i.e. if they have the capacity to conduct large scale research studies), it can create more opportunities for funding compared to regions with no infrastructure.

On a similar vein to level of funding for development and commercialisation, it was highlighted that the level of funding is also not sufficient for research at the national and EU level. The importance of funding for data management was also underlined by several research institutions and ocean observatories, whereby funding for research seldom covered the costs in collection, storage, management and analysis of data, thus compromising the potential of data to be properly stored and understood. For example, one national level research institute provided the estimate that it can cost around EUR 1 million for around 20 days of vessel time, which is a large portion of research expenditures.

5.2 Differences in financing between Europe and USA

As mentioned in the previous section, some inferences can be drawn between EU and USA financing based on the data collected through the surveys:

- Referring to the survey output on level of investment required to develop and commercialise technology as shown in Figure 21, it can be seen that both Europe and USA have similar investment needs. The majority of the technologies for both have been developed and commercialised for under 10 million euros of investment.
- For the primary investors for financing the ocean observation technologies, differences emerge between the EU and the USA players. As can be seen in Figure 22, the role of government funding in development and commercialisation

is significantly higher in the EU. In the USA, the proportion is more equally distributed between public and private investors with organisations getting funding through equity and venture capital investors.

- Comparison can also be drawn on the basis of modes of investments in the EU and the USA. Figure 23 provides an overview of responses which correlates to the investor types. More respondents in the EU indicate grants and sponsorships as the primary mode of finance whereas the modes are more uniformly distributed in case of the USA respondents.

Out of the 25 stakeholders that were asked questions on financing, only 9 stakeholders were able to comment on the differences in financing between Europe and the USA. There was, however, a general agreement that there are clear differences between them. The most common difference being the presence of the National Oceanic and Atmospheric Administration (NOAA) as part of the US Department of Commerce. Crucially, NOAA and other agencies have the ability to centralise funding in the USA for oceanographic research at a level that may not be feasible at the EU level. In addition, it was also highlighted how development costs can be covered under funding from NOAA up to 60%. NASA was also mentioned as a key area of funding in the USA with a variety of programmes specifically for oceanographic research and development.

In comparison, the current situation of financing in Europe was seen to be less centralised and dependent primarily on national level funding with support from EU-level programmes. Several stakeholders provided country specific examples of how funding is coordinated, particularly for SMEs.

- For Portugal and Spain, it was seen that there are clusters of SMEs which work together to create business cases for research and development funding.
- For the Netherlands, Denmark, Sweden and Finland it was highlighted that there are clusters of SMEs on specific topics which organise cooperation PPP programmes, while also organising demonstrations and events on new technology.
- For Greece, it was noted that SMEs tend to be created on demand in response to specific calls for proposals at the EU level, however it was highlighted that there is little support for the development of SMEs overall.
- In France, there can be numerous constraints to develop products and bring them to market due to increased rules in specific calls for proposals at the national level (e.g. this included there being multiple criteria on the type of partnerships involved and the specific topics to be addressed). It was also highlighted that there is a difference in co-funding rules in France, where it can range between 35-40% for private companies or SMEs.

It should also be noted that stakeholders were aware that there are funding opportunities for collaborations between countries. One main benefit from international funding was the co-benefits which can be achieved such as developing and widening professional networks with other countries.

5.3 Funding from defence budgets

From the survey metadata (Annex 2) as well as the investor information collected, it is observed that only three respondents indicated the availability of funding from the defence budget. All of the respondents indicating defence investments were from the EU. Furthermore, none of the USA respondents indicated defence budget as a mode of finance. As the survey was insufficient in collecting this information, no clear inferences can be drawn on defence spending.

While it was not specifically asked in the interviews, the topic of funding from or for national defence agencies was raised by a small number of stakeholders. It was noted that national defence agencies tend to purchase or procure advanced and often expensive technologies, such as autonomous subsurface vehicles. These types of high-end technologies are often built to order, thus defence agencies, with financial backing at the national/federal level, can hold a particularly important market share. More specifically, it was highlighted that defence in the USA (particularly from the USA Navy) can have larger funding capacities compared to other sectors. Defence in the UK was also raised as being an important stakeholder which can have larger funding capacities for large scale projects, often using technologically advanced equipment for monitoring purposes. While most of the stakeholders were not able to comment on the exact proportions of funding available to defence agencies, there was an overall view that their influence on the market can result in some technologies being developed for defence initiatives first, which might not be open to everybody else.

6 Task 4. Acceleration of change

Under this final task, we aimed to develop a better understanding of the progress made towards stimulating and accelerating the development and deployment of new observation technologies, as well as looking towards the future in terms of what changes need to be made to fill any gaps or problems uncovered. Thus, building on the results from Tasks 1-3, we will explore how well public and private efforts made to stimulate and accelerate development and deployment of new observation technology have worked, whether they were sufficient and adequate, and whether they added value. Based on the identified factors driving or hindering the progress made, combined with suggestions from interviewees, we will be able to provide suggestions for the future, e.g. in terms of investments needed from the EU or at national level.

At a high level, the backward-looking aspect of this task will aim to follow the Better Regulation Guidelines of the European Commission. The evaluation questions which we aimed to answer at a top level are:

- How effective have public and private efforts been?
- How efficient have public and private efforts been?
- How relevant are public and private efforts?
- How coherent are public and private efforts internally and with other (EU) actions?
- What is the public and private added value of the intervention?

In the following sections, we present our findings for each of these questions, as well as the forward-looking question regarding the need for future research, investments, and/or legislation on ocean observation technologies.

6.1 How effective have public and private efforts been?

The inventory of sensors, platforms and manufacturers does point to the high number of private enterprises active in ocean observation, at times working in collaboration with universities and research institutes.

Some projects have developed easy to use, low-cost sensors and platforms that can be used large scale either by citizens or others. Other funds have been used to improve technology by companies. Not all of these were successful: in some instances a company that had worked in an EU project seemed to be out of business.[18]

Under Task 4, all stakeholders were asked questions pertaining to the acceleration of change with regards to the public and private sectors.[19]

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[18] For example: Enitech and Albatros Marine Technologies from the http://www.bridges-h2020.eu/collaborating-partners.php project are no longer in business.

[19] This includes: Public bodies at the EU and international level, National Ministries responsible for the collection/study of ocean data, research institutes, hydrographic agencies, environmental bodies, Copernicus Marine Service Data Producers and technology providers and operators (including SMEs).

Effectiveness of public sector efforts

Overall, most stakeholders (22 out of 38) were of the view that the public sector had made and continues to make sufficient efforts in the development and deployment of new ocean observation technologies. In particular, national and international level research centres have been a driving force in accelerating development. This driving force was further explained due to the criterions that are often set for calls for proposals and open tendering which can place an emphasis on innovation and requirements on the sharing of information. As a result, the public sector was seen to have put more investment into remote sensing, investment in research for new in-situ technologies and autonomous sensor carriers.

One indirect effect from the public sector was that it can also stimulate smaller companies in the development of sensors through helping to identify available funding, providing trials, validation, certification, and then commercialisation. This was also noted by technology providers and operators; however, it was highlighted that despite this, there can issues regarding the speed of uptake which can pose problems for private organisations.

Despite the mostly positive view of the effectiveness of the public sector, 16 stakeholders were of the view that the public sector had *not* made significant efforts, of which 9 provided possible solutions on how the public sector could be more effective in the future. First, interviewees at the EU level noted that the public sector is often very conservative with the technologies they use, and often will not change to new technologies because the data obtained might not be precisely the same. To enhance new technologies further, benchmarking should be carried out on old and new technologies ensure that the data is comparable.

In a similar view, interviewees from research organisation also noted that there was still a long way to go on convincing people that the development of technologies is sustainable and not just "blue-sky" research (a common view that can be held across the sector on technological innovations). Furthermore, it is slowly being realised that humanity's ability to adapt and be resilient to climate change is dependent on our understanding of the environment, which in turn is dependent on technology. While there is a notable rise in societal awareness of climate change in the past 10 years, there has been a general lack of dialogue and cooperation between the public and private sectors transnationally across Europe on what data is required and how it should be gathered.

Effectiveness of private sector efforts

Interestingly, when asked if the private sector had made significant efforts in stimulating the development and deployment of new ocean observation technology, the main response provided (23 out of 38 interviews) was that it was not clear, with it being effective in some areas and ineffective in others. One example was that while the private sector can be quicker in terms of the uptake of new technology, they can also be slower or reluctant to publicly share data that has been collected. It is worth noting that while some data could be considered as business sensitive, the primary gap that was highlighted by stakeholders refers to non-sensitive data (i.e. data that is not gathered for specific business opportunities but rather being collected systematically for monitoring purposes).

From interviews with private sector companies, the effectiveness of the sector was seen according to two key branches: the producers and the buyers of technology. For the producers of technology, there has been significant development, specifically in their involvement in research and development programmes (predominantly from the EU). Crucially, however, producers of technology do not have an impact on other emerging technologies, but rather have the internal resources to invest in internal development of new technologies.

With respect to the buyers of technologies, there is a general awareness of new technologies that are being produced, although it is more common for investments to be made on technologies which are more established. To help provide more opportunities for the private sector to have an impact on the development of new technologies, it was suggested that there should be a greater number of tendering opportunities for smaller sized research and development projects; thus involving SMEs and buyers through simplified rules to further motivate participation.

While there was broad agreement on the effectiveness of the private sector (as mentioned above), it was also caveated that the private sector is less likely to push development unless they know they have a customer at the end of the process to purchase the technology. Thus, the market can be considered as being demand driven.

Effectiveness of public-private sector efforts

In the area of public-private sector efforts (particularly through Public Private Partnerships), there was a majority view (25 out of 38 stakeholders) that partnerships can work very well and produce positive and impactful results. In particular, a main benefit attributed to PPPs was the ability for information to be shared and used. Additionally, one national institution highlighted that having private sector organisations on board can help to move research at a faster pace and provide a means of coping with wide-scale production of technologies, which would not be feasible through individual research centres.

Despite the benefits of PPPs which were highlighted, 15 stakeholders acknowledged that more should be done to encourage PPPs. One area of encouragement which was raised was through encouraging healthy competition in the tendering process. As sensor developments expand, programmes should adopt the notion of healthy competition among technology developers. Thus, there is also a need for increased incentives and opportunities for stakeholder buy-in.

6.2 How efficient have the public and private efforts been?

Overall, both public and private efforts were generally perceived as being efficient. Despite this, there were three main areas that were raised across the interviews where further efficiency gains could be achieved.

Efficiency of the purchase and use of technology

One area that was highlighted where there is a need for increased intervention from both the public and private sector was in the cost-efficiency of technology. An example of this was that in order to gather more data in the future, there needs to be further development in both the cost and energy efficiency of automated technologies. To harness this, it was noted that in tandem with changes in the market, there also needs to be increased cooperation between the public and private sectors. More specifically, for sensor technology, increased market demand and market structures that encourage fair competition between SMEs will enable more efficient technology to be developed and deployed across the market.

Interestingly, it was highlighted that there may be incentives for private companies to reduce the costs of technologies on the market as they hold the potential to encourage a greater number of users to the market. On a similar vein, there is also a role for the public sector to promote technologies from SMEs to further encourage a shift to more affordable technologies. However, it should be caveated that while this may be one method of achieving an efficiency gain for the market as a whole, it requires risks to be taken by private organisations, thus going against the current demand-driven market structure.

One interviewee noted that if the Commission was to create a requirement on the standardisation specification for a sensor, then this would create a temporary surge in the private sector to develop this technology, due to the increased demand from the public sector to meet these requirements. However, the interviewee caveated that this approach would not be sustainable. This point was further reiterated by technology providers and operators who noted that this would restrict development and deployment in the long term and further polarise the market for those companies that may produce a specific type of technology.

Efficiency of data collection

Another area that was raised was the need to make the collection of data more efficient. For example, several interviewees were of the view that the private sector is able to be more efficient in the development and deployment of technologies. This was notably due to the increased level of resources and financial backing to invest in greater numbers of sensors, thus producing more accurate and widespread data.

Despite this, however, there is a greater need for collaboration in and between sectors on the deployment of technologies into the oceans. In particular, one national level research institute noted that there is a fear of the ocean becoming populated with multiple sensors collecting the same information but for different users.

It was also emphasised how there is an efficiency loss with regards to the collection and storage of data. While there is a push for increased deployment, many stakeholders noted how there was not a comparable push to improve the techniques in both storing and analysing data. More specifically, there was a general view that there is a lack of expertise in both the public and private sector for the analysis of data, particularly in the field of modelling.

Efficiency of agendas on ocean observations

At a broader level, it was highlighted that the differences between public and private sector agendas on ocean observation can create an efficiency loss. One example was in the collaboration between the public and private sector on large scale agendas or strategies for the future, whereby there can be a reluctance from the public sector to agree upon large-scale strategies. This was reiterated by one technology provider who noted that PPPs can work very positively, although they are hindered by different parties with differing interests, thus making it harder to tackle areas of joint interest. It should be noted, however, that this view was only held by a small number of data and technology providers/operators.

From the perspective of the public sector, however, there was a general consensus that there should be some type of strategy in place to make future efforts even more efficient. For example, issues such as intellectual property/competition concerns may slow the development in both sectors. In addition, efforts could be made even more efficient through increasing collaboration between public and private partners, a point that was further reiterated in Section 6.1.

6.3 How relevant are public and private efforts?

Across all stakeholder groups, there was overall agreement that public/private efforts are relevant in accelerating the development and deployment of new observation technologies. In addition, it was also broadly agreed that the continued relevance of public/private efforts is increasing due to there being a need to increase the availability of data and data types.

Despite this, the lack of awareness campaigns being conducted to inform stakeholders of the importance of new ocean observation technologies from public national institutions and private organisations poses a threat to the continued relevance of public private efforts. Out of the 14 interviewees who were able to answer, only 9 were aware of national level awareness campaigns while 5 noted that there is a distinct absence of effective awareness campaigns. While awareness campaigns from private organisations were seen to be more active by stakeholders, there was still a concession that more was required to further emphasise the continual relevance of new ocean observation technologies.

6.4 How coherent are public and private efforts internally and externally with other (EU) actions?

Overall, most of the interviewees were not specifically aware of the coherence between public and private efforts internally and between other actions. From those that were able to provide information, it was noted that the public sector could be considered to be more efficient in the development and deployment of technologies due to national and EU-level requirements to produce more standardised data over time. Thus, in this respect it could be noted that the external coherence between public sector actions and EU level initiatives can have a positive effect on the uptake and deployment of new ocean observation technologies.

The examples of the Water Framework Directive and the Marine Strategy Framework Directive at the European level were highlighted to have put an obligation on Member States to implement surveillance and operational monitoring programmes. This has resulted in data being produced in a more systematic manner.

6.5 What is the added value from public and private intervention?

As mentioned in the sections on the effectiveness, efficiency and relevance of public/private intervention, it is broadly agreed that this intervention has brought about benefits, such as an increase in the number of products available and an increase in research in the field of ocean observation, which could not have been achieved through any other means.

Interestingly, the main added value that was raised from public and private intervention was through joint efforts or PPPs. In particular 24 out of 38 interviewees were of the opinion that joint efforts between public and private sectors should be encouraged and operate sustainably. One of the main points of added value that was raised by stakeholders was that it enabled the sharing of information and technology.

More specifically, it also allows for new technology to not only be developed but also demonstrated, thus displaying the potential of the technology, not only as a market investment but also to oceanographic research.

6.6 What should be done in the future to further stimulate and accelerate the development and deployment of new observation technologies?

In this final section, all stakeholders were invited to comment on what the future of ocean observation should look like, while also suggesting possible strategies for the future. From analysis of the responses, five key themes emerged.

Technology and data

A clear theme that emerged was the continual advance in technology and data. Numerous aspirations were envisaged of how technology would advance in the future, including the rise of the Internet of Things, automated measurement systems, autonomous carriers and smart sensors, increased in-situ and remote sensing, a better translation of long time-series monitoring, fully operational technology for the collection of biological and chemical parameters and complimentary satellite and in-situ measurements. It was also envisaged that from advances in automated technologies, data would become more continuous, on-demand and be open and accessible for all stakeholders.

To bridge the gap between future aspirations and reality, it was highlighted that there is a need for significant improvements in sensor technologies as well as making sensors and data more interoperable in the future. For example, energy requirements and battery lifetime are a prime concern with regards to the sustainability of these technologies.
Another suggestion was for there to be a standardisation of technologies. This would mean that the main market dominances would have to converge on a standard which would potentially lead to efficiency-gains in the gathering of data. It is argued that standardisation could create an initial surge for companies to align with the standard, however in the long term this demand could lead to larger organisations taking control of the market due to their capacity to deliver technologies which are aligned with possible EC standardisations. Despite this suggestion gathering some support from public sector stakeholders, it is a view that is not widely shared by the private sector. To quote on respondent: "Standardisation of technology would not be sustainable. Our worst fear is being sent a tender to tell us how to do our job."

In particular, it was stressed that the emphasis should be placed on addressing the gaps and needs from the perspective of data needed. Through adapting a data driven approach, it has the potential not only for specific technology to be developed but also for specific data to be gathered.

Collaboration and transnational cooperation

Across all of the interviews, there was a general agreement that to increase the development and deployment of technologies there needs to be increased cooperation, collaboration and exchanges between stakeholders across countries.

In particular, some national level public research institutions noted that there was a lack of commonality between Member States as to what constitutes ocean observing. Instead, countries are seen to be conducting different observations on different parameters. This uncoordinated approach can create inefficiencies (see example in

Section 3.2.3). It should be noted, however, that while several stakeholders acknowledged that joint efforts between Member States and public private sectors were and have already been in operation, international programmes on biological parameters (specifically eDNA) were not operating at the same level as other programmes.

At a broader level, several EU and international level stakeholders noted that there should be a shift in the mindset of ocean observation, from national level thinking towards a global community. While it was caveated that this would pose a number of challenges, the example of the UN Decade of Ocean Science for Sustainable Development[20] was readily cited as being a flagship initiative to try and bring countries together. Another suggestion to address some of the issues of conflicting operating/business models was for there to be a roadmap of common priorities for technology and data.

Furthermore, it was suggested that the biggest advances may be made through creating targeted multi-national programmes to raise the efforts of sensor development from individual laboratories to nationally and internationally coordinated efforts. At the EU level, it was also suggested that the idea of knowledge centres, which had already been developed, could be an approach that would further provide a platform for cooperation.

EU-level governance

In a similar theme, it was also suggested that there should be an overarching agenda at a high political level, either at the European or global level to address the issues of cooperation and overall governance. More specifically, several interviewees highlighted how the Water Framework Directive was a good example where it focused stakeholders to align on a common purpose. Climate change was also another example of a similar banner that could be used in which to set a clear agenda, in addition to the current momentum sparked by the EU’s Green Deal.

While increased hard legislation from the EU was not highlighted as a route to enact this common agenda, it was suggested that a softer policy approach would be more appropriate. From those stakeholders who agreed that there should be an EU-level agenda on ocean observation, it was underlined that the development of an agenda should take into account existing initiatives, and work with existing communities at the national, EU and global levels on common objectives. From this approach, it would help to distil the notion of a collective ocean observation approach, compared to individual national approaches.

National and international financing approaches

Another salient theme which was raised by stakeholders was the need for there to be improvements in national and international financing approaches. A central element to this theme was the concept of sustained funding. In particular, current funding approaches were viewed as not targeting the areas which are most at need, such as in the management and analysis of data. Through the notion of “funding through the whole value chain”, one interviewee highlighted that SMEs require additional support on the development and uptake of new sensors and technology. Thus, there is a need for financial support to be placed on bringing technology to the market, particularly those that are new entrants to the market.

[20] Available at: https://www.oceandecade.org/

One idea that was mentioned by a number of stakeholders was to establish sustained co-funding for research or to increase the Technology Readiness Level[21] (TRL) of technologies. For example, it was suggested that for technologies which are in TRL 1 or 2, they should be encouraged to levels 5 and 6 which would then make them eligible for funding. Such an approach would help to encourage developed technologies into the market while also encouraging new technologies to be further developed.

At a broader level, it was suggested that for EU funding to be sustainable, it must also be complementary with other national funding initiatives. Considering that many projects at the national and international level rely on numerous funding opportunities, there is a need for a more harmonised approach.

The level of awareness of ocean observation

With regards to the future more generally, all of the interviewees highlighted that they expect technologies and data to be open and accessible for everyone in the community. This also includes raising the conversation on how best to manage and keep oceans sustainable. One method that was suggested is encouraging the sharing of data and information that can then be used more intuitively for educational and awareness raising campaigns. This approach would require the introduction of fairer principles for data systems to enable data to be interoperable and available for all.

While there is a general view that there are good examples of education on ocean observation being conducted, their effects are primarily felt at a local level, rather than nationally or internationally. Projects at the EU level, such as the EU4Ocean Coalition,[22] were highlighted as a good approach to connecting education sectors, although more is still required to improve ocean literacy.

7 CONCLUSION

At the start of this study, 4 specific objectives related to the uptake of new technologies for ocean observation were formulated. Based on the information collected through a literature review, a survey and interviews, the following answers to these questions are formulated.

7.1 Specific objective 1: summarise the present state of development of sensors and platforms for ocean observation.

The relevance of, and the need for further development of technologies used in, ocean observation is clear. Ocean observation provides much needed insight into the state of the world's ocean. This information is of relevance to scientists, policy-makers and private enterprises active in the Blue Economy and climate change sector. The inventory made identifies sensors (a total of 119), platforms (a total of 116) and companies (a total of 89) active in this sector. This overview is by no means exhaustive. The focus on

[21] As set out in pg. 29 in the Horizon 2020 Work Programme. Available at: https://ec.europa.eu/research/participants/data/ref/h2020/other/wp/2016-2017/annexes/h2020-wp1617-annex-ga_en.pdf

[22] Available at: https://webgate.ec.europa.eu/maritimeforum/en/node/4484

this study was explicitly on new technologies – not aiming to provide a complete overview.

The sensors and platforms identified are at different technology readiness levels. At one end of this spectrum are newly developed sensors and platform, the development of which is driven by research funding. At the other end of the spectrum are well established, widely available sensors used for routine ocean observation.

Taking a geographical perspective, a notable observation is that the development of sensors and platforms takes place both in the European Union, the United States of America and third countries. The EU and United States of America represent two different 'worlds' of ocean observation. In the EU the development of ocean observation is less centralised with a focus on public-private cooperation. The approach in the United States of America is more centralised, with a strong role for the National Ocean and Atmospheric Administration (NOOA). This does not suggest that one approach is preferable over the other; responses suggest that the EU sector admires what's happening in the USA, and vice versa.

The study furthermore confirmed that in the past 10 years, there has been a sustained and exponential increase in technology development and use. The investments of the European Commission have and will continue to boost the technological development by European stakeholders and the collaboration and cooperation among these stakeholders. In the coming years, different H2020 projects will focus on newly developed data methodologies in which the availability and accessibility of data will be improved.

Further information on the present state of development and platforms is provided in Annex 1.

7.2 Specific objective 2: examine how the ocean observation market operates

The nature of the companies involved differs; the ocean observation market consists of small and medium enterprises, fully dedicated to the development of sensors and platforms, and large companies active in various sectors (e.g. Fugro and Kongsberg). Another important actor in the ocean observation value chain are those companies that use third-party sensors and platform, offering their services to companies, governments and research institutes. These were identified in the context of this study.

About half of the companies identified are based in the United States of America, almost all others have their headquarters in the EU or the European Economic Area. The study did not look at the development of ocean observation technologies in other parts of the world. Based on the data provided, no single number characterising the size of the market can be given. The study has identified a total of 89 manufacturers. Some companies are exclusively dedicated to ocean observation, for others ocean observation is part of their portfolio of maritime activities.

Ocean observation technologies are used by a variety of sectors, including governments, universities and research institutes. A noteworthy observation to make is that for the users of technology, the country of origin is generally not a concern. What is needed is reliable, cost-efficient technologies that provide data compatible with earlier collected data.

In this study, no lease schemes were identified. In the interviews, a few respondents mentioned an alternative business model where the service of data collection was provided – instead of the sales of an observation technology. This however seems to be an exception in a market dominated by the pure sales model. In line with the previous remarks, the respondents generally consider the ocean observation market to be open, based on competitive tendering.

7.3 Specific objective 3: investigate how enterprises offering ocean observation equipment and services finance their business.

In the EU, governments are the primary source of investment by far; funding for development and commercialisation primarily came from public sector funds. This includes both national governments as well as EU level financing, the primary type of funding being provided in the form of grants and sponsorships. Other sources of investment include venture capital, and private foundations (including individuals). It was emphasised that while funding for the development of a technology is readily available, funding for the maintenance of the technology, the analysis and then sharing of data is seldom covered.

The study points to clear differences between Europe and the USA. The most common difference being the presence of the National Oceanic and Atmospheric Administration (NOAA) as part of the U.S. Department of Commerce. Crucially, NOAA and other agencies have the ability to centralise funding in the USA for oceanographic research at a level that may not be feasible at the EU level. In comparison, the current situation of financing in Europe was seen to be less centralised and dependent primarily on national level funding with support from EU-level programmes.

The topic of funding from or for national defence budgets did not emerge strongly from the research conducted. It was noted that national defence agencies tend to purchase or procure advanced and often expensive technologies, such as autonomous subsurface vehicles. These types of high-end technologies are often built to order, thus defence agencies, with financial backing at the national/ federal level can be a particularly important market share.

7.4 Specific objective 4: identify challenges and opportunities for a more widespread introduction of the new technologies for ocean observation in the EU.

Under this objective public and private efforts made to stimulate and accelerate development and deployment of new observation technology were evaluated. In this concluding section proposals for further measures that could be taken up by the EU and national governments are given.

Respondents point to the need of ocean observation to understand the state of the world sea, and know how this changes over time. Ocean observation thereby contributes to ocean awareness. Climate change further fuels the need to observe and understand the world's oceans, and an ambitious climate agenda is seen as an opportunity for further development of ocean observation systems.

7.4.1 *Challenges*

Technological challenges

The picture emerging from this study is that there continues to be room to further develop sensors and platforms to become reliable, proven technologies for ocean observation. In particular, several private technology providers and operators highlighted that sensor development remains a persistent gap in terms of reliability and flexibility to operate across different platforms.

Major desired innovations in ocean observation do not so much lie in improvement of existing technologies (greater range, greater depths, etc) but in the development of autonomous sensors and platforms, and the development of Internet of Things-based sensor networks, including linking of underwater network with terrestrial networks. This requires improved the communication between users on land and the underwater agents (e.g. sensors, vehicles).

The topic of the collection of biogeochemical data was raised by all interviewed stakeholders as an area that is developing at a slower rate compared to other comparable collection. Biological sensing is found to be lagging behind in terms of Technology Readiness Levels. While technologies such as eDNA are out there, they are not advanced to being autonomous. This future pathway of development is interesting to many people

Challenges in data analysis

As a consequence of collection of data at increased temporal and spatial resolution, the data volume increases. The respondents in this study highlight the fact that the capacity for data analysis has not progressed comparatively. The growing discrepancy between the development of data collection and data analysis becoming a major bottleneck for effective use of the available data.

The developments in Artificial Intelligence, machine learning and Big Data offer possibilities for enhancing use of the data and create more synergy within the blue economy sector in the EU. This warrants more attention to research funding, many funding schemes are seen as great for development of sensors and platforms, but not for storing and managing data. Related to this, questions on information sharing, ownership and transparency of data and (if used) algorithms require the development of a data governance framework (Janssen et al., 2020), tailored to ocean observation.

Challenges in development of the sector

The public sector is often very conservative with the technologies they use, and often will not change to new technologies because the data obtained might not be precisely the same. To enhance new technologies further, benchmarking should be carried out on old and new technologies to be sure that the data is comparable.

The lack of cooperation on the use and development of technologies is seen as a major restraint, one of the major factors limiting a coordinated approach across Europe is the differences in the level of importance that national governments place on the need to push development in ocean observation technologies and the collection of data across a variety of parameters.

The question whether or not a hard approach to spur development of ocean observation, including implementation of strict requirements and standards, was raised but no onedirectional answer can be given to this. Some argue that more legislation is needed, and many others disagree.

7.4.2 *Opportunities*

Based on the analysis of data collected in this study, the following opportunities for further development of the EU Ocean Observation sector are identified:

While the respondents are aware of the need for further development of the ocean observation sector, it is argued that a **closer and clearer alignment to societal challenges** such as climate change can spur further development of the sector.

There is ample room for further development of sensors and platforms, in particular when it comes to the **development of biological sensors and autonomous sensors and platforms**. This is where gaps in the availability of technologies are first and foremost felt.

Data analysis is lagging behind and developments in AI, machine learning and Big Data do offer opportunities to improve the infrastructure needed to make use of the data collected. This requires technological development and the development of standards for data collection.

The development of an EU ocean observation ecosystem, including collection, analysis and use of data, requires **ocean data governance**. Crucial questions on inter-operability, exchange of data, storage, ownership and confidentiality are not answered by technological development. They require a systematic, coordinated strategy involving EU Member States, researchers and technology developers.

The EU ocean observation sector is characterised by the close interaction between policy makers, researchers and other developers, in a decentralised setting. It was highlighted that there needed to be **more opportunities for there to be a continual dialogue** on what technology and data is readily available and what needs to be developed.

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8 APPENDICES

8.1 Overview of conducted interviews

Category	Organisations interviewed
Public bodies: EU level	European Marine Board
	EMSO-ERIC
	Euro-Argo ERIC
	LifeWatch ERIC
	EMBRC ERIC
	The European Marine Observation and Data Network (EMODnet)
	Copernicus Marine Environment Monitoring Service in Situ Thematic Assembly Centre (CMEMS In-Situ TAC)
Public bodies: international level	JCOMM in situ Observations Programme Support Centre
	International Oceanographic Data and Information Exchange (IODE)
	International Hydrographic Organisation (IHO)
	Global Ocean Observing System (GOOS)
	Ministry of Transport and Communication (FI)
Public bodies: national authorities	Ministry of Research (FR)
	Federal Ministry of Transport and Digital Infrastructure (DE)
	Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER – FR)
Research institutes (national level)	Hellenic Centre for Marine Research (HCMR – EL)
	Marine Institute (IE)
	Institute of Marine Research (IMR – NO)
	International Council for the Exploration of the Sea (ICES)
	Plymouth Marine Laboratory (eDNA)
Hydrographic agencies	Danish Geodata Agency - Danish Hydrographic Office (GST - DK)
	Hydrographic and Oceanographic Service of the Navy (Shom - FR)
	Royal Netherlands Navy, Hydrographic Service (NL)
Research (EU / international level)	European Fisheries and Aquaculture Research Organisations (EFARO)
	Integrated Marine Biosphere Research (IMBeR)
	GEBCO
Environmental bodies & NGOs	SOCIB
	SenseOCEAN
Private sector: Technology providers and operators (including SMEs)	SeaTopic (FR/DE)
	CORES
	Maris (NL)
	Saildrone (USA)
	Fugro (EU including UK and Norway, USA)
	Kongsberg (EU including UK and Norway, USA)
	Alleco Oy (FI)
	Promare
	Aanderaa
	CLS

8.2 Survey reach-out summary

The survey has been sent to all the organisations below through a direct reach-out process.

Category of stakeholder	Potential stakeholders	Survey category
Public/Private bodies	PLOCAN (ES)	Technology experts
	Bundesministerium für Verkehr Bau und Stadtentwicklung (BHS – DE)	Technology experts
	National Institute of Oceanography and Applied Geophysics (OGS – IT)	Technology experts
	Met Office (UK)	Technology experts
	Natural Environment Research Council (Nerc-Bodc – UK)	Technology experts
	Finnish Meteorological Institute (FMI – FI)	Technology experts
	Institute of Oceanography (BG – IO-BAS)	Technology experts
	Spanish Institute of Oceanography (IEO – ES)	Technology experts
	Balearic Islands Coastal Observing and Forecasting System (SOCIB – ES)	Technology experts
	Meteorological Institute (KNMI – NL)	Technology experts
	Institute of Oceanology (IOPAS – PL)	Technology experts
	Portuguese Institute for Sea and Atmosphere (IPMA – PT)	Technology experts
	Naval Oceanographic Office (NAVOCEANO – USA)	Technology experts
	European Association of Fisheries Economists (EAFE)	Technology experts
	European Inland Fisheries Advisory Commission	Technology experts
	International Long-Term Ecological Research Network (ILTER)	Technology experts
	EU fisheries and aquaculture research organisation (EFARO)	Technology experts
	Regional sea convention - OSPAR	Technology experts
	Regional sea convention - HELCOM	Technology experts
	European Environmental Bureau (EEB)	Technology experts
	European Water Association (EWA)	Technology experts
	European Union of Water Management Associations (EWMA)	Technology experts
	WWF European Policy Programme (WWF EPO)	Technology experts
	Coalition Clean Baltic (CCB)	Technology experts
	European Habitats Forum (EHF)	Technology experts
	Stichting BirdLife Europe (BirdLife Europe)	Technology experts
	TMA BlueTech (USA)	Technology experts
	Four Bridges (USA)	Technology experts
	NEXOS	Technology experts
	JPI Oceans	Technology experts
	EMSO	Technology experts
Private sector	Sea Ice TAC	Market expert
	Surface Wind TAC	Market expert
	Sea Level TAC (Sea Level Satellite Data)	Market expert
	Wave TAC	Market expert
	Multi Observations TAC	Market expert
	Monitoring and Forecasting Centers (MFC)12F[6]:	Market expert
	Global Monitoring and Forecasting Center (GLO MFC)	Market expert
	Coastal Research and Engineering Services (CORES Ltd.)	Market expert
	Helzel Messtechnik GmbH (DE)	Manufacturer of platforms
	Nodalpoint System (EL)	Market expert

	dotOcean (BE)	Manufacturer of sensors + platforms
	Dredging, Environmental and Marine Engineering (DEME)	Manufacturer of platforms
	Offshore Sensing AS (NO)	Manufacturer of platforms
	Kongsberg (EU including UK and Norway, USA)	Manufacturer of sensors + platforms
	Space Applications Services NV (BE)	Manufacturer of sensors
	Fuvex Civil SL (ES)	Manufacturer of sensors
	Mbryonics limited (IE)	Manufacturer of sensors
	Deimos Space SLU (ES)	Manufacturer of sensors
	Ingenia-Cat S.L. (ES)	Manufacturer of sensors
	Sunburst Sensors, LLC (USA)	Manufacturer of sensors
	METAS (Marine ecosystem technologies AS) (Norway)	Manufacturer of sensors
	Autonomous Marine Systems (USA)	Manufacturer of platforms
	Chelsea Technologies Group (CTG) (UK)	Manufacturer of sensors + platforms
	Ocean Array Systems (UK)	Manufacturer of sensors
	Obscape - Environmental observations (NL)	Manufacturer of sensors
	Fluidion (FR)	Manufacturer of sensors + platforms
	NKE Instrumentation (FR)	Manufacturer of platforms
	EOLOS Floating Lidar Solutions (ES)	Manufacturer of platforms
	Terradepth (USA)	Manufacturer of platforms
	Planet OS (USA)	Market expert
	Xocean (IE)	Manufacturer of platforms
	Liquid Robotics (USA)	Manufacturer of platforms
	MRV Systems	Manufacturer of sensors + platforms
	Ocean Sensor Systems (UAS)	Manufacturer of sensors
	Planet Ocean Ltd (UK)	Manufacturer of sensors + platforms
	MacArtney (BE)	Manufacturer of sensors + platforms
	Guralp Systems (UK)	Manufacturer of sensors
	Marine Environmental Data and Information Network (MEDIN) (UK)	Market expert

	Ocean Aero	Manufacturer of platforms
	OpenROV	Manufacturer of platforms
	Sea-Bird Scientific	Manufacturer of sensors + platforms
	Platypus LLC (USA)	Manufacturer of platforms
	National Oceanography Centre (UK)	Manufacturer of sensors
	Blue Ocean Gear	Manufacturer of platforms
	Delta Drone SA	Manufacturer of platforms
	AirMar	Manufacturer of platforms
	ALSEAMAR	Manufacturer of platforms
	YSI	Manufacturer of sensors + platforms
	SenseOCEAN	Manufacturer of sensors

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