# Rethinking Innovation for a Sustainable Ocean Economy

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# *Foreword*

The OECD report *Rethinking Innovation for a Sustainable Ocean Economy* emphasises the growing importance of science and technology in managing the economic development of our seas and ocean responsibly. Marine ecosystems sit at the heart of many of the world's global challenges: food, medicines, new sources of clean energy, climate regulation, job creation and inclusive growth. But we need to safeguard and improve the health of these ecosystems to support our ever-growing use of marine resources. Innovation in science and technology will play a key role in reconciling these two objectives.

In this context, new thinking and fresh approaches are required in many areas, placing innovation at the heart of society's response to the challenges facing the development of a truly sustainable ocean economy. This publication sets itself four objectives:

- Offer a forward-looking perspective on scientific and technological innovation across a range of marine and maritime applications, with a particular focus on some of the innovations already in the pipeline (Chapter 2);
- Contribute to the growing body of evidence suggesting that, with the help of innovation, the development of economic activity in the ocean and sustainability of marine ecosystems can often go hand in hand with one another, and provide a number of in-depth case studies that illustrate the potential for generating such win-win outcomes (Chapter 2);
- Investigate the emergence of new forms of collaboration in the ocean economy among research communities in the public sector, the academic world and a diverse range of private-sector stakeholders, using the example of young innovation networks that have sprung up in recent years around the world (Chapter 3);
- Highlight new approaches to measuring the ocean economy, notably by exploring the use of satellite accounts for its twin pillars – ocean-based economic activities and marine ecosystem services – and by examining ways to better measure the benefits that important sustained ocean observations provide not only to science, but also to the economy and society more generally (Chapter 4).

Based on this original study, three priority areas for action are presented: 1) approaches that produce win-win outcomes for ocean business and the ocean environment across a range of marine and maritime applications; 2) the creation of ocean-economy innovation networks; and 3) initiatives to improve measurement of the ocean economy via satellite accounts.

This publication is based on research and analytical work conducted by the OECD Ocean Economy Group in the Science and Technology Policy Division, within the Directorate for Science, Technology and Innovation (STI). This *innovation and the ocean economy* programme of work, which is continuing in 2019-20, builds up on six years of OECD

original work on the ocean economy, which featured in particular the ground-breaking report *The Ocean Economy in 2030*. This STI activity fits in the broader programme of work of the OECD Committee for Scientific and Technological Policy (CSTP).

The *innovation and the ocean economy* 2017-18 programme of work was kindly supported by voluntary financial and in-kind contributions from a wide range of government departments, agencies and research institutions, who constitute the project Steering Board. Their contributions are acknowledged with sincere thanks. The report also benefited from contributions from many other experts, inside and outside the OECD, and our sincere thanks go also to them. All these organisations and individuals are listed in the acknowledgement page.

This publication was supervised by Claire Jolly, Head of the Innovation Policies for Space and Ocean (IPSO) Unit, and of the STI Ocean Economy Group, with research and analysis conducted by James Jolliffe, Economist, and Barrie Stevens, Senior Advisor, both in the STI Ocean Economy Group. Julia Hoffman, Economist, conducted research on ocean observations, and was seconded to the OECD by the Christian-Albrechts-University zu Kiel, Germany, through the kind contributions of the Marine Research Consortium (KDM), Germany, the European Union AtlanOs Project, and the Exzellenzcluster "Future Ocean" Kiel Marine Science (KMS). Editorial assistance for the publication was provided by Chrystyna Harpluk, Project Coordinator in IPSO. Anita Gibson, who held this Project Coordinator position until she retired in August 2018, organised all the workshops for this project.

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We also acknowledge, with particular thanks, the efforts of the individual members of the Steering Board of the *Innovation and the Ocean Economy Work Programme*, and their colleagues, who have provided valuable guidance and kind support throughout the programme, including through the co-organisation and participation to OECD workshops, provision of original material, and detailed reviews of background papers that were used for this publication.

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The drafting and final wording of ***Chapter One*** owe a great deal to the comments of Dominique Guellec (Head of the Science and Technology Policy Division, OECD), and remarks from Gert Verreet, Rikke Wetter Olufsen, Marco Borra, Niall McDonough, Christina Abildgaard, Cornilius Chikwama, and Danielle Edwards (Innovation, Science and Economic Development Canada).

Beyond the many experts that were approached (with work referenced in the text), we also wish to acknowledge several OECD colleagues for their reviews of ***Chapter Two***, which was mainly researched and drafted by Barrie Stevens, Senior Adviser in the STI Ocean Economy group. Firstly, Laurent Daniel, Head of the Shipbuilding Section of the Structural Policy Division of Directorate for Science, Technology and Innovation (OECD) for very helpful comments on the case study concerning ballast water management. Also, Claire Delpeuch (Policy Analyst), James Innes (Policy Analyst) and Roger Martini (Senior Policy Analyst), all of the Fisheries Section of the Natural Resources Policy Division of the Trade and Agriculture Directorate (OECD), for very helpful comments on the case study concerning aquaculture.

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# *Abbreviations and acronyms*

| | |
|---|---|
| ANZSIC | Australian and New Zealand Standard Industrial Classification |
| AUV | Autonomous Underwater Vehicle |
| BWM | Ballast Water Management |
| BWMC | Ballast Water Management Convention |
| BWMS | Ballast Water Management System |
| BWTS | Ballast Water Treatment System |
| CICES | Common International Classification for Ecosystem Services |
| CMEMS | Copernicus Marine Environment Service |
| CPC | Central Product Classification |
| DGMARE | Directorate-General Maritime Affairs and Fisheries |
| DGMP | Portugal's Directorate-General for Maritime Policy |
| EC | European Commission |
| eDNA | Environmental DNA (Deoxyribonucleic acid) |
| EEZ | Exclusive Economic Zone |
| EFESE | Evaluation française des écosystèmes et des services écosystémiques |
| EIA | Environmental Impact Assessment |
| EMODnet | European Marine Data Observation Network |
| ENOW | US Economics: National Ocean Watch |
| EO | Earth Observation |
| EOV | Essential ocean variable |
| EPA | US Environmental Protection Agency |
| ESA | European System of Accounts |
| ESCAP | UN Economic and Social Commission of Asia and the Pacific |
| EU | European Union |
| EUMETSAT | European Organisation for the Exploitation of Meteorological Satellites |
| EuroGOOS | European Ocean Observing System |
| FAO | Food and Agriculture Organisation of the United Nations |
| GCOS | Global Climate Observing System |
| GEO | Group of Earth Observations |
| GEOSS | Global Earth Observing System of Systems |
| GIS | Geographic Information System |
| GOC | Global Ocean Commission |
| GOOS | Global Ocean Observing System |
| GVA | Gross Value Added |
| GWEC | Global Wind Energy Council |
| HAB-OFS | Harmful Algal Bloom Operational Forecast System |
| HABs | Harmful Algal Blooms |
| ICSU | International Council for Science |
| IEA | International Energy Agency |
| Ifremer | French Research Institute for Exploitation of the Sea |
| IMO | International Maritime Organisation |
| IMOS | Integrated Marine Observing System of Australia |

| | |
|---|---|
| IMP | Integrated Maritime Policy |
| IMTA | Integrated Multitrophic Aquaculture |
| IOC | Intergovernmental Oceanographic Commission (of UNESCO) |
| IODE | International Oceanographic Data and Information Exchange Programme (IOC) |
| IOOS | US Integrated Ocean Observing System |
| ISIC | International Standard Industrial Classification of all Economic Activities |
| MaREI | Marine and Renewable Energy in Ireland |
| MARSIC | Marine Autonomous and Robotics Innovation Centre |
| MAS | Marker-Assisted Sequencing |
| MPA | Marine Protected Area |
| MRE | Marine Renewable Energy |
| MSP | Marine Spatial Planning |
| NACE | General Industrial Classification of Economic Activities within the European Communities |
| NAICS | North American Industry Classification System |
| NOAA | US National Oceanic and Atmospheric Administration |
| OECD | Organisation for Economic Co-Operation and Development |
| OFI | Ocean Frontier Institute |
| ORE | Offshore Renewable Energy |
| OSPAR | Convention for the Protection of the Marine Environment of the North-East Atlantic |
| PLOCAN | Oceanic Platform of the Canary Islands |
| PRIs | Public Research Institutes |
| ROV | Remotely Operated Underwater Vehicle |
| SAIC | Scottish Aquaculture Innovation Centre |
| SAS | Satellite Account for the Sea |
| SDGs | Sustainable Development Goals |
| SEEA | System of Environmental-Economic Accounting |
| SEEA-CF | System of Environmental-Economic Accounts – Central Framework |
| SEEA-EEA | System of Environmental-Economic Accounts – Experimental Ecosystem Accounting |
| SNA | System of National Accounts |
| SUTs | Supply and Use Tables |
| TEEB | The Economics of Ecosystems and Biodiversity |
| TRL | Technological Readiness Level |
| UNESCO | UN Educational, Scientific and Cultural Organization |
| UNSC | United Nations Statistical Commission |
| WMO | World Meteorological Organization |

# *Executive summary*

Development of the ocean economy is facing an increasingly acute dilemma. On the one hand, marine resources are essential to help meet the planet's growing needs in food, energy, jobs, medicines, transport and so on. On the other, increasing use of our seas and ocean, the natural resources and the services they provide, adds to mounting pressures on marine ecosystems. The marine environment is already straining under the weight of pollution, rising water temperatures, loss of biodiversity, rising sea levels, growing acidification and other impacts associated with climate change, with the result that unsustainable growth in ocean-related economic activity risks yet further undermining the very foundations on which the ocean economy stands.

As the OECD report on *The Ocean Economy in 2030* underlined, realising the full potential of our seas and ocean demands responsible, sustainable approaches to their economic development. A durable balance between increasing ocean uses and marine ecosystems' integrity requires actions on multiple fronts, and new thinking and fresh approaches are required in many areas.

This need for new thinking and actions is occurring at a time when science, technology and innovation activities themselves are undergoing major changes. Galvanised by digitalisation, the transformation of scientific research and innovation processes is speeding up in almost all disciplines and sectors of the economy, while the adoption of disruptive technologies and new collaborative and open innovation mechanisms are gaining ground in many parts of the world.

In this context, this follow-up report *Rethinking innovation for a sustainable ocean economy* explores the role played by science, technology and innovation (STI) to propel growth in the ocean economy, while contributing possible solutions to its long-term sustainability challenges.

***What innovations are on the horizon that may benefit both economic growth and environmental sustainability?***

Ocean innovations in the pipeline – especially those building on generic advances in science (e.g. biochemistry, physics) and technology (e.g. artificial intelligence, robotics, big data) – appear set to enhance knowledge and understanding of marine ecosystems and their functions and improve ocean industries' performance markedly.

Economic progress in ocean activities has to become environmentally sustainable, and so this report devotes special attention to recent and forthcoming advances in a number of maritime sectors, which have the potential to deliver win-win solutions, i.e. strengthening economic development while at the same time supporting ecosystem preservation and restoration. Four in-depth case studies are provided. They feature cross-sector innovations, and were selected in view of their different degree of technical and business maturities, and their possible impacts. They include:

- Progress in ballast water treatment in ships, to combat the spread of (alien) marine species;
- Floating offshore wind power and its capacity for generating renewable energy and reducing greenhouse gases;
- Innovations in the marine aquaculture sector which may contribute to making the industry economically and environmentally more sustainable;
- Conversion of decommissioned oil and gas rigs and energy renewables platforms into artificial reefs.

The preliminary assessment suggests that the innovations presented in the case studies have the potential to foster sustainable ocean economic activity, with possible positive impacts beyond the marine environment, although some face more challenges than others. In addition, while science has led to many of the actual developments under consideration, one important lesson from all case studies – taking into account many differences in their operational and business models – is that major knowledge gaps in marine ecosystems' biophysical characteristics exist today, which constrain future developments and call for precautionary approaches. A continued effort is therefore required to deliver progress on both scientific and technological fronts, as to ensure win-win situations that benefit both economic growth and environmental sustainability.

***Ocean economy innovation networks: a new kind of organisational innovation among marine and maritime actors?***

As developments in many other sectors of the economy illustrate, successful innovation in science and technology often requires fresh thinking in the organisation and structure of the research process itself. And so it is with ocean-related research, development and innovation. This report focuses on a particular type of collaboration among marine and maritime actors: innovation networks in the ocean economy.

Ocean economy innovation networks are initiatives that strive to bring together a diversity of players (public research institutes, large enterprises, small and medium sized enterprises, universities, other public agencies) into flexibly organised networks. They work on a range of scientific and technological innovations, in many different sectors of the ocean economy (e.g. marine robotics and autonomous vehicles; aquaculture; marine renewable energy; biotechnologies; offshore oil and gas). Such networks are springing up in many parts of the world in response to changes in the national and international ocean research environment, and leveraging their organisational and skill diversity to benefit their partners and research in the ocean economy more generally.

The OECD has designed and administered a survey of ten selected networks with publicly (at least partially) funded organisations at their core. Such organisations often play a crucial role in orchestrating activity on behalf of the rest of the network. Facilitating effective collaboration is a central feature of a network's success, but multiple challenges are associated with doing this effectively:

- General benefits from the networks are generated in response to the challenges associated with increasingly multi-faceted research and development in the ocean economy. Examples of benefits produced include those accruing to network participants, such as improved cross-sector synergies (e.g. linking information and communications technologies and aquaculture), access to once inaccessible research facilities/specialised knowledge, and dedicated support for marine start-ups. Other associated broader benefits include the building of scientific marine capacity and knowledge, and contributions to sustainable regional and national economic activity in general.

- Challenges faced by the innovation network centres include successfully building bridges between organisations with differences in purpose and objectives; balancing opportunities for fundamental research and commercial potential; and, maintaining a culture of innovation among all partners.

Where independent assessments of the impact of ocean economy innovation networks have been carried out, they have shown generally positive impacts within and beyond the ocean economy. More effort to assess the cost-effectiveness of public expenditure on innovation network centres, in more locations, is required if their value to society is to be better understood.

***What new approaches to ocean economy measurement and monitoring should be pursued?***

Governments' policies towards science and research guide and influence business development and marine preservation; moreover they are instrumental in matters of stewardship, regulation and management of our seas and ocean. To perform those multiple assignments effectively, their policies increasingly need to be evidence-based. However, a long journey lies ahead to gather the information, data, analysis and knowledge that is vital for decision making in the ocean economy at all levels, from local to global.

Advances in economic measurement and monitoring could signify decisive breakthroughs in offering public authorities (but also many other stakeholders) the evidential support they require. Three areas that could markedly improve decision-making are:

1. Standardising approaches to measuring and valuing ocean industries, and integrating them into national accounting via satellite accounts;
2. Measuring and valuing natural marine resources and ecosystem services, and exploring ways also to integrate them into national accounting frameworks; and,
3. Better identifying and measuring the benefits of public investment in sustained ocean observation systems.

Some countries already have in place economic data sets that attempt to measure and value their ocean industries. However, methods, definitions, classification systems and measurement approaches vary considerably over time and from country to country, making it hard for decision makers to develop a consistent grasp of the value of ocean economic activity, track its contribution to the overall economy, and compare the size, structure and impacts of ocean economies internationally. Still, many countries are beginning to commit resources to collecting more robust ocean economy data within their national accounts.

► Ocean economy satellite accounts could offer a way forward. Building up on existing data collection efforts, satellite accounts offer a robust framework for monitoring aspects of a country's economy not shown in detail in the core national accounts while allowing for greater flexibility for those industries not covered by industrial classifications. Satellite accounts for the ocean economy would provide a highly organised method for collecting consistent ocean economy data. Should a critical mass of countries develop such accounts then international comparability would be enhanced.

Measuring the economic value of marine ecosystems is a complex exercise, currently far more complicated than estimating the value of ocean-based industries. Comprehensive biophysical assessments of the marine environment have not been carried out in most parts of the world, let alone in the deep-sea, where knowledge is even thinner. Nonetheless, much academic research on environmental valuation is under way, in particular order to increase awareness of the significance of healthy ecosystems to society, and thus improve their protection and management. At this stage, marine ecosystem accounting is still in its infancy, and few examples exist of established experimental accounts, although several countries have begun the process of understanding their ecosystem services better through the implementation of national ecosystem assessments.

- ► Given the strong interdependency between ocean industry activities on the one hand and marine ecosystem health on the other, ultimately it is a national accounts framework that offers a future path to integrating the measurement of both pillars of the ocean economy in a meaningful and policy-relevant way. As the knowledge base build-ups on marine ecosystems, more efforts to share internationally experiences would greatly benefit the process of refining both the international environmental accounting guidelines and marine ecosystem service classifications.

Finally, systems for sustained ocean observations are an essential part of worldwide efforts to better understand the ocean and its functioning. These observing systems comprise fixed platforms, autonomous and drifting systems, submersible platforms, ships at sea, and remote observing systems such as satellites and aircraft, using increasingly efficient technologies and instruments to gather, store, transfer and process large volumes of ocean observation data. The data derived from such instruments are crucial for many different scientific communities and for a wide range of public and commercial users active in the ocean economy. They underpin a wide range of scientific research, and critically support the safe, effective and sustainable use of ocean resources and the ocean environment. Developing and sustaining them requires significant public investment, the justification for which calls for rigorous assessment of the associated costs and benefits and value to society.

- ► The report proposes fresh approaches to close the gaps. Solutions include improved tracking of users (both scientific and operational), the mapping of value chains, and improvements to methodologies through the development of international standards or guidelines for the valuation of ocean observations.

A focal point of this new OECD publication has concerned innovation in many areas, and combinations of innovations, which may have the capacity to foster both economic development and ocean sustainability. Further OECD work will be ongoing in 2019-20 as to provide more evidence on the development of a sustainable ocean economy.

# 1. Overall assessment and recommendations

*Chapter 1 summarises the main findings and recommendations of the OECD report "Rethinking innovation for a sustainable ocean economy". It emphasises the growing importance of science and technologies in improving the sustainability of our seas and ocean. It then identifies three priority areas for action: encourage innovation approaches that produce win-win outcomes for ocean business and the ocean environment; seek ways to foster the creation and nourish the vitality of ocean-economy innovation networks; and support new pioneering initiatives to improve measurement of the ocean economy.*

## 1.1. The crucial role of innovative approaches for a sustainable ocean economy

The ocean and its resources are increasingly recognised as indispensable for addressing the multiple challenges that the planet faces in the decades to come. By mid-century, enough food, jobs, energy, raw materials and economic growth will be required to sustain a likely population level of between 9 and 10 billion people. The potential of the ocean to help meet those requirements is significant, but fully harnessing it will require substantial expansion of many ocean-based economic activities. That will prove challenging, because the ocean is already under stress from over-exploitation, pollution, declining biodiversity and climate change. Indeed, ocean health is declining rapidly in many parts of the world, with dramatic socio-economic consequences. Dealing with these challenges calls for fresh thinking in many areas. The time is ripe therefore to explore innovative approaches as many changes are unfolding both in the ocean and in the science, research and innovation (STI) policy landscape.

### *1.1.1. A conducive policy context to test new approaches*

The last few years have seen a growing awareness of the importance of ocean sustainability issues, which has led to numerous new ocean initiatives at national, regional and global levels. In parallel, the much broader science, research and innovation (STI) policy landscape has been evolving rapidly, driven by the emergence of a host of new technology developments, by digitalisation, and by a resetting of priorities in national research agendas. Taken together, these changes offer an abundance of opportunities to develop innovative approaches for a sustainable ocean economy.

In less than a decade, the ocean has become a priority for many OECD and developing countries around the world, as it is increasingly recognised as an important source of economic growth and employment. At the same time, there is a growing realisation that the ocean is a fragile environment on which humanity depends for its climate, its weather, and – especially in coastal regions – for its very survival. Over-exploitation, pollution of all kinds from human activity, and climate change all contribute to undermining both the long-term stabilising effects of the ocean, and the socio-economic gains that it can yield, if used responsibly (OECD, 2016[1]).

In this context, the number of ocean governance-related initiatives at national, regional and global levels has multiplied. To name but a few, they include: the establishment of a specific ocean-related United Nations (UN) Sustainable Development Goal 14, with targets as early as 2020 (Box 1.1); the holding of a large-scale UN Ocean Conference in 2017 in New York; the announcement of a new UN Decade of Ocean Science (2021-30); the forthcoming (2019) publication of the first-ever report by the Intergovernmental Panel on Climate Change on the ocean and cryosphere, which will provide crucial information on the health of the ocean; the start in September 2018 of the negotiations on an international agreement to protect marine biodiversity in areas beyond national jurisdiction (ABNJ) in the high seas; and ongoing efforts by European countries to establish by 2020 the targets and indicators necessary to achieve Good Environmental Status under the European Union’s Marine Strategy Framework Directive. A plethora of ocean-related conferences and other major events are also being held these days, organised by a wide variety of stakeholders from industry, academia, government and civil society.

All these ocean-related initiatives are occurring at a time when science, technology and innovation activities themselves are undergoing major changes (OECD, 2018[2]).

Galvanised by digitalisation, the transformation of scientific research and innovation processes is speeding up in many parts of the world, in almost all disciplines and sectors of the economy. The adoption of disruptive technologies (e.g. artificial intelligence, big data, blockchain) is starting to affect academic research areas and business innovation cycles alike. The promotion of collaborative and open innovation is also changing the way researchers are training and working together (OECD, 2017[3]). At policy level, a number of national research agendas are increasingly emphasising the need to tackle "grand challenges", in economic, societal and environmental areas. In some countries, this new focus takes the shape of mission-oriented STI policies, steering the direction of science and technology towards ambitious and socially relevant goals, with Sustainable Development Goals re-shaping in some cases STI policy agendas (OECD, 2018[2]).

**Box 1.1. SDG 14 "Life below Water" with direct implications for science and technology**

The SDG 14 aims to conserve and sustainably use the oceans, seas and marine resources for sustainable development. Its targets includes:

14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution

14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans

14.3 Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels

14.4 By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics

14.5 By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information

14.7 By 2030, increase the economic benefits to small island developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism

14.A Increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, in order to improve ocean health and to enhance the contribution of marine biodiversity to the development of developing countries, in particular small island developing States and least developed countries.

Source: United Nations (2018[4]), *Global Indicator Framework for the Sustainable Development Goals and Targets of the 2030 Agenda for Sustainable Development,* United Nations Statistical Commission, 49th session, A/RES/71/313, New York, March.

As the OECD report on *The Ocean Economy in 2030* emphasised, realising the full potential of our seas and ocean will demand responsible, sustainable action on numerous fronts to achieve a durable balance between ocean use and marine ecosystem integrity (OECD, 2016[1]). While such actions will necessarily encompass initiatives in a range of policy areas, from regulatory and structural reform to changes in environmental policy and governance, developments in science, technology and innovation will continue to play their crucial part in addressing many of the challenges facing the use and protection of our seas and ocean.

### *1.1.2. Summary of the fresh approaches proposed in this report*

Putting an original focus on science, technology and innovation highlights fresh approaches that may help tackle the challenges of a sustainable ocean economy. With that in mind, this publication sets itself four objectives:

- Offer a forward-looking perspective on scientific and technological innovation across a range of marine and maritime applications, with a particular focus on some of the innovations already in the pipeline (Chapter 2);
- Contribute to the growing body of evidence suggesting that, with the help of innovation, the development of economic activity in the ocean and sustainability of marine ecosystems can go hand in hand with one another, and provide a number of in-depth case studies that illustrate the potential for generating such win-win outcomes; (Chapter 2)
- Investigate the emergence of different forms of collaboration in the ocean economy across research communities in the public sector, the academic world and a diverse range of private-sector stakeholders, using the example of innovation networks that have sprung up in recent years around the world (Chapter 3);
- Highlight new approaches to measuring the ocean economy, notably by exploring the use of satellite accounts for its twin pillars – ocean-based economic activities and marine ecosystem services – and by examining ways to better measure the benefits that important sustained ocean observations provide not only to science, but also to the economy and society more generally (Chapter 4).

On the basis of the analysis presented in this report, three priority areas for action are recommended and summarised in the follow-up sections:

1. encourage innovation that produces win-win outcomes for ocean business and the ocean environment;
2. seek ways to nourish the vitality of ocean-economy innovation networks; and
3. support new initiatives to improve measurement of the ocean economy.

## 1.2. Encourage innovation that produces win-win outcomes for ocean business and the ocean environment

The ocean is now being used more intensively than ever before, raising questions about its physical capacity to cope. At the same time, however, scientific understanding of the ocean and its ecosystems – their properties and behaviour, their health and role in weather and climate change – is gradually improving. To respond effectively to the growing challenges associated with the development of economic activity in the ocean, increased attention needs to paid to the possibilities for greater interaction and stronger synergies between ocean-related science on the one hand and ocean business on the other.

### *1.2.1. Recent acceleration of research interests in ocean-related innovations and their applications*

The breadth and depth of scientific and technological advances in today's ocean economy are the product of a flourishing, highly dynamic innovation landscape. The OECD 2030 report noted a string of enabling technologies with the potential to improve efficiency, productivity and the cost structure of many ocean activities in the coming decades. Scientific research, shipping, energy, fisheries and tourism are but a few examples of the activities likely to be impacted (OECD, 2016[1]). The enabling technologies highlighted in the report include imaging and physical sensors, advanced materials, autonomous systems, biotechnology, nanotechnology and subsea engineering. In addition, there are a range of likely disruptive and step-change innovations combining multiple technologies and finding application in activities as varied as ocean floor mapping, smart shipping, and tracing fish stocks and fish products. Considerable potential therefore resides in leveraging technology synergies across science disciplines and among different ocean sectors.

The update provided by the present report suggests that, in the years since the publication of *The Ocean Economy in 2030*, there has been a further acceleration of interest in the potential applications of a range of technologies, both for commercial purposes and for gaining a better understanding of marine ecosystems, their workings, and the requirements for their better management. It notes an increasingly pervasive spread, throughout the ocean domain, of such generic technologies as artificial intelligence, big data, complex digital platforms, blockchain, drones, sophisticated arrays of sensors, small satellites, genetics, and acoustics. All appear set to contribute in important ways to the sustainable development of the ocean economy, not least by vastly improving data quality, data volumes, connectivity and communication from the depths of the sea, up to the surface for further transmission.

### *1.2.2. Innovations that may foster both economic development and ocean sustainability*

Looking beyond the general picture of recent advances in science and technologies, a focal point of the report concerns innovations, and combinations of innovations, which may have the capacity to foster both economic development and ocean sustainability.

To do this, it presents four in-depth innovation case studies that were chosen, because of the high interest they generate in different parts of the world, and their different levels of technical and business maturity that help draw some interesting lessons learned. The four case studies are: floating offshore wind power; conversion of decommissioned oil and gas rigs and renewables into artificial reefs; advances in ballast water treatment to combat the spread of (alien) species; and innovations in the marine aquaculture sector which contribute to making the industry economically and environmentally more sustainable.

The four case studies are very different. They differ in scale and in the degree of maturity of the respective activity. Floating wind power is still in its infancy, with only one commercial-scale facility in operation in the world. Ballast water treatment technologies have so far been installed in only a small number of ships, but expansion could be rapid. Oil and gas rig conversion into artificial reefs is current in some parts of the world, but not in others, and no renewables-to-rigs programmes exist anywhere. Marine aquaculture, by contrast, is well established in many parts of the world, is undergoing rapid expansion, and is being transformed at great speed by a whole host of innovations. For this reason the marine aquaculture case study is addressed in more detail and at sector-wide level. Moreover, innovation in the four activities is driven by different forces and different challenges. Despite these differences, examination of innovation activity in the four areas reveals that they share many common features.

### *Innovations in marine sectors are science-led and often interconnected*

Progress made in all the areas has clearly been science-led or at least science-based, underlining the vital role that science plays in the ocean economy. Moreover, the innovations are seldom "stand-alone" innovations; rather, they develop in combination with – or at least in association with – other innovations and technologies.

**Table 1.1. Step change progress in the development of sustainable ocean activity requires multiple innovations from different disciplines and sectors**

| Floating wind energy | Rigs/Renewables to Reefs | Ballast water treatment | Marine aquaculture |
|---|---|---|---|
| Siting (eg. satellite remote sensing + modelling) | New types of well plug | Detection of organisms & bacteria (e.g. lab-on-chip techniques, new-generation DNA etc.) | Siting/area-wide assessment (earth observation high spatial resolution; GIS mapping + modelling) |
| New construction materials and methods (e.g. rotor blades, foundations) | Subsea vehicles for survey and inspection | Conventional disinfection processes (e.g. ultraviolet irradiation, electro-chlorination) | Breeding (selective breeding, genome sequencing, marker assisted selection) |
| New designs (e.g. twin hulls/multi-turbine arrays, dynamic cable systems) | DNA barcoding, population fingerprinting for connectivity analysis | New environmentally friendly treatments, e.g. pasteurisation | Feed (micro-algae, plant- and insect-based, fish oil replacements) |
| Inspection, maintenance & repair (e.g. AUVs / ROVs, AI-driven monitoring) | For renewables – ecosystem impact modelling of biomass aggregation | | Waste management (IMTA, sensor-platforms, decision algorithms) and disease control (eDNA tools, mass spectrometry +AI, use of cleaner-fish) |
| | Network analysis and modelling tools | | Open ocean engineering |

The steep falls in the cost of energy expected in floating offshore wind turbines, for example, will stem from improved siting with the help of satellite data, from new foundation designs, use of composite materials in turbine blade manufacture, and deployment of marine automated unmanned vessels (AUVs) and remotely operated vehicles (ROVs) for monitoring, inspection, maintenance, and repair of offshore facilities. In marine aquaculture, multiple approaches are being brought to bear on the problem of disease prevention, control and treatment, ranging from advances in breeding for greater disease resistance (e.g. marker assisted selection) and new generation of vaccines, to hyperspectral analysis for detecting lice infestations. And in ships's ballast water treatment, research has given rise to hundreds of different applications that use a variety of underlying technological principles ranging *inter alia* from ultra violet, oxidation and de-oxygenation, to electrolysis, ultrasound and heat.

### *The economic stakes for ocean economy innovations are high*

From an economic and business perspective, the innovations and combinations of innovations under way may be associated with significant potential gains. And selected sector-specific innovations tend to generate spillover benefits for other sectors of the ocean economy.

In terms of potential sector-specific gains:

- Floating offshore wind farms could in the longer term provide a further boost to the already rapidly expanding world market for offshore wind power as a whole – projected to generate by 2030 around USD 230 billion global value added and 435 000 full-time jobs (OECD, 2016[1]).
- Thousands of oil and gas platforms will need to be decommissioned in the coming decades. Reef creation requires leaving at least part of the infrastructure in place if fish, molluscs and other marine life are able to thrive. Partial removal of the infrastructure, as opposed to almost complete removal, could save the operators billions of dollars in decommissioning costs.
- The potential global market for ballast water management systems – based on a range of different scenarios and assumptions concerning the number of retrofitted vessels and average cost per refit – is estimated to be in the order of USD 50 billion (OECD, 2017[5]).
- In the marine aquaculture sector, the cumulative effect of innovations promises to be an important contributing factor in enabling gross value added to grow at well over 5% per year, trebling the sector's value between 2011 and 2030 to around USD 11 billion (OECD, 2016[1]).

In addition to potentially providing economic benefits for their respective ocean industry, the innovations and combinations of innovations described here tend to generate significant spill-over effects for other sectors of the ocean economy. These spill-over effects may take the form of further technology development or extension of technology to other sectors, or more generally they may lead to further economic activities in neighbouring sectors.

By way of illustration, economic benefits from the accelerated deployment of floating offshore wind farms are expected to flow to ports, shipbuilders, and marine equipment suppliers and operators. Initiatives to encourage conversion of rigs and offshore wind platforms to reefs have the potential to benefit capture fisheries, aquaculture, downstream offshore services, and remote and autonomous marine vehicles' activities. More widespread uptake of ballast water treatment processes stands to benefit marine equipment suppliers and the shipbuilding and repair business industries. And sustainable expansion of marine aquaculture promises economic gains for downstream sectors such as the seafood processing industry, as well as upstream services and inputs such as cleaner-fish breeders, providers of remote sensing and inspection equipment, and suppliers of aquafeed and supplements (a global market already estimated in 2017 at well over USD 100 billion, and projected to reach over USD 172 billion by 2022 (Research and Markets, 2017)).

### *The benefits to marine ecosystems could be significant but are still hard to quantify*

The benefits to marine ecosystems stemming from these innovations are highly diverse and difficult to quantify. However, a summary of the types of ecosystem benefits likely to be realised is provided below.

Direct benefits to ocean ecosystems are identifiable in all of the cases (Table 1.2). The installation of floating offshore wind platforms entails less interference with the seabed. Innovations in ships' ballast water treatment are expected to make a significant contribution to reducing the spread of alien marine species. The conversion of rigs and renewable energy infrastructure to reefs can lead to restoration of fish and mollusc stocks, to reduction in disturbance of the seabed and in destruction of benthic fauna and flora, although the conditions under which these benefits occur are yet to be fully understood. In some circumstances, they may enhance the network of hard substrate ecosystems for certain species by acting as bridges (via larval dispersion) between otherwise distinct networks, be they in the deep sea, in fjords or in marine-protected coral areas (Roberts et al., 2017[6]).

**Table 1.2. Potential benefits to marine ecosystems may be significant, but hard to quantify**

| Area of innovation activity | Examples of potential direct benefits to marine ecosystems | Examples of potential indirect benefits to marine ecosystems |
|---|---|---|
| Floating offshore wind farms | Less interference with seabed | Reduction in GHG emissions = slower rise in water temperatures & acidification and slower reduction of oxygen levels |
| Ballast water treatment | Reduction in spread of (alien) marine species, reduced use of chemicals | Lower levels of bio-fouling leading to lower fuel consumption |
| Marine aquaculture | Reduction in coastal water pollution, in use of wild fish stocks for feed (and cleaning) and in use of antimicrobial treatments | Reduction in CO2 emissions from lower energy consumption due to automation, remote monitoring etc. |
| Rigs/Renewable energy infrastructure -to-reefs | Enhancement or restoration of fish and mollusk stocks, reduction in the damage to the seabed and to benthic fauna and flora, enhancement of hard substrate ecosystem networks | Reduction in GHG emissions from reduced dismantling of platforms and transport to and from port. |

In the case of scientific and technological advances in marine aquaculture with respect to site selection, breeding, feed, waste treatment, and disease control and treatment, all would appear to benefit on balance the sustainability of coastal ecosystems. These benefits could potentially be overshadowed by the engineering solutions that increase the likelihood of moving aquaculture offshore. Open-ocean aquaculture appears to offer many advantages compared to coastal seafood farming: fewer spatial constraints, less environmental impact, lower risk of conflicts with other ocean users, and fewer problems with disease. However, very few large-scale open-ocean farms are currently in operation, not least because they face a host of challenges: designing structures that can withstand the harsh conditions of the open ocean; access to the facility for monitoring, harvesting and maintenance purposes; communications; and safety of personnel, to name but a few. Yet recent studies suggest the potential area for ocean aquaculture is large. Indeed, it could theoretically encompass an area of over 11 million square kilometres for finfish and over 1.5 million kilometres for bivalves – sufficient to grow 15 billion tonnes of finfish a year, or 100 times the current global levels of seafood consumption (Gentry et al., 2017[7])).

Indirect benefits to the environment are thought to be substantial in the case of floating offshore wind energy, given its potential to reduce global CO2 emissions. Estimates of carbon emissions from offshore wind generation conducted in 2015 place life-cycle emissions in the range of 7 to 23 grams of CO2 equivalent per kilowatt (gCO2e/kWh). This compares with around 500 g for gas-fired conventional generation and about 1000 g for coal-fired conventional generation (Thomson and Harrison, 2015[8]). The potential decline in CO2 output, in turn, stands to benefit the world's ocean ecosystems by contributing indirectly to a reduction in acidification, de-oxygenation and the rise of sea temperature and sea levels.

### *Future development may be constrained by gaps in scientific knowledge*

Although some evidence points to possible positive impacts on the economy and ecosystems alike, many crucial questions remain to be answered in terms of the potential effects of many of the above-described innovations, which may hamper or at least slow their application on a larger scale.

**Table 1.3. Limited scientific knowledge of the potential impacts on marine ecosystems could prove a constraint for some sectors**

| Area of innovation activity | Examples of knowledge gaps |
|---|---|
| Floating offshore wind farms | As yet, too few floating platforms in operation for evidence-gathering, but potential impacts of large-scale operations on (migrating) bird life, fish and marine mammals, as well as on seabed and benthic habitats due for example to wide ecological footprint of some mooring systems. |
| Rigs/ Renewable energy infrastructure -to-reef conversion | Risk of chemical pollution from infrastructure left in place. Some studies available on effects on fish populations (the "stock enhancement" versus "attraction" debate) but little thorough-going research into other ecosystem effects (bio-diversity, benthic habitats etc.) especially at deep-sea sites. |
| Ballast water treatment | Issues surrounding practical implementation of on-board ballast water treatment and also efficacy of currently available technologies in different marine environments. |
| Marine aquaculture | Few open ocean farming projects currently in operation around the world, technical hurdles considerable, data on ecosystem impact weak, area-wide impact of large scale and concern about operations. |

A big question around open-ocean aquaculture concerns the area-wide impact of the activity in the form of intensive, high-volume operations, and the implications for ocean carrying capacity. Data on this scale of ecosystem impact is very limited, making it particularly challenging to set a baseline of ecologically meaningful reference points such as minimum distance, depth, and current velocity.

With very few floating wind platforms as yet in operation at commercial scale, gaps remain in knowledge about the potential drawbacks for the marine environment. These include the impact on (migrating) bird life, the effects on fish and marine mammals, as well as those on the seabed and benthic habitats. And questions remain about ballast water treatment. These range from fundamental issues surrounding our understanding of how aquatic species spread through our ocean and seas, to concerns about the efficiency of various ballast water treatment technologies in different marine environments. For example, common and abundant seawater phytoplankton have frequently been found to be resistant to UV treatment, and especially smaller organisms and microbes often survive. And electro-chlorination has been found to demonstrate lower disinfection efficiency in upper reaches of estuaries and freshwater surroundings because of their lower salinity (Batista et al., 2017[9]).

Finally, conversion of rigs to reefs is a controversial issue, largely because of environmental considerations at the decommissioning stage. The United States has been implementing numerous rig-to-reef conversions for some years now, through dedicated rig-to-reef programmes. However, these are much less common elsewhere. Many countries have regulations that require complete or almost complete removal of offshore oil and gas infrastructures and subsequent clean-up of the seabed by the operator. Such regulations are motivated by concern that infrastructures left in place may pollute the marine environment through oil leaks or through chemical contamination, and that current generations have a duty to leave as clean an environment as possible for future generations. Recently, however, a growing debate has emerged among marine scientists and conservationists about whether a more flexible approach to decommissioning should be considered which leaves some of the lower infrastructure of some platforms in place. Several arguments are put forward in favour of partial as opposed to full removal of infrastructure. First, complete removal risks disturbing or destroying valuable habitats and biodiversity hotspots that have grown around and on the infrastructures, and in some cases disrupting the functioning of surrounding interconnected natural ecosystems. Second, complete removal may also lead to pollution by releasing trapped chemicals from the seafloor and/or disturbing toxic drilling waste on the seabed. Third, full removal is likely to generate much noise and disturb marine life in the area. And finally, complete removal of infrastructure may entail opening up previously classified no-fishing zones for fishing activity. Given the high stakes and the uncertainties and lack of knowledge around each of the options, much scientific work remains to be done (Fowler et al., 2018[10]).

### *1.2.3. Next steps*

In conclusion, realising the full potential of innovations in the ocean economy will demand major efforts in science and technology research, on both sides of the equation: in achieving the breakthroughs that are required to exploit sustainably the rich opportunities now emerging for ocean industries, and in addressing the many vital knowledge gaps about the ocean environment which may act as impediments to the ocean economy's future development.

Two issues illustrate possible directions of future action, so as to balance the activities of ocean-based industry with careful management of the ocean environment:

- In terms of commercial opportunities for innovators, decision makers seeking to encourage and support the development of innovations and their application in the ocean economy should bear in mind the bigger ocean-economy picture, so as not to miss the potential economic benefits that could flow to upstream and downstream segments of the sector in question, or indeed the spill-overs, both in terms of economic activity and technological progress, to other ocean-based sectors outside of the sector in question. This would entail up-to-date and regular industry mapping, as to keep track of the growing synergies between sectors.
- And in environmental terms, increasingly significant areas for scientific research will concern the complex impacts on marine ecosystems stemming from the expected growth of economic activity in the ocean, in combination with increasing climate change effects. The need to address major scientific gaps will have often to take precedence before launching into major developments, via a co-ordination of public and private actors taking precautionary approaches together, so as to avoid damaging the ocean environment dramatically.

## 1.3. Seek ways to nourish the vitality of ocean economy innovation networks

As developments in many other sectors of the economy illustrate, successful innovation in science and technology often requires fresh thinking in the organisation and structure of the research process itself. And so it is with ocean-related research, development and innovation. Chapter 3 of this report focuses on a particular type of collaboration among marine and maritime actors: the innovation networks in the ocean economy.

### 1.3.1. Features of ocean economy innovation networks

For decades, marine and maritime actors have been working together, via industry clusters, joint research programmes and various knowledge networks. For the first time, the OECD has been exploring ocean economy innovation networks. They are initiatives that strive to bring together a diversity of players – public research institutes, small and medium sized enterprises (SMEs), large enterprises, universities, other public agencies – to work on a range of scientific and technological innovations in many different sectors of the ocean economy (e.g. marine robots and autonomous vehicles; aquaculture; marine renewable energy; biotechnologies; offshore oil and gas). Such networks respond to changes in the national and international research environment and leverage their diversity to the benefit of the ocean economy and, potentially, society more broadly.

Innovation networks in the ocean economy take numerous forms, from loose relationships between various independent actors to relatively formalised associations or consortia pursuing common goals. They also involve multiple types of organisations, implying that effective collaboration is a central feature in the success of such innovation networks.

Publicly funded organisations often play a significant role in federating interested parties, channelling funds and facilitating common projects. Their role as both brokers and/or orchestrators of networked activity is a reason why the OECD has surveyed ten selected innovation networks with publicly (at least partially) funded organisations at their core (i.e. the innovation network centres) (Table 1.4). Typically, innovation network centres conduct a number of important functions on behalf of the rest of the network, including designing membership, structure and position, and managing various aspects of the networks' activities (Dhanaraj and Parkhe, 2006[11]). They also tend to facilitate access to research facilities, engage academia in industry and vice versa, and support small and medium sized enterprises.

**Table 1.4. Innovation networks responding to OECD questionnaire**

Innovation network centre name and country of origin

| Name of innovation network | Country |
|---|---|
| Ocean Frontier Institute | Canada |
| Offshoreenergy.dk | Denmark |
| Innovative Business Network (IBN) – Offshore Energy | Belgium (Flanders) |
| Campus mondial de la mer | France |
| Marine Renewable Energy (MaREI) | Ireland |
| EXPOSED Aquaculture | Norway |
| MARE StartUp | Portugal |
| Scottish Aquaculture Innovation Centre | United Kingdom |
| Oceanic Platform of the Canary Islands (PLOCAN) | Spain |
| Marine Autonomous & Robotic Systems Innovation Centre | United Kingdom |

Shepherding the innovation process among a diversity of actors remains a challenging endeavour. Some of the issues that were addressed include orchestrating broad types of organisations with sometimes competing priorities; balancing commercial potential and opportunities for more research; and, maintaining a culture of innovation among all participants in the network.

The innovation networks that were surveyed involve many different types of organisations. Universities play a significant role both as a source of basic knowledge and as potential partners for industry (OECD, 2008[12]). The inclusion of small and medium sized firms and entrepreneurs in ocean economy innovation networks is also often seen as a priority, as they can be not only beneficiaries of potential spillovers from larger knowledge-intensive firms, but also sources of new ideas and inventions for the other network partners (Karlsson and Warda, 2014[13]). Collaboration in this regard is often an important source of innovative knowledge for large firms, which are two to three times more likely to collaborate with public research organisations than SMEs (OECD, 2017[14]). SMEs, on the other hand, tend to collaborate more with their suppliers.

Activities of the innovation networks are quite broad, ranging from ocean monitoring to aquaculture to marine renewable energies. One interesting lesson learned from the survey, is that innovation in the ocean economy is often no longer focused on developing a single new technology for a given sector, but on identifying smart combinations of existing and/or new ones to tackle complex problems. As seen already in the previous sections, sustainable growth of the ocean economy is likely to rely on technological advancements that are both multi-faceted within and across domains of expertise and reliant on numerous emerging and fast-changing enabling technologies. The types of technologies under development by the innovation networks in question include robotics, autonomous systems, wave and tidal technologies, new materials and structures, biotechnology and advanced marine sensors. Ocean economy innovation networks are one construction through which the synergies between such technological advancements and their uptake in ocean-based industry are being realised.

### *1.3.2. Well-run innovation networks generate a range of benefits for the ocean economy and beyond*

Ocean-related innovation networks, like other networks active in different sectors of the economy, have the objective to bring different types of benefits to their stakeholders and beyond. The importance of evaluating the performance and benefits of these networks will be an important step in ensuring the sustainability of these networks.

Independent and credible scrutiny is required to ensure that public funds reach their target of facilitating co-operation between different stakeholders and lead to innovations. Furthermore, evaluating performance of innovation networks over time will help ensure their effectiveness and sustainability as they mature. Where independent assessments of ocean economy innovation networks have already been carried out, they have shown generally positive impacts within and beyond the sector under investigation. However, more efforts to assess impacts in more locations will be required if their value is to be fully assessed and widely understood.

Documented benefits are often generated in response to the challenges associated with increasingly multi-faceted research and development in the ocean economy:

- For example, a fragmentation in ocean research objectives and efforts is often observed among stakeholders (OECD, 2016[1]). In response, innovation networks provide a co-ordinated approach across disparate research communities and improve cross-sector synergies;
- A second challenge concerns the growing scientific, technological and logistical complexity of applied research in the ocean economy. A well organised innovation network brings together a diverse range of actors and partners and can strengthen multidisciplinary approaches and activities. It may also enable the

exploration of opportunities for combining established and emerging technologies;

- The third challenge in this regard concerns exploiting the synergies between and across sectors.

In addition, innovation networks may produce benefits that spill over to society more generally. Scientific capacity and knowledge may be increased in any number of ways. One potential avenue that is actively pursued by innovation networks is more cost-effective ocean monitoring, as the ability to measure and observe the ocean is the cornerstone of ocean sciences. Advances in this area lead to greater scientific and societal understanding of the ocean. The exchange of knowledge between economic sectors beyond the ocean economy also offers opportunities for progress. Innovation networks therefore play an important role in tracking technological developments, considering possible ocean applications and communicating advances to their partner organisations. Finally, innovation specifically in networks has a major role to play in the realisation of a sustainable ocean economy in more intangible ways. Matching collaborators with complementary but different expertise is likely to result in development paths that are some combination of the objectives of all parties involved. For example, the independent involvement of marine scientists in ocean projects early on, to study and model possible environmental impacts, may result in better acceptability to society for some projects, than products resulting from innovative efforts conducted by industry alone.

In areas where the advantages outweigh the disadvantages and positive impacts are likely, policymakers may wish to encourage ocean economy innovation networks through a number of potential policy steps.

### *1.3.3. Next steps*

In view of the diversity of the ocean economy innovation networks that exist, there is no ‘one size fits all’ recommendation. However, policymakers and other decision-makers looking to evaluate the impacts and encourage ocean economy innovation networks in their countries may wish to consider the following options:

- Evaluating performance of the innovation networks over time will help ensure their effectiveness and sustainability as they mature. Where independent assessments of ocean economy innovation networks have already been carried out, they have generally shown benefits within and beyond their main fields of activity. However, more efforts to assess impacts will be required if their value is to be fully assessed and understood widely.
- Where appropriate, efforts could be made to ensure ocean regulations are orientated towards innovation, by increasing their flexibility (e.g. demonstrators). Consulting ocean economy innovation networks during the regulatory-making process – and this is already the case for most of the surveyed networks – is likely to result in a clearer, more effective and innovation-friendly regulatory environment;
- Although public funding of innovative activities is often only available for early technology readiness levels (e.g. from fundamental research to early demonstration phases), further support may be required at times in the latter stages of development of certain innovation activities, both in terms of facilitating access to finance and in accessing test facilities and demonstration sites;

- Finally, the types of innovations under development, particularly those concerning ocean monitoring, could have many uses beyond their scientific and commercial applications, and as such they may be tested and exploited as advanced new tools for ocean governance.

Given all of the above, a possible OECD research agenda for further analysing ocean economy innovation networks emerges. Although collaboration with diverse actors was already taking place for many of the innovation network centres surveyed, the networks were established rather recently and are sure to be undergoing fast-paced changes, mirroring the rapid innovation occurring in the areas in which they operate. A follow-up work programme will examine more centres, in different parts of the world, with different set-ups and characteristics, and explore new lines of enquiry. Finally, a study of the roles of intellectual property policies and alternative sources of finance for SMEs seems particularly pertinent to the ocean economy.

## 1.4. Support new pioneering initiatives to improve measurement of the ocean economy

The technological and organisational innovations described in the previous sections, could potentially contribute significantly to the development of economic activity in the ocean and to the conservation and sustainable use of marine ecosystems. The balance between the two will be crucial for achieving greater sustainability of the ocean economy.

National policies towards science and research will play a crucial role in guiding and influencing business development and marine preservation; moreover, they will be instrumental in matters of stewardship, regulation and management of our seas and ocean. To perform those multiple assignments effectively, policies need to be evidence-based. However, a long journey still lies ahead to gather the information, data, analysis and knowledge that is vital for decision making in the ocean economy at all levels, from local to global.

With the above in mind, Chapter 4 outlines three examples of areas in which major advances in economic measurement, methodology and monitoring could signify decisive breakthroughs in offering public authorities (but also many other stakeholders) the evidential support they require for markedly improved decision making. These are:

- standardising approaches to measuring and valuing ocean industries, and integrating them into national accounting via satellite accounts;
- measuring and valuing natural marine resources and ecosystem services, and exploring ways also to integrate them into national accounting frameworks;
- and better identifying and measuring the benefits of public investment in sustained ocean observation systems.

### *1.4.1. Measuring and monitoring ocean-based industries*

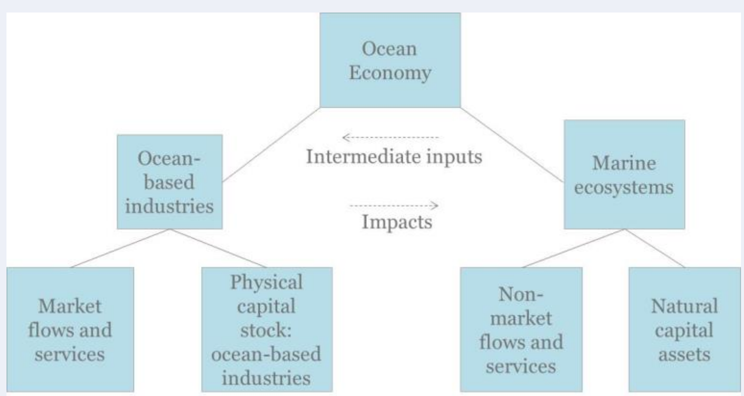
The importance of measuring the economic performance of ocean-based industry is becoming increasingly apparent to both public policymakers and private decision-makers alike. Many countries already have in place data sets that attempt to measure and value their ocean industries. However, methods, definitions, classification systems and measurement approaches vary considerably over time and from country to country, making it hard for decision-makers to develop a consistent grasp of the value of ocean economic activity, track its contribution to the overall economy, and compare the size, structure and impacts of ocean economies internationally.

Despite the benefits associated with consistent ocean economy measurements, economic data has often been collected in an *ad hoc* manner. This has resulted in inconsistencies within measurements and a plethora of issues concerning comparability, both between the ocean-based industries that make up the ocean economy and between it and other sectors.

**Box 1.2. Measuring the ocean economy's two pillars**

The ocean economy is defined by the OECD as the sum of the economic activities of ocean-based industries, together with the assets, goods and services provided by marine ecosystems (OECD, 2016[11]). These two pillars are interdependent, in that much activity associated with ocean-based industry is derived from marine ecosystems, while industrial activity often impacts marine ecosystems. The economic value associated with each pillar can be differentiated according to whether the goods and services that flow from it are traded in markets or not. This concept of the ocean economy as an interaction between two pillars with corresponding economic value is depicted in the figure below.

**Figure 1.1. The concept of the ocean economy**




*Source*: OECD (2016[1]), *The Ocean Economy in 2030*.

The interdependency of the two pillars, combined with increasingly severe threats to the health of the ocean, have led to a growing recognition that management of the ocean should be based on an integrated ecosystem approach (OECD, 2016). Several management strategies have been suggested to achieve this, including Integrated Coastal Zone Management (ICZM), Marine Spatial Planning (MSP) and Marine Protected Areas (MPA). Crucial to each framework is accurate and extensive information base on ocean economic activity, the marine environment and the interactions between the two. Revealing the economic value of marine ecosystems aids this process. Robust measurements, in a common metric, are fundamental to ensuring ocean-based industries and marine ecosystems are managed in an integrated manner.

Many countries are beginning to commit resources to collecting more robust ocean economy data, however. Efforts to collect data through the national statistical systems of many countries are gaining momentum. Some, such as Portugal, have moved towards adopting satellite accounts for ocean-based industries that are compatible with the core national accounting system. Others have begun measuring ocean economic activity using methods similar to those used in satellite accounting. The Marine Institute of Ireland has collected economic data on an annual basis since 2004 and issues reports analysing key trends. Canada measures gross domestic product (GDP) and employment in several industries, while the EU Commission has collected similar data. Norway produces several publications detailing economic statistics in ocean-based industries, including tracking changes in natural resources. The Danish Maritime Authority monitors activity across a number of core and secondary industries of its maritime cluster. Italy has produced several metrics of its maritime economy, including value-added and employment. The Korean Maritime Institute has recently extended the scope of its ocean economy measurements to include marine services and resource development. An alternative approach has been adopted by the National Marine Data and Information Service of China, which uses ratios to disaggregate data on ocean-based industries from broader statistics.

### *Issues preventing consistent measurements of the ocean economy*

Although efforts to collect robust information on the ocean economy are increasing, economic data currently collected through most countries' national statistical systems remains incompatible for two core reasons. First, data from official sources tend not to be disaggregated by the area of the economy on which it is focused. For example, activity in the oil and gas industry is often reported as an aggregation between offshore and onshore drilling. Second, it is sometimes difficult to define precisely which activities qualify as land-based and which count as ocean-based. Ports, for example, are land-based centres of much economic activity that would not exist were it not for the ocean.

Such issues are concerned primarily, but not only, with the difficulty of ensuring industrial classifications separate all ocean-based industries from their land-based counterparts. OECD research suggests that only three ocean-based industries appear in the UN Statistical Commission's International Standard Industrial Classification of all Economic Activities (ISIC) at the level of detail collected by most statistical administrations. This is considerably lower than the 19 ocean-based industries defined in *The Ocean Economy in 2030* (OECD, 2016[1]). If the appropriate classifications for all ocean-based industries were to exist, then data appropriate for the entire ocean economy would be identifiable through the system of national accounts and made available by national statistical offices alongside comparable data on all other economic sectors.

### *Ocean economy satellite accounts offer a way forward*

Presenting extensive ocean economic data through satellite accounts to the existing national accounting system provides a solution to such problems. Satellite accounts offer a robust framework for monitoring aspects of a country's economy not shown in detail in the core national accounts while allowing for greater flexibility for those industries not covered by industrial classifications. To maintain coherency, the basic concepts and accounting rules of the core national accounting system are adopted. However, important data otherwise missing from measurements of the total economy – such as data collected outside of the usual surveys used for the national accounts – can also be included, enabling full coverage of the ocean economy. Many national statistical systems already produce satellite accounts for a range of sectors – such as housing, health, social welfare, national defence, education, research and the environment – and accounts could conceivably be compiled for any sector in which there is sufficient interest. The creation of a satellite account for the ocean economy could be managed along the same lines as those already inaugurated, with an agency relevant to the ocean working alongside the statistical authority.

*Next steps*

Satellite accounts for the ocean economy would provide a highly organised method for collecting consistent ocean economy data. Should a critical mass of countries develop such accounts then international comparability would be enhanced. Given this, a framework is necessary for countries wishing to move towards satellite accounting for the ocean economy. The National Accounts Division of the OECD's Statistics and Data Directorate has developed guidance for sectoral experts wishing to pursue satellite accounts. The limitations described above suggest the international community is still some way from being able to formalise ocean economy satellite accounts.

There are, however, promising signs. Many countries have begun collecting data on the ocean economy either directly or via industry-led surveys. Such studies represent a good first step in the development of future accounting measures. These efforts could continue to be supported – accumulating as much data as possible on the scope of the ocean economy within a country will provide a valuable baseline from which a more formal ocean satellite account can be built. International efforts will be aided considerably if the results and methodologies relied upon to do so are distributed openly and widely.

The process of developing a satellite account for all ocean-based industries is almost certainly a process that requires expertise in the ocean economy and expertise in national accounts. Therefore, resources could also be committed for ocean economy specialists to work alongside national accountants to lay the foundations for experimental satellite accounts in interested countries. In parallel, there are additional steps that could be taken at the international level. Fundamentally, industrial classifications are required that capture all ocean-based activities and differentiate between land-based and ocean-based industries. Countries wishing to pursue internationally comparable measurements should continue to work on common basic definitions to aid the revision process in this regard.

### *1.4.2. Measuring and monitoring marine ecosystems*

Measuring the value of marine ecosystems is a complex exercise, currently far more complicated than estimating the value of ocean-based industries. For this reason, many estimations of the value of the ocean economy quantify only ocean-based industries and leave the value of marine ecosystems services to be discussed mainly in qualitative terms. This approach, however, does not enable the interactions of both pillars of the ocean economy to be analysed in a robust manner. Several countries have therefore begun to quantify changes in marine ecosystem services at the national level. Norway, for example, uses information collected in the Nature Index of Norway to assess the general health of Norwegian marine ecosystems.

While such efforts are to be commended, they do not enable the assessment of ocean-based industries and marine ecosystems in a common metric. An important reason for expressing the value of marine ecosystems in monetary terms is the conversion of biophysical data on the marine environment into a form compatible with other economic measures – such as the monetary values used for ocean-based industries. Readily available estimations of the economic value of marine ecosystem services would reduce the costs associated with ensuring data recorded through economic transactions and typically non-monetary environmental information are comparable. The resulting data can then be fed into analysis that attempts to understand the impact of particular decisions on the marine environment.

### *Satellite accounts offer a way forward here too*

An ocean economy satellite account could conceivably include accounts related to marine ecosystems. Although the core system of national accounts is designed for the measurement of economic activity (through key indicators such as GDP, value added and employment), the interdependency of ocean-based industry and marine ecosystems imply the inclusion of environmental information is of particular importance. While ocean-based industry could be measured according to the core system of national accounts, comprehensive data on the value of marine ecosystems, both in physical and monetary units, can also be accounted for. There are examples of countries attempting to measure the value of ecosystem services in ways that are compatible with the national accounting system. The Marine Institute of Ireland, for example, has estimated the value of marine ecosystem services using definitions given in the European Environment Agency's (EEA) Common International Classification of Ecosystem Services (CICES). The Australian Bureau of Statistics has developed an experimental ecosystem account for the Great Barrier Reef. And Portugal has outlined its intention to include marine and coastal ecosystems services in its Satellite Account for the Sea.

In order to ensure satellite accounts containing environmental information meet the rigorous accounting standards of the system of national accounts, the international statistical community has developed further guidelines for accounting for environmental impacts, goods and services. The System of Environmental-Economic Accounting 2012 - Central Framework (SEEA Central Framework) is the internationally accepted standard for accounting for environmental stocks and flows (United Nations, 2012[15]). The System of Environmental-Economic Accounting – Experimental Ecosystem Accounting is a framework for accounting for ecosystem services, not yet accepted as an international standard due to its experimental status (United Nations, 2012[16]).

### *But accounting for marine ecosystem services remains a work-in-progress*

Marine ecosystem accounting is in its infancy, with very few examples of established experimental accounts available. The accounts detailed in the SEEA Central Framework and Experimental Ecosystem Accounting are suitable for most terrestrial ecosystems and many freshwater bodies, but do not cover marine ecosystems particularly well. The classification system used in order to avoid double-counting between different types of ecosystem services may not be entirely suitable for marine ecosystem services and continues to be refined more broadly. Finally, most estimations of the value of marine ecosystem services are based on welfare measures. Such studies, while crucial to many types of policy analysis, are not suitable for ecosystem accounting that requires estimations based on exchange values.

### *Next steps*

Much progress is needed before marine ecosystem accounts can be added to an ocean economy satellite account, in view of the experimental nature of ecosystem accounting. The few examples that do exist should be studied by any organisation looking to begin accounting for marine ecosystem services. As the knowledge base build ups on marine ecosystems, more efforts to share experiences internationally would greatly benefit the process of refining both the international accounting guidelines and ecosystem service classifications. In the meantime, valuations based on exchange values should be considered as an option for those wishing to make the transition to ocean accounts that include marine ecosystem services.

### *1.4.3. Measuring and monitoring the benefits of sustained ocean observation*

The need to better understand the ocean, its dynamics, and its role in the global earth and climate system has led to the development of complex ocean observing systems at local, regional, national and international levels. These observing systems comprise fixed platforms, autonomous and drifting systems, submersible platforms, ships at sea, and remote observing systems such as satellites and aircraft, using increasingly efficient technologies and instruments to gather, store, transfer and process large volumes of ocean observation data. Those data are crucial for many different scientific communities and for a wide range of public and commercial users active in the ocean economy.

The ultimate beneficiaries of ocean observations are end users whose activities or businesses benefit from ocean data and information in terms of better scientific understanding of the ocean, improved safety, economic efficiency gains or more effective regulation of ocean use and the protection of the ocean environment.

It is clear that the economic and societal benefits underpinned by ocean observations, measurements and forecasts are large. However, they are difficult to quantify. There have been no comprehensive global attempts to describe and quantify these benefits, although numerous case studies have sought to understand and quantify socioeconomic benefits associated with use of ocean data in support of specific ocean uses or regulatory measures. In aggregate, the cost of obtaining and using ocean observations is almost certainly only a small percentage of the value of the benefits derived.

#### *Tracking the benefits of ocean observations*

Recent work by the OECD has sought to collate and summarise the existing literature concerning the benefits of sustained ocean observations. It provides a review of much of the existing literature concerned with the role and value of ocean observations in enabling and supporting the ocean economy.

Science remains a crucial driver for most ocean observations. Observations and measurements derived from diverse platforms (e.g. in situ, research vessels, satellite remote sensing) contribute to advancing fundamental knowledge on the ocean, weather and the climate, directly and via their use in driving, calibrating and verifying ocean, atmospheric and climate models. In the Intergovernmental Oceanographic Commission's (IOC) Global Ocean Science Report, around 80% of data centres that provide ocean observation data, products and services named scientific communities as their most important end users (IOC, 2017[17]).

Many of the social benefits associated with improved science are not readily associated with economic value, partly because they do not flow through markets and do not generate economic benefits in and of themselves. For this reason, the literature has often considered ocean observation data to be a public good, the benefits of which are difficult to identify and value. Despite the relative complexity of valuing social benefits, a number of recent studies have used a range of methodologies to do so. Further valuation of social benefits is of particular importance to undertaking a thorough assessment of the value of ocean observing systems and is of crucial importance to any future overall economic assessment.

There is a wide diversity of operational products and services based on sustained ocean observations. Based on the OECD literature review, weather forecasts (36%), sea state forecasts (21%), and climate forecasts (7%) are the products and services most taken up for operational use. Some of the traditional operational user groups include navies and coastguards, offshore oil and gas industry, and commercial shipping fisheries and aquaculture. User domains benefiting from ocean observations and covered the most by the literature do not, paradoxically, mirror the distribution of these traditional user groups. This is because much of the work on quantifying these areas exists only in the 'grey' literature rather than as peer-reviewed material. The socio-economic assessments consider primarily aquaculture and fisheries (13%); agriculture (9%); environmental management (8%); tourism and cruises (8%); pollution and oil spills (8%); military, search and rescue (8%); and commercial shipping and maritime transport (8%).

Benefits of publicly funded ocean observation systems recognised within the literature can be categorised according to three broad domains:

- Direct economic benefits are the revenues associated with the sale of information products derived in whole or in part from ocean observations, for example, the sale of sea surface temperature products used by the commercial and sport fishing industries to aid in the location of target fish species. This category is relatively straightforward, but the economic data needed to conduct the assessment are generally quite scarce.
- A second category comprises indirect economic benefits. These are accrued when an end user derives an indirect benefit from purchase of an information product or service resulting in whole or in part from ocean observations (e.g. better ship routes as a result of accurate weather forecasts, valued, for example, by reduced fuel costs as a result of avoiding bad weather). The indirect economic benefits follow gains in efficiency or productivity from using improved ocean observations. This category is the most represented in the literature with cost savings (30%), cost avoidance (15%) and increased revenues (14%) as the three most frequent types of benefits cited in the studies.
- Finally, societal benefits are received by society in general in ways that are often easier to identify than to quantify (e.g. improved ocean governance, environmental management or better understanding of the impacts of climate change valued, for example, by estimation of the avoided costs associated with mitigating climate change). The most frequent types of societal benefits are improved environmental management (10%), lives saved (7%) and improved forecasting (6%).

These different types of benefits can be assessed with qualitative or quantitative measures. While ongoing efforts are to be commended and recent progress has been made on mapping operational user communities, data on intermediate and end users are often not collected.

### *Next steps*

A thorough assessment of the value of ocean observations requires further effort in identifying and understanding the different communities of intermediate and end-users, their use of ocean observations and the associated benefits, based on common standards for the evaluation process. Quantifying socio-economic benefits of ocean observing activity in support of the ocean economy will support a stronger argument for the sustainability and improvement of ocean observations.

Following on from the OECD's study on the socio-economic valuation of sustained ocean observations, the following steps could contribute to achieving this:

- Increased efforts among providers of ocean observations to track user groups, their downloads and use of the data would help identify associated marketable and social values. This would involve improved identification and mapping of end users, both scientific or operational. Dedicated surveys of end users of ocean observations could be a useful tool to further characterise users, the products and services they require, and the benefits they realise by using ocean observations. These surveys could be conducted in co-operation with open data platforms, such as the Australian Open Data Network, the Copernicus Marine Environmental Monitoring Service (CMEMS), the European Marine Observation and Data Network (EMODnet) or the U.S. Intergrated Ocean Observing System (U.S. IOOS), with their user bases as the target survey groups. CMEMS already gathers some of this information through its user registration process.
- A more thorough and detailed analysis of dedicated value chains for some of the main products and services derived from ocean observations could also contribute to a more robust valuation of socio-economic benefits. There are useful efforts underway at international and national levels (e.g. work by IOC, NOAA and under the European AtlantOS project, as well as a recently commenced project being undertaken by US IOOS Regional Associations to survey their users. Convening an expert meeting specifically on lessons learnt from mapping user groups' value chains would be very useful for the ocean observing community.
- Studies differ considerably in spatial and temporal scope, methodology used, and user domain considered. The ocean observation community would benefit from international standards or guidelines for the valuation of ocean observations. This would simplify the comparison of different studies and allow the aggregation of results. There are several general challenges when assessing the benefits of ocean observations, e.g. the public good character of many ocean observations, complex value chains and taking stock of a variety of stakeholders. Comparing the results of individual studies can be complicated by varying temporal, sectoral and spatial scales applied in the assessments. Improvements in methodologies are, however, possible. The weather and the environmental policy communities have both tested and paved the way for useful and proven value of information techniques that may be applicable to ocean observations.

In conclusion, recent years have seen a rapidly growing awareness worldwide of the importance of our seas and ocean as a key natural resource and engine of economic growth. Harnessing and simultaneously safeguarding the ocean economy will require deeper scientific knowledge, and more data than are currently available.

## References


Batista, W. et al. (2017), "Which Ballast Water Management System Will You Put Aboard? Remnant Anxieties: A Mini-Review", *Environments*, Vol. 4/3, p. 54, http://dx.doi.org/10.3390/environments4030054. [9]

Dhanaraj, C. and A. Parkhe (2006), "Orchestrating Innovation Networks", *Academy of Management Review*, Vol. 31/3, pp. 659-669. [11]

Fowler, A. et al. (2018), "Environmental benefits of leaving offshore infrastructure in the ocean", *Frontiers in Ecology and the Environment*, Vol. 16/10, pp. 571-578, http://dx.doi.org/10.1002/fee.1827. [10]

Gentry, R. et al. (2017), "Mapping the global potential for marine aquaculture", *Nature Ecology & Evolution*, Vol. 1/9, pp. 1317-1324, http://dx.doi.org/10.1038/s41559-017-0257-9. [7]

IOC (2017), *Global Ocean Science Report Intergovernmental Oceanographic Commission Sustainable Development Goals United Nations Educational, Scientific and Cultural Organization*, http://www.unesco.org/open-access/terms-use-ccbysa-en. [17]

Karlsson, C. and P. Warda (2014), "Entrepreneurship and innovation networks", *Small Business Economics*, Vol. Vol. 43, no. 2, pp. 393-398, https://doi.org/10.1007/s11187-014-9542-z. [13]

OECD (2018), *OECD Science, Technology and Innovation Outlook 2018: Adapting to Technological and Societal Disruption*, OECD Publishing, Paris, https://dx.doi.org/10.1787/sti_in_outlook-2018-en. [2]

OECD (2017), *Analysis of Selected Measures Promoting the Construction and Operation of Greener Ships*, OECD, Paris. [5]

OECD (2017), *OECD Science, Technology and Industry Scoreboard 2017: The digital transformation*, OECD Publishing, Paris, https://dx.doi.org/10.1787/9789264268821-en. [3]

OECD (2017), "The links between global value chains and global innovation networks: An exploration", *OECD Science, Technology and Industry Policy Papers*, No. 37, OECD Publishing, Paris, https://dx.doi.org/10.1787/76d78fbb-en. [14]

OECD (2016), *The Ocean Economy in 2030*, OECD Publishing, Paris, https://dx.doi.org/10.1787/9789264251724-en. [1]

OECD (2008), *Open Innovation in Global Networks*, OECD, Paris. [12]

Roberts, J. et al. (2017), *ANChor, Summary Report Final, December.* [6]

Thomson, R. and G. Harrison (2015), *Life Cycle Costs and Carbon Emissions of Offshore Wind Power*, ClimateXChange. [8]

United Nations (2018), *Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development*, United Nations Statistical Commission, 49th session, A/RES/71/313, March, https://unstats.un.org/sdgs/indicators/Global%20Indicator%20Framework%20after%20refinement_Eng.pdf (accessed on 14 May 2018). [4]

United Nations (2018), *The Sustainable Development Goals Report 2018*, https://unstats.un.org/sdgs/files/report/2018/TheSustainableDevelopmentGoalsReport2018-EN.pdf (accessed on 14 May 2018). [18]

United Nations (2012), *System of Environmental-Economic Accounting 2012: Central Framework*, https://seea.un.org/sites/seea.un.org/files/seea_cf_final_en.pdf (accessed on 03 November 2017). [15]

United Nations (2012), *System of Environmental-Economic Accounting 2012: Experimental Ecosystem Accounting*, https://seea.un.org/sites/seea.un.org/files/websitedocs/eea_final_en.pdf (accessed on 03 November 2017). [16]

# 2. Science and technology enabling economic growth and ecosystems preservation

*After reviewing selected ocean-related scientific and technological advances, Chapter 2 shifts to four individual in-depth case studies that serve to illustrate how some innovations in the ocean domain may potentially both enable economic development and support ecosystem improvement and preservation. The case studies include floating offshore wind power, ballast water management, innovation in the marine aquaculture sector, and possible conversion of decommissioned oil and gas rigs and renewables into artificial reefs.*

## 2.1. Recent developments in science and technology

While the concept of sustainable or green growth is gaining ground in the ocean-user community, there is nonetheless continuing debate about the cost of trade-offs between economic development and environmental integrity involved in its implementation. This chapter offers insights into specific innovations and combinations of innovations, which can attain both objectives simultaneously: promote the economic development of ocean-based industries while fostering marine ecosystem sustainability.

With that context in mind, this OECD chapter has a threefold purpose:

- Provide a brief update on ocean-related scientific and technological advances;
- Contribute to the growing body of evidence indicating that the development of the ocean economy and sustainability of marine ecosystems can go hand in hand with one another;
- And offer further insights into how science and technology innovation can contribute to improving that balance between economic development and environmental concerns.

After reviewing selected ocean-related scientific and technological advances, Chapter 2 shifts to four individual in-depth case studies that serve to illustrate how some innovations in the ocean domain may both enable economic development and support ecosystem preservation and improvement. The case studies include floating offshore wind power, conversion of decommissioned oil and gas rigs and renewables into artificial reefs, ballast water management, and innovation in the marine aquaculture sector. These case studies shed light on a trend in the ocean domain that is already emerging in many other areas of the economy, namely, the increasingly complex, rapidly changing, multifaceted nature of the challenges that science and technology are called on to address.

### *2.1.1. Ocean-sustainability challenges that science needs to address*

Science is crucial to achieving global sustainability and adequate stewardship of our ocean, since it provides the wherewithal to deepen our understanding and monitor the ocean's resources, its health, as well as predict changes in its status.

Recent years have seen the publication of numerous reports by national and international organisations setting out, from their standpoint, the main challenges and priorities that ocean science need to address. There are a good number of shared themes, for example: climate change and its impacts on the ocean (sea-level change, acidification, etc.), the deterioration of ocean and coastal ecosystems as a consequence of human activity, marine biodiversity loss, plastic pollution, declining fish stocks, ocean-related disasters, geohazards, and ocean governance, to name but a few.

However, there are also some divergences among the organisations in terms of national and regional priorities. For example, the impact on coastal communities and the issue of the Arctic are of key importance to the Canadian ocean scientific community's report (Council of Canadian Academies, 2013[1]); the future of marine food webs figures prominently in the US National Research Council *Decadal Survey of Ocean Sciences* (National Research Council, 2015[2]); the European Marine Board identifies the need for a functional and dynamic definition of marine ecosystem health (European Marine Board, 2013[3]); and the uneven global distribution of benefits from the use of the ocean and its resources represent an important source of concern for the United Nations *First Global*

*Integrated Marine Assessment* (United Nations, 2017[4]). A significant achievement of the UN Sustainable Development Goals for the ocean (SDG 14) was to capture for the first time and compress the essence of many diverse challenges facing the ocean science community (Box 2.1).

**Box 2.1. Sustainable Development Goal 14 "Life below Water" with direct implications for science and technology**

14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution.

14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans.

14.3 Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels.

14.4 By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics.

14.5 By 2020, conserve at least 10% of coastal and marine areas, consistent with national and international law and based on the best available scientific information.

14.7 By 2030, increase the economic benefits to small island developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism.

14.A Increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, in order to improve ocean health and to enhance the contribution of marine biodiversity to the development of developing countries, in particular small island developing States and least developed countries.

Source: United Nations (2016[51]), *Global Indicator Framework for the Sustainable Development Goals and Targets of the 2030 Agenda for Sustainable Development,* United Nations Statistical Commission, 49th session, A/RES/71/313, New York, March.

One crucial element that all reports agree on is that the ocean is a very complex ecological and biogeochemical system, which is under major threat (e.g. human-made pollutions, overfishing in most parts of the world, destroyed marine ecosystems impacting the subsistence of local coastal populations) that is still not well understood. How much pressure can the ocean take? How will an increasingly unhealthy ocean impact the planet's biodiversity, the weather, the climate and our societies?

Two important and interdisciplinary capabilities are still needed to get a better understanding of the ocean:

- The capability of studying and integrating together many diverse ecosystem dynamics and various biogeochemical cycling across different scales -- including temporal scales (in the order of days or centuries) and spatial scales (from a few kilometres to very large basins);

- The capability to observe throughout the water column, all the way to the sea floor, the pressures and ecological-biogeochemical responses in the ocean interior (e.g. nutrients, oxygen, components of the plankton and indicators of their physiological status) to describe how very small processes could contribute to critically important and much wider variability.

This needed multifaceted understanding of the ocean involves many scientific disciplines, from biology to physical sciences, building on years of data from across broad expanses of ocean being analysed, new data collected, and new technologies being used. International cooperation will be key, taking into account that the organisational setups and ocean science capacities vary also greatly country to country (IOC, 2017[6]). In addition to the different ocean science communities, other scientific disciplines are also joining in fundamental research that may benefit eventually the ocean. For example, dedicated research and development on new sustainable petrochemical production routes (from production, use and disposal of products) may contribute to efforts to curve and stop the leaking of plastic pollution and other harmful chemical products in the ocean (IEA, 2018[7]). This primarily land-based pollution finds its way to the ocean via domestic and commercial wastewater (e.g. cleaning and sanitary products), agricultural run-off, and leakage from disposal sites. Much progress needs to be made at the root of this chemical pollution, both in terms of R&D needed to find potential alternatives that would be less-damaging to the environment, and in the current production and consumption practices (e.g. building on the circular economy concept) (OECD, 2018[8]).

Two milestones for the global ocean science community are forthcoming. For the first time, the Intergovernmental Panel on Climate Change (IPCC) will be producing a *Special Report on the Ocean and Cryosphere in a Changing Climate* in the second half of 2019 (IPCC, 2018[9]). Over 100 scientists from more than 30 countries are currently assessing the latest scientific knowledge about the physical science basis and impacts of climate change on ocean, coastal, polar and mountain ecosystems, and the human communities that depend on them. And 2021 will see the launch of the United Nations Decade of Ocean Science for Sustainable Development (2021-2030), with the objective that very diverse scientific communities and users of the ocean work together to develop further the knowledge base on the ocean (IOC, 2018[10]).

### *2.1.2. Selected trends in ocean science and technology*

The OECD report on the ocean economy in 2030, written in 2015, already described many of the key advances under way in science and technology to help address the bulk of the challenges outlined above (OECD, 2016[11]).

In the course of the next couple of decades, a string of enabling technologies promises indeed to stimulate improvements in efficiency, productivity and cost structures in many ocean activities, from scientific research and ecosystem analysis to shipping, energy, fisheries and tourism. These technologies include imaging and physical sensors, satellite technologies, advanced materials, information and communication technology (ICT), big data analytics, autonomous systems, biotechnology, nanotechnology and subsea engineering (Table 2.1). In addition to incremental innovations, there is the prospect of different technologies emerging and converging to bring about quite fundamental shifts in knowledge acquisition and marine industry practices.

**Table 2.1. Selected incremental technologies and their use in the ocean economy**

| Incremental technology | Expected use in ocean economy |
|---|---|
| Advance materials | Capable of making structures stronger, lighter and more durable in offshore oil and gas, offshore wind, marine aquaculture, tidal energy etc. |
| Nanotechnology | Nano-scale materials that are self-diagnostic, self-healing and self-cleaning, used in coatings, energy storage and nano-electronics. |
| Biotechnology (including genetics) | Breeding of species, vaccine and food development in aquaculture. Development of new marine biochemical substances for pharmaceutical, cosmetic, food and feed use. Algal biofuels and new biomarine industries. |
| Subsea engineering and technology | Underwater grid technology, power transmission from deepwater, subsea power systems, pipeline safety, moorings and anchorings for floating structures, etc. |
| Sensors and imaging | Smart sensors, techniques and platforms that rely on miniaturisation and automation to create low-power, low-cost devices for measurement of the marine environment. |
| Satellite technologies | Improvements in optics, imagery, resolution of sensors, quality and quantity of satellite transmitted data, greater coverage by small, micro and nano-satellites, are expected to enable many activities. |
| Computerisation and big data analytics | Smart computing systems and machine learning algorithms set to make sense of vast amounts of data generated throughout the maritime economy. |
| Autonomous systems | Deployment of autonomous underwater vehicles (AUVs), remotely operated underwater vehicles (ROVs) and autonomous surface vehicles (ASVs) set to expand considerably. |

*Source*: OECD (2016[11]), *The Ocean Economy in 2030*, http://dx.doi.org/10.1787/9789264251724-en.

A cursory glance at the more recent literature suggests that, in the short period that has elapsed since the writing of the ocean economy to 2030 report, there has been an acceleration of research interest in the potential for applications of some of those technologies in gaining a better understanding of marine ecosystems, their workings, and the requirements for their better management (Box 2.2).

**Box 2.2. Selected innovations enhancing knowledge of marine ecosystems, their management and their protection**

***Remote sensing using high-frequency radar and high-resolution satellites, with applications in:***

- Monitoring and modelling of oil spills from ships and offshore platforms, and of chemical contaminants (Singha and Ressel, 2016[12]; Li et al., 2016[13]; White et al., 2016[14]; Tornero and Hanke, 2016[15]; Strong and Elliott, 2017[16]; Spaulding, 2017[17]; Nevalainen, Helle and Vanhatalo, 2017[18]; Mussells, Dawson and Howell, 2017[19]; Azevedo et al., 2017[20]);
- Measurement ocean surface currents using AIS (Guichoux, 2018[21]) and mapping global fishing activity (Kroodsma et al., 2018[22]);
- Biochemical modelling of plankton biomass (Gomez et al., 2017[23])
- Management of coastal zones and wetlands ( (Kim et al., 2017[24]; Wu, Zhou and Tian, 2017[25]).

***Genetics, eDNA and other genetic toolkits applied in***

- Monitoring and assessment of (invasive) species in ecosystems (e.g. (Darling et al., 2017[26]));

- Monitoring seabed mining disturbances (Boschen et al., 2016[27]);
- Detecting bacteria in ballast water (Pereira et al., 2016[28]).

***Acoustics, imagery and artificial intelligence advances in:***

- Monitoring (migratory) fish movements (Martignac et al., 2015[29]; Geoffroy et al., 2016[30]; Shafait et al., 2016[31]);
- Monitoring marine habitats and ecosystem characteristics (Wall, Jech and McLean, 2016[32]; Cutter, Stierhoff and Demer,(n.d.)[33]; Trenkel, Handegard and Weber, 2016[34]); and recognition of marine species ( (Siddiqui et al., 2018[35]; Chardard, 2017[36]);

***Autonomous systems. Progress in Unmanned Autonomous Vehicles (UAVs), gliders and Autonomous Underwater Vehicle (AUVs), including improved sensors, and high-resolution tools for 4D oceanic measurements***:

- Use of gliders in marine surveys (Colefax, Butcher and Kelaher, 2018[37]);
- Use for research purposes in otherwise inaccessible and remote locations, including in the polar regions, and as key components of the Global Ocean Observing System (GOOS) (Forshaw, 2018[38]);
- Monitoring and inspection in oil spill response (Dooly et al., 2016[39]; Gates, 2018[40]).

Enabling technologies appear set to contribute in important ways to the sustainable development of the ocean economy, not least by vastly improving data quality, data volumes, connectivity and communication from the depths of the sea, through the water column, and up to the surface for further transmission. While the examples are far from exhaustive, they do serve to illustrate the richness of current innovations in the ocean economy that are addressing either the one or the other objective. Two are particularly highlighted below:

- Blockchain and big data analytics applications, for example, are starting to be deployed in port facilities and maritime supply chains. Shipping companies, logistics businesses, port operators and other maritime transport stakeholders are looking to more integrated services across the entire supply chain as a means of generating cost savings and greater efficiencies, as well as improvements in quality of service. The prospects for achieving those benefits by getting the various relevant operations (administration, logistics, shipping, terminal and port) to work together more smoothly have been boosted by the advent of digital platform technologies. For example, within the administrative segment of shipping operations, transport operators are currently exploring the potential for using distributed ledger technology (DLT), most notably blockchain. This technology does away with the need for an intermediary in transactions between stakeholders, while potentially offering a rapid and secure authentication method for freight transport. New players are emerging in the form of shipping tech start-ups with the capacity to leverage higher data volumes. They include digital freight forwarders, rate analytics services, collaboration or exchange platforms, tracking platforms and service fulfilment networks (International Transport Forum, 2018[41]).
- The emergence of autonomous ships is also an important disruptive element for some industries. They include Autonomous Underwater Vehicles (AUVs) and gliders with improved sensor platforms, which have progressed from niche status to an established part of operations in various marine sectors; in the oil and gas

sector, however, the technology still has to mature to a stage at which oil and gas operators consider AUVs a vital component of operations (Wilby, 2016[42]). This technology is deployed in monitoring and inspection for leakages in underwater carbon capture facilities, as well as in the inspection of deep-sea pipelines (Forshaw, 2018[38]). There are future opportunities for deployment in offshore decommissioning (Westwood Global Energy Group, 2018[43]) and possibilities for use in offshore wind (Westwood Global Energy Group, 2018[44]).

Other selected innovations primarily supporting the development of the sustainable commercial use of the seas and ocean are presented in Box 2.3.

**Box 2.3. Selected innovations primarily supporting the development of the (sustainable) commercial use of the seas and ocean**

***Artificial intelligence applications in acoustics and imagery:***

- Development of machine learning to interpret subsurface images from seismic studies using computer vision technology and automate the analysis of technical documents with natural language processing technology (Zborowski, 2018[45])
- Fisheries - Single beam and multi-beam echo sounder systems, real-time 3D visualisation software, sonars and catch monitoring systems (Kongsberg, 2017[46]), video imagery and recognition of fish species assisted by artificial intelligence (AI) (Siddiqui et al., 2018[35]);
- AI in renewable ocean energy used for e.g. sea wave height prediction, sea-level variation prediction, wave hindcasting (Jha et al., 2017[47]).

***Remote sensing using high-frequency radar and high-resolution satellites with applications in:***

- Decision making on suitability of aquaculture sites (Fernandez-Ordonez, Soria-Ruiz and Medina-Ramirez, 2015[48])
- Offshore wind farms (Zecchetto, Zecchetto and Stefano, 2018[49]), (Kubryakov et al., 2018[50]).
- Algal bloom forecasting for aquaculture insurance purposes (Miller, 2018[51]).

***Modelling progress in applications in:***

- Development of methodologies and numerical modelling of wave and tidal energy and their environmental impacts (Side et al., 2017[52]; Venugopal, Nemalidinne and Vögler, 2017[53]; Heath et al., 2017[54]; Gallego et al., 2017[55]);
- Wind resource assessments (Zheng et al., 2016[56]) (Kulkarni, Deo and Ghosh, 2018[57])
- Impact of wind and waves on ocean facilities, e.g. siting of aquaculture facilities (Lader et al., 2017[58])

### *2.1.3. Introducing the four case studies*

Beyond recent advances in science and technologies, the focus of this chapter is on innovations and combinations of innovations which embody the very the notion of green growth in the ocean by successfully fostering economic development and ocean sustainability simultaneously. To do this, it presents four in-depth innovation case studies: floating offshore wind; ballast water management; marine aquaculture; and rig- and renewables-to-reefs.

The four case studies are very different. They differ in scale and in the degree of maturity of the respective activity. Floating wind power is still in its infancy, with only one commercial-scale facility in operation in the world. Ballast water treatment technologies have so far been installed in only a small number of ships, but expansion could be rapid. Oil and gas rig conversion into artificial reefs is current in some parts of the world, but not in others, and no renewables-to-rigs programmes exist anywhere. Marine aquaculture, by contrast, is well established in many parts of the world, is undergoing rapid expansion, and is being transformed at great speed by a whole host of innovations. For this reason, the marine aquaculture case study is addressed in more detail and at greater length, in order to illustrate the sector-wide dimension of the innovation process.

Moreover, innovation in the four activities is driven by different forces and different challenges. Innovation in floating wind power is largely science and technology driven; rigs-to-reefs conversions are driven both by industry's need to reduce decommissioning costs and conservationists' desire to create or restore ocean ecosystems; innovation in ballast water treatment is propelled essentially by regulation; and innovation in the marine aquaculture sector is motivated by multiple factors: the challenge of feeding a growing world population, the incentive to develop business opportunities, and the need to reduce pressures on coastal environments. As different as the drivers may be, progress in all the cases is science-led or at least science-based.

Each case study endeavours to address a number of key issues: the background and global context; the economic and environmental issues at stake; the research and technological innovations in prospect; and the contribution that the innovations could make to enabling economic development within the sector (e.g. through cost-savings, new business generation, emergence of new industries) and environmental sustainability to go hand in hand.

## 2.2. Case Study 1: Innovation in floating offshore wind energy

### *2.2.1. The economic and environmental issues at stake*

Until recently, floating offshore wind technology was largely confined to research and development, but the coming decades could see it emerge on a commercial scale. For that to happen, however, a wide range of technological, economic, regulatory and environmental challenges will need to be addressed.

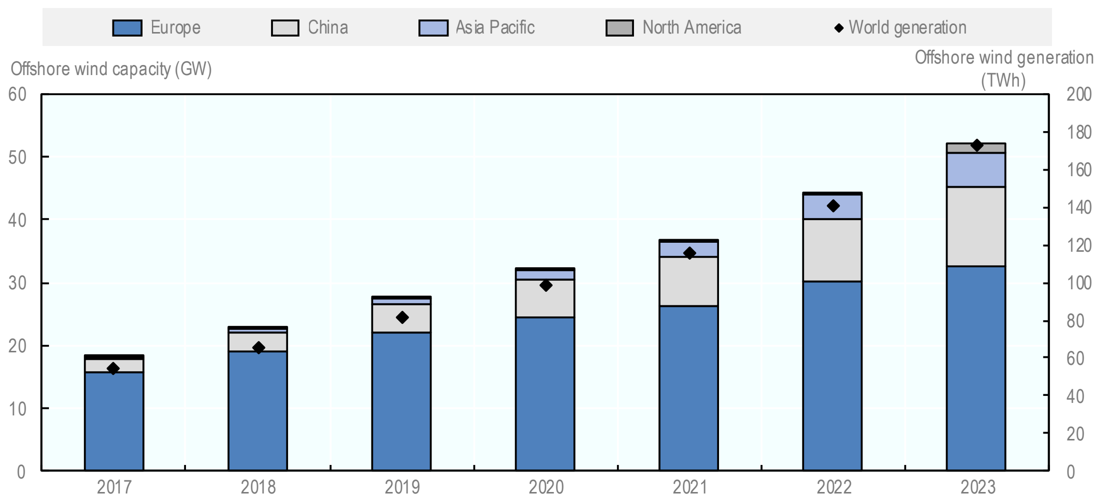
The offshore wind industry has grown at an extraordinary rate over the last 20 years or so, from almost nothing to a total capacity of 18 GW in 2017. The way has been led mainly by Europe and China. Growth prospects are strong. Between 2017 and 2023, total global capacity is expected to almost triple to 52.1 GW (IEA, 2018[59]).

The potential economic benefits of such a rapid expansion are considerable. The OECD's 2016 report on the Ocean Economy in 2030 suggests that, on a business-as-usual basis, the global gross value added generated by offshore wind power could increase eight-fold and employment more than twelve-fold between 2010 and 2030. As a consequence, its share of the global ocean economy could grow from less than 1% in 2010 to 8% in 2030 (OECD, 2016[11]).

Wind power also offers considerable benefits to the environment through its contribution to reducing global $CO2$ emissions. By way of illustration, estimates of carbon emissions from offshore wind generation conducted in 2015 place life-cycle emissions in the range of 7 to 23 g of $CO2$ equivalent per kilowatt (gCO2e/kWh). This compares with around

500 g for gas-fired conventional generation and about 1 000 g for coal-fired conventional generation (Thomson and Harrison, 2015[60]). A similar result was arrived at in a more recent study by Kadiyala et al. (2017[61]) which estimated the mean life-cycle emissions of the offshore wind installations surveyed at 12.9 gCO2e/kWh (with an environmental payback period of just 0.39 years).

**Figure 2.1. Forecast of regional offshore cumulative capacity (GW) and wind generation (TWh) 2017-2023**




*Source:* Adapted from IEA (2018[59]), *Renewables 2018: Analysis and Forecasts to 2023*, https://dx.doi.org/10.1787/re_mar-2018-en.

Moreover, the potential contribution to reducing CO2 output stands to benefit indirectly the world's ocean ecosystems by helping to slow the increase in acidification, de-oxygenation and the rise of sea temperature and sea levels. Hence, further rapid expansion of offshore wind power suggests further gains for the environment in terms of CO2 reductions.

To date almost all offshore wind turbines are of the fixed-bottom type, installed in shallow water (up to around 50-60 meters) in proximity of the coast. Fixed-base wind turbines are arguably today successfully delivering low energy costs, improved energy security and low environmental impact, and much of the future growth in total offshore wind generation will continue to stem from this type of platform. However, over time, fewer near-coast shallow-water sites will become available due to growing competition for space from other ocean users, as well as to the lack of physically suitable locations. The latter applies in particular to countries like Japan and parts of North America and Latin America whose coastal zones are situated in deep water. Floating offshore wind platforms offer a way out of this dilemma. They could be installed in positions benefitting from more space, less potential interference with other ocean activities, and stronger more regular winds. In principle, the potential is very large indeed (Table 2.1).

**Table 2.2. Potential for floating offshore wind power**

| Country/Region | Share of offshore wind resource in +60 m depth | Potential for floating wind capacity |
|---|---|---|
| Europe | 80% | 4 000 GW |
| United States | 60% | 2 450 GW |
| Japan | 80% | 500 GW |
| Taiwan | -- | 90 GW |

*Source*: Catapult and Carbon Trust (2017[62]) *Floating Wind Joint Industry Project: Policy and Regulatory Appraisal*, https://www.carbontrust.com/media/673978/wp1-flw-jip-policy-regulatory-appraisal_final_170120_clean.pdf.

Despite being able to draw quite heavily on the experience that the offshore oil and gas industry has with floating structures, seabed fixtures and related technologies, floating wind farms have taken some time to emerge as a commercial-scale installation. Indeed, to date, there is only one single large-scale offshore wind platform operating in the world: The 30 MW *Hywind* is situated off the Scottish coast and has been operating successfully – even surpassing expectations – since 2017 (Hill, 2018[63]). Nevertheless, at the time of writing, not one floating offshore technology has proved itself to the extent that it could be purchased off the shelf (Dvorak, 2018[64]).

However, many more projects are approaching fruition or are currently under development. The Scottish government has approved the 50 MW Kincardine Floating Offshore Wind Farm. The Council of Ministers in Portugal has given the go-ahead to the development of the 25 MW WindFloat Atlantic (WFA) project in Viana do Castelo, 20 km off the coast of Northern Portugal. France has approved a total of four pilot floating wind projects: a 24 MW pilot floating wind farm in the Gruissan area; a 24 MW floating wind farm planned by Eolfi and CGN for the Groix area; a 24 MW floating wind farm in the Faraman area; and another 24 MW project off Leucate. Work is also underway on the 2 MW Floatgen floating wind project in the Port of Saint-Nazaire. Japan installed the Fukushima Hamakaze floating wind turbine in 2016, and has initiated several further floating wind projects, such as the demonstration one off Kitakyushu. In the United States, the 12 MW New England Aqua Ventus I floating offshore wind demonstration project is under way in the Gulf of Maine. More developments are in the pipeline for projects off the coasts of Scotland, Wales and Ireland (offshoreWIND.biz, 2017[65]).

Consequently, expectations are running high that the market will develop rapidly in the coming decade, growing from almost nothing in 2017 to around 1 300 MW in 2030 and providing a total installed capacity of over 5 GW by 2030 (GWEC Global Wind Energy Council, 2017[66]). The basis for such optimism would appear to be, *inter alia*, recent progress in research, development and innovation.

### *2.2.2. Developments in research and technology*

At the moment there are three designs of substructures under development: spar-buoy, spar-submersible, and tension leg platform (TLP); see IRENA (2016[67]), for more detail. A fourth foundation design – barge – is also well advanced, though less so than the others.

The high expectations of vigorous market expansion in the coming years are built on estimates of the potential for floating solutions and on the progress that has been made in bringing floating wind turbines up to an advanced level of technological readiness.

According to Wind Europe (2017[68]), the spar design is already at technology readiness level (TLR) 9, and the others are expected to reach that score within the next five years: Expectations are further fuelled by advances that are being made in such areas as the siting of turbines, construction materials and methods, new designs, and monitoring and inspection, as the following examples illustrate.

### *Improved siting of turbines*

Remote sensing is playing an increasingly important role as a decision support tool in choosing the most suitable locations for wind energy offshore. The key advantage of satellites over conventional surface observations is that satellite data can cover a wider spatial range, allowing for more comprehensive assessment of potential offshore wind energy resources. Zheng et al. (2016[56]) note, however, that there are a limited number of satellites and orbits, so that the data gathered may be inadequate in terms of time synchronisation and spatial resolution, as they may not be able to cover large surface areas at the same point in time during observation. Moreover, they cannot capture variations in the wind field at different altitudes. Satellite data can however be enhanced by applying numerical simulation methods to the energy resource evaluations. As a consequence of technological progress in modelling, recent years have seen more and more reanalysis data successfully deployed in this field. James et al. (2018[69]), for example, report on a successful modelling exercise using a three-year dataset of wind forecasts above ground level over offshore regions of the United States to support and improve energy resource assessments and wind forecasts for New England and other coastal regions of the United States.

Looking to the longer term, Zheng et al. (2016[56]) point to the need for improvements in a range of related fields, including: short-, medium- and long-term forecasting of wind energy; and early warning of natural disasters that pose a risk to wind farms. Over the even-longer term there is the issue of climate change and the uneven distribution around the globe of potential changes in the wind induced by global warming. Wind farms in some areas are likely to be impacted more severely than those in other regions. Here too more research is called for (Kulkarni, Deo and Ghosh, 2018[70]).

### *Improved construction materials and methods*

As turbines have become ever larger over the years, so too have their rotor blades. They have increased in length quite considerably in recent years, from about 30 m in the 1990s to more than 100 m today. The blades themselves are composed mainly of fibreglass reinforced resins with add-ins of balsa wood and carbon fibre. The carbon fibre enhances the stability of larger turbines, thereby providing higher capacity. Thus, in future the share of carbon fibre is expected to rise, despite the fact that it is more expensive than other materials (McKenna, Ostman v.d. Leye and Fichtner, 2016[71]). Advances are also expected in meeting the challenge of the higher loads associated with larger rotors. Tests are under way on active load-control techniques such as trailing edge flaps and smart structures, intelligent pitch control systems, smart sensors to monitor blade load, and microtabs to modify the loads on the turbine structure. Other innovative concepts include smart blades that adapt to conditions and reduce or replace the requirement for active control (McKenna, Ostman v.d. Leye and Fichtner, 2016[71]).

The harsh conditions of the ocean climate place particular demands on the structure and workings of floating offshore wind energy platforms. Turbine blades are now manufactured from composite materials, in which further advances can be expected in the coming years. They need to remain in service for around 25 years, but are very vulnerable to rust and require regular inspection and treatment. Hence, preventive coatings for turbine blades are under development which aim to reduce substantially inspection and maintenance costs[1] (Fraunhofer, 2016[72]).

Research is also under way to develop criteria to support decisions on the selection of materials for the foundations of floating wind farms. In the case of tension leg platforms, for example, various materials and methods are available but these tend to have different characteristics when it comes to lifecycle costs, CO2 emissions, etc. Kausche et al. (2018[73]) calculate that pre-fabricated steel or pre-stressed concrete have clear advantages over welded steel solutions, a research outcome that could apply equally to spar-buoy and semi-submersible type foundations, on which however to date no data have been published.

### *New designs*

It is estimated that around 20 players are currently working to move new foundation designs from the concept stage to commercialisation (Renewable Energy Agency, 2016[67]). Numerous innovations are in the pipeline. The Spanish company Saitec, for example, is developing a cost-effective floating wind farm solution SATH (Swinging Around Twin Hull) fitted with two twin concrete hulls that are fastened to a single mooring point, allowing the platform to swing around. The economic advantages arise from the single mooring point system, which shortens installation times and facilitates returning to port for major work, as well as from the fact that the platform and turbine equipment are assembled on shore at the harbour, thereby minimising operations at sea (offshoreWIND.biz, 2017[65]).

Swedish specialist Hexicon is building platforms with floating foundations equipped with twin turbines for greater cost efficiency, and the platforms being designed by Swedish manufacturer TwinSwirl reduce manufacturing and maintenance costs by installing the parts requiring maintenance inside the easily accessible generator housing above water level (SeaTwirl, 2018[74]). On matters of grid connection, where one of the key problems is power transmission from a platform subject to significant movement, Japanese researchers have developed and demonstrated a dynamic cable system capable of stabilising power transmission (Taninoki Ryota et al., 2017[75]).

Looking to the longer-term horizon, designs are expected to progress from the single-rotor model deployed today to multi-turbine arrays on a single structure, generating as much as 20 MW of power from numerous 500 kW turbines and cutting both installation and maintenance costs. And as of 2040, the sector is expected to be making inroads into solving the weight-related problems posed by ever larger turbines on tower-structure designs. Vertical axis turbines, currently still in their infancy, offer considerable potential in this respect (Carbon Trust and Offshore Renewable Energy Catapult, 2017[76]).

It is noticeable however, that for many of these innovations, the timeframe is long and it is unclear how quickly they will find their way into commercial scale use.

### *Monitoring, inspection, maintenance and repair*

Remote monitoring of conventional fixed-bottom wind energy facilities is already widespread, remote maintenance and repair operations on the other hand are still in their infancy. But as floating offshore wind becomes mainstream, platforms will increasingly be located in deeper waters and harsher conditions at ever greater distance from the coastline. As a consequence, installation, operation, maintenance, and repair will become more difficult, more dangerous and more expensive. Solutions will need to be sought in automated, remotely operated technologies. This should open up further opportunities for AUVs, ROVs, subsea robotics, and so on. Indeed, the United Kingdom's Catapult (2017[76]) predicts that, a few decades from now, the deployment of drones and AI-driven monitoring systems for offshore wind farms – fixed and floating – is set to become commonplace, as is the use of remotely controlled and even autonomous underwater repairs and maintenance. Again, however, many of the above are unlikely to find their way into commercial scale application for many years yet.

### *2.2.3. Challenges facing floating wind technology*

The high expectations with respect to the near and medium term development of floating wind technology need to be put in perspective, since there are many economic, technological, institutional and environmental challenges ahead.

While much can be learned from fixed-base offshore wind farms, floating wind technology is far from being a simple extension of that technology innovation system. The supply chain is different from that used for fixed-base turbines in shallow, near-shore waters; the technologies are different, as are the cost structures; the impact on the marine environment is different; and other ocean users may be affected in other ways (Bento and Fontes, 2017[77]). The difference in cost structure is particularly striking with respect to capital expenditure. While the foundations make up only 20% of total capex for conventional fixed-base offshore turbines (the main cost components are related to the turbines themselves), they account for around two-thirds of total capex in the case of tension-leg (TLP) floating wind platforms (Kausche et al., 2018[73]).

Costs figure among the most important potential barriers to rapid development of floating offshore wind farms. Higher average distance to shore correlates with higher wind speeds and higher capacity factors, but entails lengthier export connection cables to grid. Water depth usually increases with distance to shore, but is associated with higher installation and foundation costs, in particular mooring costs (Myhr et al., 2014[78]). Compensating cost savings may be expected from more integrated supply chains, economies of scale, upscaling of turbines, and major repairs conducted onshore, but most such savings will take time to come through. The longer term also holds further challenges. For example, grid integration costs are likely to increase as levels of penetration by variable power generation sources rise. The Levelised Cost of Energy (LCOE) for existing offshore wind farms in Europe in 2015 ranged from 7.3 €ct/kWh to 14.2 €ct/kWh, higher than the LCOE of onshore wind energy or conventional generation technologies (Höfling, 2016[79]). The LCOE of floating wind turbines, in turn, will very probably be higher than for both onshore and fixed-bottom offshore installations: according to the IEA, about 6% higher than the 2014 baseline in the IEA medium-term scenario (Wiser et al., 2016[80]). The results of the IEA's survey of over 150 world experts in offshore wind power suggest that trend reductions in the LCOE of floating wind energy solutions could converge with those of fixed wind power platforms, but not until around 2030.

According to the findings of the IEA survey of experts, the most significant enabler for driving down the levelised cost of energy is – in addition to learning from experience – research and development. Significant technical innovations will be required to improve the competitivity of floating wind farms, but so will innovations in site identification, serial production, supply chain integration and management, and logistics during construction and operation.

### *2.2.4. Impacts on the environment and marine ecosystems*

As noted earlier, the net contribution of floating wind energy to the reduction of CO2 emissions is significant compared to fossil-fuel based energy sources. There are nonetheless non-negligible drawbacks for the marine environment. These include the impact on (migrating) birdlife, the effects on fish and marine mammals, as well as those on the seabed and benthic habitats.

Most of the available research on ecosystem impacts draws on Northern European experience with fixed-base offshore turbines. Offshore structures can under certain circumstances enhance the marine environment due to increased biological productivity (of fish, molluscs and other forms of marine life). However, the construction phase would appear to be particularly invasive, with construction noise and disturbance of the seabed having effects on benthic habitats and many species of marine life, and once complete may in addition disrupt habitat connectivity both in and beyond the immediate area. Once in operation, the turbines can be a source of acoustic disturbance for a range of marine animals. There are also risks to bird life: potential flight displacement, risk of collision, and fragmentation of habitat by creating a barrier between birds' nesting grounds and their feeding grounds. Some progress is being made in developing the technological and scientific tools to address some of these problems. In the case of risks to avian species, for example, techniques ranging from radar monitoring, Thermal Animal Detection Systems (TADS) and acoustic detection, to video surveillance and computational collision models are currently being deployed in the study of bird flight and behaviour in the proximity of offshore wind farms.

The view is emerging that, at least as concerns the construction/installation phase, floating wind turbines would be less intrusive during dredging and seabed preparation operations than fixed-bottom turbines (Carbon Trust and Offshore Renewable Energy Catapult, 2017[76]). Nonetheless, numerous issues remain. For example, for floating platforms, cable routes still need to be prepared and cables laid, activities that are associated with considerable disturbance of sediments. Also, the mooring systems for floating turbines need a large mooring spread. For a typical (catenary) mooring system, the spread diameter increases by 14 m with every 1 m increase in water depth. For a wind farm installed at a water depth of 150 m, for example, this would translate into a mooring system that required a 2 km diameter area of seabed for every turbine in the farm. Not only does that significantly raise the cost of mooring system materials, it also increases the lease area and expands the seabed environmental impact (Hurley, 2018[81]).

Also, the ornithological impact would depend greatly *inter alia* on how close to shore the floating facility is deployed. In relation to interaction of the floating foundation with fish and marine mammals, little research appears to be available, not least due to the fact that as of today few floating platforms exist.

The construction and operation of floating facilities should benefit from the experience of installing and running fixed-base wind turbines with ecosystem impact assessment. But even here, there are still large knowledge gaps. Lack of baseline data is a considerable impediment to the evaluation of impacts. Indeed, baseline research is needed on a whole range of natural phenomena including on marine species' population structures and status, and their distribution and abundance over many annual cycles. And much remains to be done to improve the knowledge base on long-term ecosystem impacts as well as on the cumulative effect of multiple impacts. Similarly, information about the effects on the whole ecosystem (as opposed to those on single species or specific ecosystem components) is generally quite limited, although there are signs of progress; see for example Pezy, Raoux and Dauvin (2018[82]).

### *2.2.5. Concluding observations*

With innovation evolving apace and levelised costs of energy projected to follow a downward trajectory similar to those of fixed-base wind platforms, a promising future is discernible for the floating wind energy sector. The growth potential is considerable, and from a broader ocean industry point of view, one would expect economic spill over benefits to flow to other maritime sectors such as ports, shipyards (construction and repair), marine equipment, and shipping. But given the many challenges this new sector faces, it seems unlikely that floating wind energy will be making a perceptible impact at commercial level in the near or medium term. Hence, also the indirect and direct benefits to the marine environment through displacement of fossil fuels will take time to have any effect. Science and technology are at the leading edge of developments to address the engineering and cost-reduction challenges, just as they will be required to play a key role in closing knowledge gaps and resolving many of the uncertainties still surrounding the environmental impacts of floating wind platforms.

## 2.3. Case Study 2: Marine invasive alien species and ballast water treatment

Marine invasive alien species have been spreading across the globe for centuries, often wreaking considerable damage on native ocean and coastal ecosystems. Ships have been the principal cause, and as globalisation in recent decades has gone hand in hand with rapid growth in maritime transport, so too has the dispersion of invasive alien species grown across the world's oceans. Innovation in ballast water treatment may contribute to control this growing issue better.

### *2.3.1. The economic and environmental issues at stake*

The marine invasive alien species' problem is extraordinarily diverse and truly global in geographical scale, as the International Maritime Organisation's (IMO) list of the world's most troublesome invasive species indicates. In many instances, the impact on the environment has been devastating, depleting zooplankton stocks, competing with, displacing and sometimes wiping out local native marine life, disrupting food webs, obstructing coastal structures, and even posing a threat to public health. The environmental impacts are often associated with substantial economic costs, ranging from losses to fisheries and aquaculture, foregone revenues from tourism, deterioration of port facilities, and so on. The overall costs are thought to run into the USD tens of billions annually (King, 2016[83]).

Some examples of aquatic bio-invasions causing major impact are listed in the table below, but there are hundreds of other serious invasions, which have been recorded around the world (Table 2.3).

**Table 2.3. Selected invasive aquatic species**

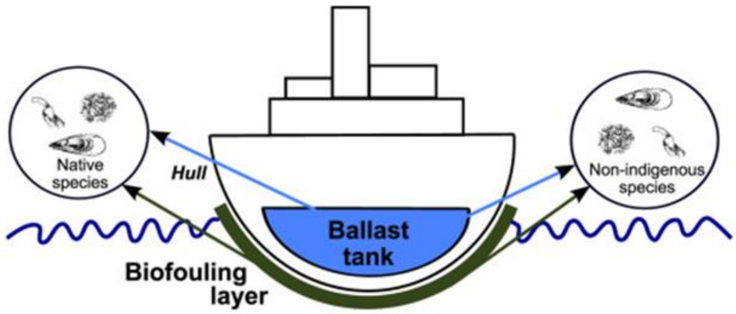
| Name | Native to | Introduced to | Impact |
|---|---|---|---|
| Cholera *Vibrio cholerae* (various strains) | Various strains with broad ranges | South America, Gulf of Mexico and other areas | Some cholera epidemics are reported to be associated with ballast water |
| Cladoceran Water | Black and | Baltic Sea | Reproduces to form very large populations |

| | | | |
|---|---|---|---|
| Flea *Cercopagis pengoi* | Caspian Seas | | that dominate the zooplankton community and clog fishing nets and trawls, with associated economic impacts. |
| Chinese mitten crab *Eiocheir sinensis* | Northern Asia | Western Europe, Baltic Sea and west coast North America | Undergoes mass migrations for reproductive purposes. Burrows into river banks and dykes causing erosion and siltation. Preys on native fish and invertebrate species, causing local extinctions during population outbreaks. Interferes with fishing activities. |
| Toxic algae(red/brown/ green tides) various species | Various species with broad ranges | Several species have been transferred to new areas in ships' ballast water | May form harmful algae blooms. Depending on the species, can cause massive kills of marine life through oxygen depletion, release of toxins and/or mucus. Can foul beaches and impact tourism and recreation. Some species may contaminate filter-feeding shellfish and cause fisheries to be closed. Consumption of contaminated shellfish by humans may cause severe illness and death. |
| Round goby *Neogobius melanostomus* | Black, Azov and Caspian Seas | Baltic Sea and North America | Highly adaptable, invasive, increases in numbers and spreads quickly. Competes for food and habitat with native fishes, including commercially important species, preys on their eggs and young. Spawns multiple times per season, survives in poor water quality. |
| North American comb jelly *Mnemiopsis leidyi* | Eastern seaboard of the Americas | Black, Azov and Caspian Seas | Reproduces rapidly (self-fertilising hermaphrodite) under favourable conditions. Feeds excessively on zooplankton. Depletes zooplankton stocks; altering food web and ecosystem function. Contributed significantly to collapse of Black and Azov Sea fisheries in 1990s, with massive economic and social impact. Now threatens similar impact in Caspian Sea. |
| North Pacific seastar *Asterias amurensis* | Northern Pacific | Southern Australia | Reproduces in large numbers, reaching 'plague' proportions rapidly in invaded environments. Feeds on shellfish, including commercially valuable scallop, oyster and clam species. |
| Zebra mussel *Dreissena polymorpha* | Eastern Europe (Black Sea) | Introduced to: western and northern Europe, including Ireland and Baltic Sea; eastern half of North America | Fouls all available hard surfaces in mass numbers. Displaces native aquatic life. Alters habitat, ecosystem and food web. Causes severe fouling problems on infrastructure and vessels. Blocks water intake pipes, sluices and irrigation ditches. Economic costs to USA alone of around US$750 million to $1 billion between 1989 and 2000. |
| Asian kelp *Undaria pinnatifida* | Northern Asia | Southern Australia, New Zealand, west Coast of the United States, Europe and Argentina | Grows and spreads rapidly, both vegetatively and through dispersal of spores. Displaces native algae and marine life. Alters habitat, ecosystem and food web. May affect commercial shellfish stocks through space competition and alteration of habitat. |
| European green crab *Carcinus maenus* | European Atlantic coast | Southern Australia, South Africa, the United States and Japan | Highly adaptable and invasive. Resistant to predation due to hard shell. Competes with and displaces native crabs and becomes a dominant species in invaded areas. Consumes and depletes wide range of prey species. Alters inter-tidal rocky shore ecosystem. |

*Source*: IMO (2018[84]) *Invasive Aquatic Species (IAS)*, http://www.imo.org/en/OurWork/Environment/BallastWaterManagement/Pages/AquaticInvasiveSpecies (AIS).aspx

The two main vectors by which marine invasive species are redistributed globally are biofouling (largely on ships' hulls) and ballast water (Figure 2.2).

**Figure 2.2. Biofouling and ballast water**




*Source:* Fernandes et al. (2016[85]) *Costs and benefits to European shipping of ballast-water and hull-fouling treatment: Impacts of native and non-indigenous species,* http://dx.doi.org/10.1016/J.MARPOL.2015.11.015.

This case study focuses on the latter, namely the water that is used to maintain ships' stability and integrity under different operational situations. As the size of merchant vessels increased and maritime traffic expanded over the last seventy years or so, the volume of untreated ballast water being transferred unintentionally from one location to another has grown enormously. It is thought that today tens of billions of tons of ballast water are carried between the world's seas every year (Davidson et al., 2016[86]), spreading thousands of marine organisms – larvae, plankton, bacteria, microbes, small invertebrates, etc.- into the local marine ecosystem when discharged. This ballast-related redistribution of invasive species is widely recognised as a major environmental and economic problem, challenging, complex and currently still unresolved (Batista et al., 2017[87]). As a result, the need to treat ballast-water has become a priority initiative at global level, encompassing national efforts to strengthen regulation as well as multilateral efforts to design and implement an international convention.

### *2.3.2. Current state of regulation*

International ballast water management regulation has been long in the making. Indeed, the International Maritime Organization (IMO) has been tackling it since the 1980s, when Member States of the organisation began alerting its Marine Environment Protection Committee (MEPC) to their concerns. The year 1991 saw the adoption of Guidelines to address the issue, followed by work to build the IMO Ballast Water Management Convention, adopted in 2004. The Convention was eventually ratified by the IMO in September 2016. Although scheduled to come into force on September 8, 2017, implementation has been delayed until 2019 (see Box 2.4). All ships to which the Convention applies should be equipped with a Ballast Water Management System (BWMS) no later than 8 September 2024.

**Box 2.4. The Ballast Water Management Convention**

The Ballast Water Management (BWM) Convention requires all ships in international trade to manage their ballast water and sediments, according to a ship-specific ballast water management plan. All ships must carry a ballast water record book and an International Ballast Water Management Certificate. Ship-based diffusion of organisms (including invasive species) may vary by vessel type. Moreover, there are significant knowledge gaps also with respect to the natural spreading of organisms.

> *"All ships engaged in international trade are required to manage their ballast water so as to avoid the introduction of alien species into coastal areas, including exchanging their ballast water or treating it using an approved ballast water management system.*
>
> *Initially, there will be two different standards, corresponding to these two options.*
>
> *The D-1 standard requires ships to exchange their ballast water in open seas, away from coastal waters. Ideally, this means at least 200 nautical miles from land and in water at least 200 metres deep. By doing this, fewer organisms will survive and so ships will be less likely to introduce potentially harmful species when they release the ballast water.*
>
> *D-2 is a performance standard which specifies the maximum amount of viable organisms allowed to be discharged, including specified indicator microbes harmful to human health.*
>
> *New ships must meet the D-2 standard from today while existing ships must initially meet the D-1 standard. An implementation timetable for the D-2 standard has been agreed, based on the date of the ship's International Oil Pollution Prevention Certificate (IOPPC) renewal survey, which must be undertaken at least every five years.*
>
> *Eventually, all ships will have to conform to the D-2 standard. For most ships, this involves installing special equipment."*

Source: IMO (2017[88]) *Global treaty to halt invasive aquatic species enters into force*. http://www.imo.org/en/MediaCentre/PressBriefings/Pages/21-BWM-EIF.aspx

Full success of the Convention depends on a number of issues, the most important being the following:

- It will only apply to ships from flag states having ratified the Convention, and to ships entering their jurisdictions. At present the treaty has been ratified by more than 60 countries representing more than 70% of world merchant shipping tonnage. Given that this includes the dominant shipping nations as well as a host of other countries, it would be practically impossible to sail internationally without complying with the Convention. This effectively puts a brake on the exchange of invasive species, as vessels from nations not complying with the Convention are restricted to their own territorial waters.
- In view of the widespread lack of awareness about the environmental and economic consequences of ballast water, major efforts will be required to integrate and train ship crews and port staffs.

Further international negotiation and collaboration in the years ahead will be critical factors in consolidating, implementing and expanding the Convention.

### *2.3.3. Current state and future development of ballast water treatment technologies*

The Ballast Water Management (BWM) Convention standard applies to water upon discharge. However, ship owners are fully aware of the biological growth in ballast tanks, and so many already have or will in future have procedures for ballast water treatment in place for both water uptake and discharge.

The design and operation of BWM systems face multiple challenges. They have to be usable for many different types of vessel, prove effective in destroying a wide range of organisms, and be able to operate efficiently and safely under all kinds of ballast water conditions such as varying ranges of salinity and temperatures. Consequently, research has given rise to hundreds of different BWM applications that use a variety of underlying technological principles. These currently range *inter alia* from ultra violet, oxidation and de-oxygenation, to electrolysis, ultrasound and heat, as well as chemical biocides. (Latarche, 2017[89]). However, among the many vessels already equipped with BWM systems that are approved for use by the IMO and United States Coast Guard (USCG) , the vast majority utilise two main technologies for disinfection purposes – electro-chlorination or ultraviolet irradiation – often in combination with filtration (Batista et al., 2017[87]).

Both technologies have been subject to criticism. For example, common and abundant seawater phytoplankton have frequently been found to be resistant to UV treatment; especially smaller organisms and microbes often survive; and so the question of population re-growth in the ballast tank persists (Davidson et al., 2017[90]; Batista et al., 2017[87]; Wollenhaupt, 2017[91]). Electro-chlorination, in turn, has been found to demonstrate lower disinfection efficiency in upper reaches of estuaries and freshwater surroundings because of their lower salinity (Batista et al., 2017[87]). Moreover, environmental concerns have been raised about problems related to pollution from some chemical treatments being applied to ballast water (Davidson et al., 2017[90]).

In the absence of more effective treatments today, what is in the innovation pipeline for tomorrow?

One solution may lie in the development of green, environmentally friendly treatments that can handle the double challenge of making significant inroads into the spread of invasive species at reasonable cost while at the same time reducing impacts on the marine environment. An example is pasteurisation technology that does without UV, filters and chemicals. The Danish Bawat BMS (2018[92]), for example, is aiming for USCG-type approval in the course of 2019.

Meanwhile, currently available technologies are undergoing continual improvement through evolutionary (rather than revolutionary) advances, and through innovations that aim to mitigate the shortcomings of existing techniques. To date, over 65 ballast treatment systems have been given type approval by the IMO. And in terms of mitigation (e.g. sampling), research is apparently generating numerous applications that allow testing for some organisms whose continuing presence post-treatment would involve severe penalties from the regulators. While such applications do not detect all organisms or bacteria identified by IMO or USCG regulations, they can provide indications of whether the treatment system is working effectively and allow the vessel operators to undertake further action. Increasingly, these are small, relatively inexpensive hand-held devices that detect the presence of viable algal organisms, microbial activity etc. in the ballast water. (Latarche, 2017[89]). In addition, advanced lab-on-chip detectors have been tested recently which can measure various characteristics of certain microorganisms in ballast water, for example number, size, shape and volume (Maw et al., 2018[93]), and detection of bacteria in ballast water by new-generation DNA techniques has also been successfully tested (Brinkmeyer, 2016[94]).

### *2.3.4. Estimating economic costs and benefits*

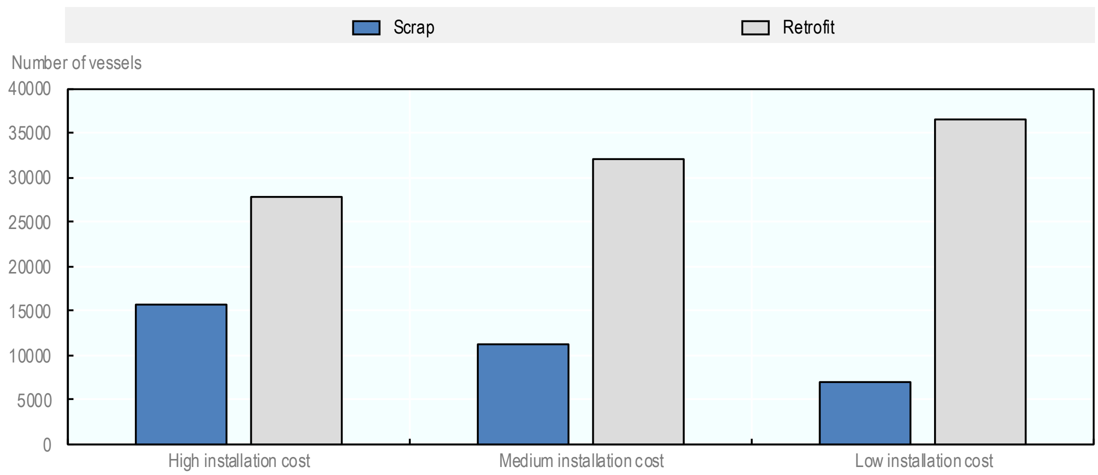
In complying with the requirements of the Convention, there are clearly large potential gains for the environment. For the shipping industry however there are costs involved, in the form either of installing BWMS in the newly built vessels or in retrofitting existing vessels. The flipside of the coin is that the shipbuilding and maritime equipment sectors stand to benefit from the extra revenue this involves. But how large is the additional revenue likely to be?

Several attempts have been undertaken in recent years to estimate the size of the potential additional BWMS market. All of them necessarily entail building multiple scenarios because the many different types of ship of different size require different ballast water volumes and different equipment. In their work on the costs and benefits of biofouling and ballast water in the European market, Fernandes et al. (2016[95]) rely upon three categories of ballast water volume (< 1 500 $m^3$, 1 500 to 5 000 $m^3$, > 5 000 $m^3$), five categories of vessels and four categories of tonnage. Splitting each of the three categories of ballast water volume into two categories of vessels accounts for 93% of the world fleet that uses ballast water. Creating categories in this way reduces the complexity of assessing the potential costs of measures across a range of vessels. For example, all ships with ballast waters volume of less than 1 500 $m^3$ are passenger and fishing vessels of less than 10 000 tonnes.

Estimates of the number of ships in the global merchant fleet likely to install/retrofit ballast water treatment systems vary considerably depending on the model used, assumptions made, and possibly the juncture in the shipping/shipbuilding cycle at which the estimates were made. (King D.M. et al., 2012[96]) ventured a rough estimate of 68 000 vessels installing on-board BWTS between the time of writing and 2020, assuming full compliance of the Convention. Linder (2017[97]) suggests between 30 000 and 40 000 vessels could be candidates for retrofitting. Clarksons Research (2017[98]) projects potential retrofit demand at around 25 400 ships, plus 1 000 to 2 000 ships per year in newbuild demand. And the OECD (2017[99]) indicated around 27 000 to 37 000 existing vessels might be expected to retrofit BWMS between September 2017 and September 2024.

Estimates also vary when it comes to the average cost of retrofitting BWMS. Linder (2017[97]) estimates capital expenditure at USD 80 000-1 500 000, installation cost at USD 100 000-1 000 000, running cost at USD 0.01-0.02 per ton of ballast water, and sampling at USD 75 000-125 000 per vessel. Recent work of the OECD Secretariat (Figure 2.3) assess the impact of the Convention on additional demolition volume and retrofitting activity on the basis of three scenarios (OECD, 2017[99]). These are a high level scenario with installation costs reaching USD 3 million per ship; a medium level scenario with costs of USD 1.5 million per ship; and a low level scenario of costs of USD 0.5 million per ship.

**Figure 2.3. Potential demand for retrofitting ballast water management systems under low, medium and high installation cost scenarios (number of vessels)**




*Source:* OECD (2017[100]) *Analysis of Selected Measures Promoting the Construction and Operation of Greener Ships,* http://www.oecd.org/sti/shipbuilding.

A highly simplified calculation, taking 25 400 existing vessels at an average retrofit cost of USD 2 million, would suggest a potential global BWMS market in the order of USD 50 billion. [The figure is in line with estimates of USD 45 billion by Linder (2017[97]), and at the low end of estimates of USD 50-74 billion by King et al. (2012[96]), albeit for the period 2011-2016). What is clear, however, is that the Convention could have a significant impact on the ship repairing industries, generating business opportunities which – under the proviso of further analysis – "may occupy around 20% to 50% of retrofitting capacity in the coming 7 years" (OECD, 2017[99]).

How likely is it that the huge additional potential of the global BWMS market will materialise in the coming years?

Economic theory at least suggests that uptake could well be slower than expected. As noted earlier, concerns have been raised by the shipping industry about the effectiveness of many ballast water treatment systems and their ability to meet consistently IMO and USGC discharge standards. Furthermore, King (2016[83]) indicates that IMO guidelines for certifying and testing are considered by many observers as vague and open to interpretation, and that USGC is thought to be tending towards lowering BWMS testing standards in order to facilitate market access for USCG-certified BWMS. King (2016[83]) goes on to apply two well-established theoretical approaches to analyse the situation in the budding BWMS market. The first, based on work by the economists Akerlof, Spence and Stiglitz, indicates that "quality uncertainty" may prevent markets from developing or at least may result in poorer quality goods or processes, especially in regulation-driven markets. In the BWMS market, lack of strict quality criteria from the outset is likely to see bad quality replace good quality, thereby undermining a potentially successful regulatory regime. The second theoretical approach, namely "game theory", draws on work by the economists Harsanyi, Nash and Selten, to explore inter alia how regulated industries react to such quality uncertainty by deploying strategies aimed at avoiding or delaying compliance, or reducing the costs of compliance. This would suggest that further action by governments and regulators will be required if an effective and viable regulatory regime is to emerge.

However, a counter-argument can be made to the effect that lowering the USCG standard may in fact prove beneficial, to the extent that it could result in one single common international ballast water standard. After all, the fact that the USCG standard is stricter than the UN IMO standard is thought to have caused uncertainties in the maritime industry – both among developers of ballast water treatment technologies and among ship owners – in respect of which standard to apply and which technology to purchase.

Finally, it should be noted that it may prove difficult to meet the requirements of the Ballast Water Management Convention within the proposed time range given both the limited conversion capacity and the corresponding costs for ship owners.

### *2.3.5. Concluding observations*

Successful implementation of the BWMC, underpinned both by further improvement of conventional treatment technologies and by innovation in greener technologies (such as pasteurisation), holds out the prospect of substantial benefits to marine life and to biodiversity more generally in ocean ecosystems. Economic benefits should arise on multiple fronts: cost savings in the maintenance of coastal and port facilities, enhancement of native fishery stocks, reduction of harmful impacts on marine aquaculture, increased tourist revenues, to name but a few. Even the shipping sector, that undoubtedly shoulders the lion's share of the costs associated with installation and retrofitting of ballast water treatment systems, ultimately also stands to gain as the knock-on effects expected from compulsory BWT feed through to lower levels of bio-fouling and consequently to fuel savings and lower emissions; see for example Fernandes, (2016[85]). However, it may prove difficult to meet the requirements of the BWMC within the proposed time range given the limited conversion capacity and the corresponding costs for ship owners. There is room for public policy both to encourage innovation in ballast water treatment and to ensure that a viable, effective regulatory system be implemented and sustained.

## 2.4. Case Study 3: Innovation in marine aquaculture

Marine aquaculture is a striking example of a sector in which scientific and technological innovations are combining in ways that can contribute significantly to both economic and marine-ecosystem sustainability.

### *2.4.1. The economic and environmental issues at stake*

The importance of aquaculture has been growing rapidly in recent decades as an expanding world population, rising incomes and changing food consumption patterns have all combined to push up global demand for fish food. Moreover, with growth in capture fisheries having plateaued, future growth in seafood production is expected to come largely from aquaculture, further underlining its key role in global food security.

Marine aquaculture production – finfish, crustaceans, molluscs and aquatic plants – currently stands at about 59 million tonnes, equivalent to just over one-half of global aquaculture production (FAO, 2018[101]). It produces some 6.6 million tonnes of finfish, almost 5 million tonnes of crustaceans, and almost 17 million tonnes of molluscs (FAO, 2018[101]). The vast bulk of farmed aquatic plants consist of macro-algae or seaweed. At 30 million tonnes, they make up more than half of total marine aquaculture by weight, but in terms of value – USD 11.7 billion – their share is quite small (FAO, 2018[101]). Global production of seaweed has been growing quickly, more than doubling over the period 2005-16, but remains dominated by China and Indonesia, which account for over 85% of the total (FAO, 2018[101]).

Future growth of aquaculture production volumes appears to be set on a slowing trajectory compared to the last few decades. The latest OECD-FAO Agricultural Outlook (OECD/FAO, 2018[102]) for example sees growth slowing to 2.1% p.a. in the period 2018-27 compared to the 5.1% of the previous decade. Important contributing factors are the increasingly scarce raw materials for fish feed, limited availability of appropriate sites at current levels of technology, concern about the environmental footprint of aquaculture, and increasingly crowded coastal waters raising the risk of disputes among other ocean users (shipping, fishing, oil and gas etc.). In addition to these, the licensing environment (Innes, Martini and Leroy, 2017[103]) and national policy have a significant role to play. The development of "investment ready" aquaculture zones for example in places such as Australia show how national policy can encourage production. Conversely, China's 13th five-year plan (2016-20) is expected to slow growth in domestic production. Objectives there have shifted away from the past emphasis on increasing production and moved towards a more sustainable and market-oriented sector, where the focus is on improving quality and optimising industry structure. This will affect global aquaculture production due to the importance of China's output at world level (OECD/FAO, 2018[102]).

Higher rates of growth in the coming decades are conceivable, but this would necessitate marked progress at several levels. Improvements in policy, licensing approaches and marine spatial planning could make important contributions. In addition, however, steps would need to include a reduction of the environmental impact of fish farms in coastal regions (e.g. destruction and/or pollution of coastal and aquatic ecosystems, introduction of exotic species into ecosystems, transmission of disease and parasites to wild populations), improved disease management, significantly higher proportions of non-fish feed for carnivorous species, and more rapid advances in the engineering and technologies required to establish offshore aquaculture operations (OECD, 2016[11]). In other words, future fish farming methods will need to be technically more sophisticated and more intelligent, requiring a "shift from experience-driven to knowledge-driven approaches" (Føre et al., 2018[104]). That in turn highlights the need also for scientific and technological innovation on multiple fronts.

### *2.4.2. Innovations in the pipeline*

Innovation in aquaculture has in the past been largely technology driven. With some notable, albeit relatively recent exceptions, it has operated much through technology transfer, i.e. through mono-disciplinary research producing new technologies that emerge from the research system, get diffused by intermediaries such as advisory services, and adopted by users at farm level. Technology transfer is still regarded as the predominant approach to innovation in aquaculture, and is indeed considered the dominant culture in developing countries in South and Southeast Asia and Africa (Joffre et al., 2017[105]). While it has undoubtedly given rise to continuous innovation and remarkable increases in productivity, its practices have been subject to increasing criticism for what is considered to be inadequate consideration of ecological and social sustainability, and for creating growing challenges for ensuing generations of innovation processes. Systemic approaches on the other hand (e.g. systems innovation, socio-ecological approaches) which take a contextual, more holistic perspective on innovation, have become somewhat more widespread in recent years in developed countries. These tend to be multi-dimensional approaches, integrating technical, biophysical, environmental, economic and institutional dimensions into account (Joffre et al., 2017[105]).

In light of the above-described challenges and changes facing aquaculture development in the years ahead, especially for larger-scale intensive fish farming in developed countries, systemic approaches to innovation are moving increasingly into focus. Growing complexity of operation will call for novel solutions. In salmon farming, for example, direct observation as a means to garner key information on the state of populations and optimise their growth and welfare may become unviable for facilities housing millions of individual fish. And if, as expected, farms begin to move offshore[2] into more exposed locations, access for personnel will become more problematic and remote automated operation more necessary (Føre et al., 2018[104]).

What kind of innovations are in the pipeline, which would contribute to addressing many of the challenges outlined above? What follows is an overview of advances unfolding in the various phases of aquaculture planning, implementation and operation, namely: aquaculture site selection, breeding, feeding, waste control, health monitoring and treatment, and engineering solutions.

### *Aquaculture site selection and area-wide assessment*

Earth observation, with its exceptional spatial coverage, is considered to have substantial potential to support aquaculture management across a wide range of objectives, including aquaculture site selection, mapping of fish farm locations and surrounding area, as well as environmental monitoring (e.g. water quality) and the identification and tracking of toxic algal blooms (Kim et al., 2017[24]). While earth observation has been in use for some years in aquaculture research, recent advances in sensing can be expected to strengthen its contribution to improved aquaculture management in the years to come. Recent years have seen improvements in remote sensing with very high spatial resolution on board satellites programmed to revisit at shorter intervals, thereby expanding the capacity for tracking and monitoring sites. More such satellites are scheduled.

High data costs can of course limit access to advanced remotely sensed data, especially for developing countries, but here too the situation is evolving. Ever more high-resolution data from optical and radar satellites are becoming downloadable free of charge. The United States Geological Survey's decision in 2008 to provide free access to its Landsat data archives proved ground-breaking in this respect. And more is on the horizon with the free and open data policy that applies to the Copernicus programme of the European Space Agency from its high resolution Sentinel-1A/B radar satellites and the optical Sentinel-2A/B sensors (Ottinger, Clauss and Kuenzer, 2016[106]).

Identifying appropriate sites for marine aquaculture is key to successful operation. On a smaller spatial scale than earth observation, a number of other useful tools exist for the purpose of site selection. These include for example GIS-based mapping, and modelling. GIS-based mapping affords access to marine and coastal datasets providing information for fish farm operators on availability of potential sites, as well on key factors such as environmental interactions and the presence of other, possibly competing ocean users. Recent progress has made it possible to combine GIS-based mapping with advanced modelling that provides further essential information such as predictions on oceanography, currents, animal growth, productivity and ecological environmental effects. The result is considerable enhancement of the outcome of the site-selection process by simultaneously augmenting farm productivity and reducing adverse impacts on the marine environment (Bricker et al., 2016[107]; Lader et al., 2017[58]).

Algal blooms figure among the greatest existential hazards to aquaculture. Around 300 different types of algal bloom have been identified, of which about one-quarter are toxic. When toxic algal blooms occur in shallow waters, they may pose a direct threat and can lead to severe reductions or complete loss of entire harvests. As non-toxic phenomena, they may also pose an indirect threat insofar as they can cause oxygen depletion (Ottinger, Clauss and Kuenzer, 2016[106]). In recent years, harmful algal blooms (HABs) of numerous varieties have occurred in a geographically wide range of waters: in North America (from New York to the Gulf of Mexico and the Pacific coasts of Canada and northwest United States), Scandinavia, Scotland, the Canary and Madeira Islands, and the Spanish and French Mediterranean, to name but a few. Harmful algal blooms are a natural occurrence in many areas and do not necessarily result from anthropogenic activity, and vary considerably over time, space and toxicity. Moreover, with growing climate change pressures, it is considered conceivable that harmful algal blooms may increase in frequency and severity (Wells et al., 2015[108]).

The economic cost of algal blooms is considerable. For example, in 2016 a series of HAB events caused severe damage to aquaculture in Chile. Salmon farmers lost some 39 million fish, equivalent to a harvest weight of 100 000 metric tons and a value of some USD 800 million (Anderson and Rense, 2016[109]). Shetland lost about half a million fish to one single harmful bloom in 2013. And until recently, the annual losses alone to the mussel industry in France, Ireland, Portugal, Spain and the United Kingdom totalled over EUR 30 million (Copernicus, 2016[110]). Looking to the future, harmful algal bloom events seem set to increase (Wells et al., 2015[108]).[3] That, combined with expanding marine aquaculture capacity around the world, suggests the possibility of mounting economic costs in years to come unless science and technology begin to make substantial progress in developing an effective forecasting toolbox for early action (e.g. moving fish cages or reducing stocking density, or early or delayed harvest of shellfish).

The way forward consists in combining multiple approaches – earth observation (EO), *in situ* remote sensing, geographic information systems, new analytical tools for toxins, and mathematical modelling including algorithms. Although few in number, such systems that combine observation, modelling, etc. to predict harmful algal blooms do exist. In the United States, for example, the National Oceanic and Atmospheric Administration (NOAA) operates a forecasting system (HAB-OFS) for Florida and Texas that is based on a mixture of satellite imagery, field observations and mathematical models. A limitation is that it only identifies mono-specific high biomass blooms that can be detected from space with the help of ocean colour algorithms (Davidson et al., 2016[86]).

An additional example of such an integrated approach is the "ASIMUTH" project (Applied Simulations and Integrated Modelling for the Understanding of Toxic and Harmful Algal Blooms) set up as a response to the demand for short-term forecasts of harmful algal blooms events along the western European seaboard using earth observation (EO) data (Davidson et al., 2016[86]). Remote sensing satellite data and monitoring images track chlorophyll and water temperature. The system downscales the products of the Copernicus Marine Environment Service (CMEMS) and brings them together with biological data and input from harmful algal bloom experts to distribute warning bulletins to aquaculture producers via the internet or mobile devices. This permits the operators of fish and shellfish farms to make contingency plans (e.g. earlier harvest) to reduce the impact of the algal bloom event.

The benefits are twofold. Economic benefits are derived from accurate forecasting, and from timely action by farm operators. (Savings for mussel farmers in five major European aquaculture producing countries are estimated at over USD 2.5 million per annum (Copernicus, 2016[110]). Public health benefits are derived in the form of lower contamination rates of produce and lower impacts on human health.

*Breeding*

Selective breeding in aquaculture is generally aimed at raising profit rates through increasing harvest weight, improving disease resistance or shortening the time to harvest. Over recent years, breeding programmes at company level have shown that they can be highly profitable. In the case of sea bass or sea bream, for example, revenues typically surpass investment costs after five years and gross margins continue to increase thereafter. Selective breeding programmes for Atlantic salmon in Europe are estimated to raise production by 0.9% per year and additional profits by a total of almost EUR 31 million per annum. For sea bass, sea bream and turbot combined, extra annual production through selective breeding is estimated at 1 700 tonnes, and extra annual profits at EUR 2.7 million. Profits are expected to double in the coming years as more businesses launch selective breeding for sea bass and sea bream.

However, profitability alone may not remain the guiding principle in future, as concerns about the environmental impacts of marine aquaculture are growing. For example, excess feed and nutrient excretion contribute significantly to local eutrophication. Using European sea-cage farmed sea bass as an illustration, Besson et al. (2017[111]) show that the expected increase in sea bass production of almost 14% between 2014 and 2017 is likely to raise the rate of eutrophication by almost the same percentage, if nothing is undertaken to mitigate this. In addition, according to Komen (2017[112]), climate change can be expected to lead to rising and more extreme water temperatures, which in turn would exacerbate the problem.

In general, profitability and the potential environmental risks and impacts of marine aquaculture will vary considerably across regions and are influenced by a whole host of factors ranging from the number and density of cages and the species being farmed, to the specific ecology and environmental conditions of the farm location.

But there is clearly a place for selective breeding in future efforts to achieve a greater balance between business development and environmental sustainability. Increasing fish's feed conversion ratios could considerably reduce the impact of excess nutrients on the environment while lowering feed costs and raising profitability. The economic and environmental sustainability of aquaculture already features among fish breeders' key objectives (Besson et al., 2017[111]). But tomorrow's breeding programmes will also need to consider the challenge of strengthening an animal's resilience to changes in climate and environment, furnishing yet more incentives to re-orient breeding programmes towards environmental values.

In parallel with selective breeding, breakthroughs are emerging in genomics which foreshadow important potential improvements in the years ahead in fish breeding and aquaculture more generally. Underlying those breakthroughs are rapid advances in next-generation sequencing technologies and bioinformatics analysis of large sequencing datasets, leading to whole genome sequencing in aquaculture. According to Yue and Wang (2017[113]), more than 24 species have had their genome sequenced in at least draft form. Both GS and marker-assisted sequencing promise to bring about rapid improvements in broodstock and shorter breeding cycles in fingerlings, thereby accelerating the introduction of better species at farm level compared to what can be achieved through conventional selective breeding. Moreover, the latter should also eventually benefit from improved integration of molecular and genomics tools at the research and industrial levels. Yue and Wang also foresee progress in epigenomics (epigenetic modifications are reversible modifications on a cell's DNA that affect gene expression without altering the DNA sequence) which cast more light on the interactions between the biochemical characteristics of marine organisms and environmental factors, thus contributing to both the sustainability and profitability of aquaculture[4].

### *Feed*

Feed is an extremely important input in marine aquaculture. It accounts for between 50 and 80% of total aquaculture production costs (FAO, 2017[114]). Moreover, feed can have a high impact on the environment in the form of waste (excess food, nutrient excretions, etc).

Significant progress has been made in recent years towards reducing or replacing fishmeal in the diets of many aquaculture species without compromising health or performance. Fish processing by-products, for example, currently make up around 25-30% of marine ingredients (Shepherd, Monroig and Tocher, 2017[115]). Efficiency increases are helping recover increasing quantities of oil and fishmeal from fish waste, along with increased demand for fillets which produces more waste. This means that production of fishmeal and fish oil from fish residue is expected to continue to rise (at rates of 2.8% and 1.6% per year, respectively) over 2018-27, taking the share of total fish oil obtained from waste fish from 39% to over 41% and that of fish-waste based fishmeal from 29% to more than 33% over the same period (OECD/FAO, 2018[102]). The consequences on the composition and quality of fishmeal and oil of increasingly relying on fish waste to produce them is also a source of uncertainty, as it will generally result in more minerals and less protein.

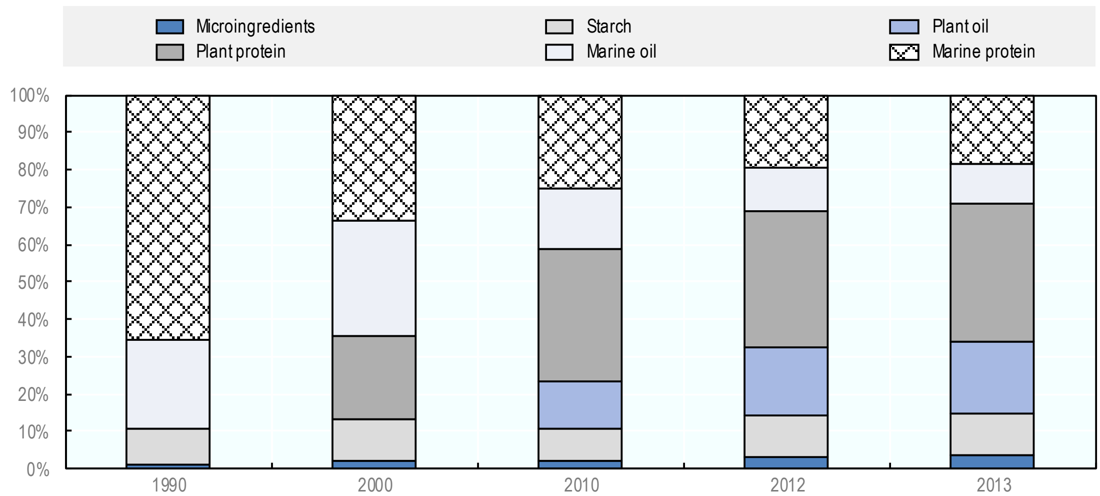
New ingredients for fishmeal include micro-algae, insect-based feeds, and plant-based feeds. Micro-algae are considered an environmentally sustainable alternative as they can be cultivated on a large scale and are not typically products destined for human consumption ( (Perez-Velazquez et al., 2018[116]; Henry et al., 2015[117]). Plant-based feeds include yeast-fermented rapeseed meal, soya, cereal grains, and so on. Results have been encouraging with respect to the proportions of fish meal replaced by plant-based inputs (Dossou et al., 2018[118]; Torrecillas et al., 2017[119]; Davidson et al., 2016[86]).

Similarly, much research has gone into the replacement of fish oil, not least because global fish oil supplies will not be able to satisfy the growing future demand for fish oil in aquafeeds, especially for carnivorous fish, and new alternative lipid sources are required to secure the future expansion of the aquaculture sector (Davidson et al., 2016[86]). Some of the studies indicate the possibility of high to very high replacement rates through vegetable oils (e.g. soybean, linseed, rapeseed, olive oil, palm oil, and so on) and algal-based oils across a wide range of fish and crustaceans, e.g. European seabass, red seabream, Atlantic salmon, red drum, rainbow trout and shrimp. For reviews of recent studies, see for example (Yıldız et al., 2018[120]; Torrecillas et al., 2017[119]; Shepherd, Monroig and Tocher, 2017[115]).

The effects on the composition of fish nutrition that the increasing replacement of marine products can bring about is illustrated very clearly in the farming of Norwegian salmon where between 1990 and 2013 the proportion of total marine sourced inputs fell from almost 90% to less than 30% (Figure 2.4).

**Figure 2.4. Nutrient sources in Norwegian salmon farming feed resources from 1990 to 2013**

Each ingredient type is shown as its percentage of the total diet.




*Source:* Ytrestøyl, Aas and Åsgård (2015[121]), *Utilisation of feed resources in production of Atlantic salmon (Salmo salar) in Norway,* http://dx.doi.org/10.1016/J.AQUACULTURE.2015.06.023.

In environmental terms, a downside has been that the fishmeal-free diet has been found to generate greater quantities of fish waste, notably total phosphorous and total suspended solids, as well as affecting oxygen demand in the water, although the poorer water quality did not negatively impact fish performance (Shepherd, Monroig and Tocher, 2017[115]). However, this is a matter that can be addressed *inter alia* by waste treatment technology (see following subsection).

On the economic front, the growing demand for fishmeal and fish oil replacements is translating into growing demand for alternative aquafeeds and supplements. The industry estimates the value of the global aquafeed market in 2017 at well over USD 100 billion and projects that figure to reach over USD 172 billion by 2022. That is equivalent to a compound average growth rate of around 10% (Research and Markets, 2017[122]).

### *Waste treatment*

Marine aquaculture can affect the immediate ocean environment in different ways. As noted above, some types of farms (especially finfish) contribute to poor water quality through nutrition pollution and in some cases chemical pollution. The magnitude of the impacts depends on such factors as the species farmed, animal density in the cages, feeding method and location. Other types of aquaculture, notably algal and bivalves, have the potential to improve water quality: algae by taking up nitrogen, phosphorous and carbon, and bivalves by reducing phytoplankton and therefore eutrophication.

One systemic way to address the pollution problem associated with finfish farming is to introduce integrated multitrophic aquaculture (IMTA), which pairs different trophic levels of aquaculture in the same location with the aim of replicating natural ecological nutrient cycling. The fed fish produce excess organic matter which in turn feeds the bivalves and algae.

IMTA is widely acknowledged to hold considerable promise for significantly improving the sustainability of aquaculture, since it can potentially help achieve multiple objectives, including improved ecological efficiency, environmental acceptability, and profitability. However, while well established in many parts of Asia, IMTA is a much less familiar system to producers in Western countries where it faces numerous obstacles. In Europe, for example, challenges include lack of seed for promising local species, legislation issues, general lack of R&D knowledge, difficulties in handling the complexity of IMTA, and public acceptance (Kleitou, Kletou and David, 2018[123]).

There are however other innovations coming on stream which should be able to address many of the pollution issues facing marine aquaculture. These range from sensor platforms to detect uneaten food pellets falling to the cage bottom and algorithms to decide when the fish have had enough to feed, through procedures for improving food digestibility, to automated feeding techniques. In the latter case, technologies are available to observe behavioural variables in the fish; these include sonars, computer vision techniques, acoustic telemetry, spatial mathematical modelling combined with remote sensing, and artificial intelligence (Føre et al., 2018[104]).

### *Disease control and treatment*

Of the many possible causes of aquaculture production losses suffered by aquaculture operators globally, disease is a major factor, accounting for around 40% of lost aquaculture production (Bastos Gomes et al., 2017[124]). Numerous outbreaks of disease in recent decades have proved particularly costly.[5] Various innovations are in the pipeline to help address these problems.

#### *a) Breeding for greater disease resistance*

The worldwide increase in aquaculture production has given rise to many challenges including greater threats from diseases in both the freshwater and marine environments. Viral diseases such as infectious pancreatic necrosis, pancreas disease, cardiac myopathy syndrome, and heart and skeletal muscle inflammation have in the past wrought devastation on many a salmon farm. Sea lice for their part are considered the principal threat to sustainable salmon production around the world, having already inflicted significant economic and environmental harm. Selective breeding can reduce susceptibility to these pathogens, but conventional approaches require several generations to achieve results. In the case of Atlantic salmon, it is claimed that molecular genetics tools (e.g. MAS, genomic selection) will usher in major improvements in the accuracy and efficacy of procedures aimed at selecting for higher levels of resistance to pathogens and parasites (Norris, 2017[125]).

Eventually, with declines in sequencing costs and genotyping on the one hand and growing threats from climate change and pathogens on the other, it is expected that aquaculture science will move from genomic selection to genomic grading. In other words, it should become possible to tailor the genotype of a smolt to a specific location or even farm so as to optimise its survival (Norris, 2017[125]).

#### *b) Prevention*

Notable progress has been made in recent decades in controlling bacterial diseases – and therefore losses – in aquaculture through vaccination early on in the freshwater production stage. However, this does not apply to all regions and all species. Commercial development of vaccines for warm water fish and shrimp, for example, is still quite limited and in need of further development (Dadar et al., 2017[126]). Moreover, much less success has been achieved in tackling viruses and parasites (Norris, 2017[125]). Indeed, for some experts, most efforts in developing vaccines for aquatic animals are still very much in their infancy, and many hurdles will need to be overcome on the road towards multi-component, cost-effective vaccination programmes (Dadar et al., 2017[126]).

Success in prevention treatments will be vital to the sustainable growth of aquaculture at the rates required to meet rising demand for fish from an expanding world population. That focus on greater economic and environmental sustainability is one of the key drivers behind the aquaculture health sector, a business estimated to be already worth USD half a billion (Business Wire, 2016[127]).

### *c) Monitoring and detection:*

Salmon farming is particularly susceptible to deadly outbreaks of the bacterial pathogen *Piscirickettsia salmonis* as well as the sea louse *Caligus rogercresseyi*. However, detecting them is in most cases both time-consuming and expensive. According to Føre et al. (2018[104]), this makes such an operation an excellent candidate for automation, deploying mainly optical tools. Spectral analysis can be used to distinguish sea lice from salmon skin, or hyperspectral analyses to detect alterations in the colour and texture of skin provoked by sea louse infestation. Estimations of sea lice numbers could then be constantly evaluated through an AI application that would compare the louse count to the legally set limits, and alert the farm operators when that limit is approached so that action can be taken. On this, see also Lopez Cortes et al. (2017[128]) and Gomes et al. (2017[124]) on the potential of eDNA approaches.

### *d) Treatment*

Treatment (and in some cases prevention) of numerous pathogens has conventionally been through the application of chemotherapeutic approaches, finding widespread use in many aquaculture producing countries around the world, from Europe to Asia and Latin America. The obvious drawback of such techniques is that some chemicals may have negative effects both on the environment and on human health. Also widely used until some years ago were antibiotics. They too have been shown to have potentially serious drawbacks, notably by producing antibiotic resistance in the target pathogens, as well as raising concerns about the effects of prolonged use of antibiotics on human health in the form of antibacterial resistance. As a result, the administration of antibiotics in aquaculture is now strictly regulated in many countries, which has led to much sparser use of antibiotics (a notable exception being Chile in 2015). In turn, strategies for improved monitoring and prevention have also contributed to lower the necessity to use antibiotics. A frequently cited case is that of Norway where the use of antibiotics has fallen steeply to almost zero since the 1990s (Grave and Oslo, 2016[129]).

Attention has increasingly focussed on other means to treat outbreaks of disease. Among these is the growing interest in natural products. Studies are under way, for example, on the use of medicinal plants, marine algae, herbs and so on for disease management in fishes and prawns (Thanigaivel et al., 2016[130]). There is also further movement on the biotechnology front in biocontrol strategy research Defoirdt et al. (2011[131]) identify some promising novel biocontrol strategies that target the pathogens, e.g. bacteriophages that kill specific bacteria, bacterial growth inhibitors, and bacterial virulence inhibitors. At the time of that publication, the alternative biocontrol strategies discussed were still in the research phase and had not yet been tested in commercial aquaculture facilities.

A form of natural treatment of sea lice infestations which has gained considerably in popularity in salmon and rainbow trout farming is the use of cleaner fish – wrasse and lumpfish in Northern and North Western Europe, and potentially the robalo in Chile. Their use in Europe has increased enormously. Alone in Norway the numbers of cleaner fish used rose from tiny amounts in the 1990s to 1.8 million in 2000, to over 37 million in 2016. (OECD, 2017[99]; Norwegian Directorate of Fisheries, 2018[132])). The dynamics of cleaner fish use in salmonid aquaculture are a useful illustration of innovations that embody both economic development and environmental sustainability.[6]

### *Offshore aquaculture engineering and operations*

A promising route for future expansion in the production of marine food is open-ocean aquaculture. It appears to offer numerous advantages compared to coastal seafood farming. These include fewer spatial constraints, less environmental impact, lower risk of conflicts with other ocean users, and fewer problems with disease. However, very few large-scale open-ocean farms are currently in operation, not least because they face a host of challenges: designing structures that can withstand the harsh conditions of the open ocean; access to the facility for monitoring, harvesting and maintenance purposes; communications; and safety of personnel, to name but a few.

Even assuming these challenges can be successfully addressed, just how big is the theoretical potential capacity for offshore aquaculture?

A recent study on the subject (Gentry et al., 2017[133]) suggests that the total potential area suitable for ocean aquaculture is immense. It estimates the area at over 11 million square kms for finfish and over 1.5 million kms for bivalves: sufficient to grow 15 billion tonnes of finfish a year, or 100 times the current global levels of seafood consumption. The process involves whittling down the total ocean surface available in continental regions at depths of up to 200 m and then mapping out and deducting a series of major constraints on the area suitable for growth: Marine Protected Areas, shipping traffic, oil rigs, areas of low chlorophyll concentrations (for bivalve cultures), and areas of low dissolved oxygen. Conservative thresholds were chosen for each of these variables, resulting in the elimination of some areas that may in fact be able to support marine aquaculture. Result: the area was reduced from 26 748 980 km$^2$ to 11 402 629 km$^2$ for fish and 1 501 709 km$^2$ for bivalves. The final suitable global surface included both tropical and temperate countries, with many of the areas found to be located in warm, tropical regions. The total potential production is considerable: if all areas designated as suitable in this analysis were developed, the authors estimated that approximately 15 billion tonnes of finfish could be grown every year—over 100 times the current global seafood consumption.

Further economic, environmental and social constraints could come into play. These might include, for example, environmentally sensitive and/or high-biodiversity areas such as coral reefs, economic considerations like the distance to ports or access to markets, military zones, shoreside infrastructure, and intellectual or business capital. The social interactions with wild fisheries, jobs, prices and cultural heritage should also be taken into consideration. Other uses of these areas, such as by the military or for energy production, may also limit the available space. The result could be a further shrinking of the estimated area, but given the sheer scale of space available overall, there would still be ample room for adjusting future aquaculture sites to those additional constraints (Gentry et al., 2017[133]). A similar study by Oyinlola et al. (2018[134]), calculates a much larger area, but using a different methodological approach and fewer constraints.

Clearly, before such immense potential can be more fully exploited and scaled up in economically and environmentally sustainable ways, much more research will be required and many engineering solutions designed and field tested. Already many new models have been proposed[7].

New designs are also likely to be much larger, containing millions of fish as opposed to thousands at present. Indeed, at the time of writing, some of them are close to completion and even operation. Foremost among these perhaps is Salmar's Ocean Farm 1, installed off the Norwegian coast in 2017 and preparing for full operation later in 2018.[8] An alternative concept is being developed by the United States company, InnovaSea, namely a set of submerged pens configured in a grid system and anchored to the ocean floor.[9]

In light of the size of the potential ocean surface available for marine seafood farming, the development of open ocean aquaculture on such a scale as sketched out here holds out the promise of huge business opportunities over the longer term which could at the same time make a major contribution to global fish farming sustainability. Those business opportunities are expected to emerge not only in the form of the revenues from efficient and sustainable growth of aquaculture itself, but also from the many new, smart economic activities that will form an integral part of the sector. For finfish, and to a large extent also algae (Kim et al., 2017[24]), these range from the mass development and installation of autonomous systems and technologies for remote operations as well as to complex decision support systems, to the design and construction of novel service vessels for exposed operations as well as autonomous and remotely operated undersea vehicles for site assessment, maintenance and repair.

However, before that era dawns, much scientific, technological and economic research across very many different disciplines will be required to pave the way. This applies no less to the environmental impact of open ocean aquaculture and the carrying capacity of ocean and seas. Since only few offshore farming projects are actually in operation around the world, data on ecosystem impact is very limited. That makes it particularly challenging to set a baseline of ecologically meaningful reference points such as minimum distance, depth, current velocity, etc. Without that data from impact analysis, the risks involved will first have to be explored using more theoretical model-based methods, perhaps along lines akin to those commonly applied in capture fisheries research (Froehlich et al., 2017[135]).

### *2.4.3. Concluding observations*

If a large part of the many innovations described in this case study were to come on stream in the years ahead – especially those achieving a reduction in the environmental footprint of seafood farming – then marine aquaculture production could expand at more rapid rates than those generally projected. Since growth in the value of aquaculture production has been outstripping volume growth for some years now, the economic returns on innovations that help loosen the aforementioned constraints on output expansion could be substantial. Indeed, it could mean that gross value added of the global marine aquaculture sector could grow at well over 5% per year, trebling the sector's value between 2011 and 2030 to around USD 11 billion (OECD, 2016[11]). Moreover, recent research indicates that there could in addition be positive knock-on effects further down the value chain. Input-output analysis for Ireland by Grealis et al. (2017[136]) suggests that expansion of aquaculture output could generate revenue and employment gains for both the aquaculture and seafood processing sectors on a significant scale.

## 2.5. Case Study 4: From rigs and renewable energy infrastructure to reefs

### *2.5.1. The economic and environmental issues at stake*

Decommissioning of offshore oil and gas structures is a rapidly expanding industry with strong growth prospects. There are currently over 8 000 offshore oil and gas platforms in use around the world (OFS Research/Westwood Global Energy Group, 2018[137]), the vast bulk of them in the Gulf of Mexico and Western Europe .Close to 1 400 platforms operate in SE Asia and some 1 800 in the Asia Pacific region (Jagerroos and R Krause, 2016[138]).

Although several thousand platforms have already been decommissioned over the last few decades, principally in the Gulf of Mexico, the decommissioning industry is considered to be still very much in its infancy. The oil and gas industry currently decommissions around 120 structures annually (International Energy Agency, 2018[139]), the bulk of them in North America. This is set to continue apace over the coming years. It is estimated that more than 600 structures will be decommissioned over the 2016-20 period, and a further 2 000 more between 2021 and 2040 (Cimino, 2017[140]; IHS Markit, 2016[141]). These estimates are broadly in line with those recently published by the IEA (2018[139]), namely between 2 500 and 3 000 offshore projects by 2040. While to date the bulk of decommissioning has occurred in North America, the next 25 years will see a much wider geographical spread of such activities, including Central and South America, Europe, Africa, Middle East, Eurasia and the Asian Pacific.

Moreover, it is mainly steel platforms in shallow water that have been decommissioned so far. In the coming years, however, many more deep-water installations and subsea tie backs (connecting subsea equipment on the seabed to the floating vessel or platform via risers) will be coming to the end of their service life. Such installations are more complex to decommission, signifying a steep increase in the engineering, financial and environmental challenges involved. As time goes on, decommissioning of wind turbines will add to the list of structures requiring removal as they reach the end of their life expectancy of 20-30 years (Smyth et al., 2015[142]).

Technically speaking, a range of options is available for decommissioning offshore rigs which range from complete removal from the site to partial removal to conversion into an artificial reef (Table 2.4).

**Table 2.4. Options for decommissioning offshore rigs**

| Options | Description |
|---|---|
| Disposing at land | Bringing the installation onshore, cleaning it, breaking it upinto scrap for recycling in the steel industry, or disposal at licensed sites. |
| Toppling on site | Cleaning the installation, placing or toppling the cut section on the seabed. |
| Placing in deep water | Cleaning the installation, and then towing it and placing it in a deep water site. |
| Leaving on site | Making the installation safe and leaving in-situ. |
| Artificial reef | Cleaning the installation and using it to form an artificial reef to improve local marine life. |
| Re-use in another location | Cleaning the installation, carrying out non-destructive tests, removing and transporting to another site suitable for the platform's characteristics, then installing it at the new site. |
| Re-use for another scope | Making the installation safe and transferring use/purpose and potential ownership. |

*Source*: Shaw, Seares and Newman (2018[143]) *Decommissioning offshore infrastructure: a review of stakeholder views and science priorities*, http://www.wamsi.org.au/decommissioning-offshore-infrastructure-review-stakeholder-views-and-science-priorities.

The status quo approach to decommissioning prescribed in many countries is complete removal of the platform. That generally entails a series of steps by the oil and gas company to safely remove the structures: shutting down production, securely plugging and abandoning the subsea wells below the mudline, cleaning and removing all production and pipeline risers, removing the platform from its foundation, disposing of the platform on land in a scrapyard or fabrication yard, and ensuring that no debris remain that could potentially obstruct other users of the site location. This makes decommissioning an expensive business. The lion's share of the expenses is often consumed by the plug and abandonment of the well, usually requiring a cement plug fitted by dedicated rig. Also very costly are the topside and substructure removal, transport and onshore deconstruction. Some cost savings may of course be achieved through the sale of the scrapped steel, whereby subsea materials in particular can prove to have high scrap value. Estimates put the total decommissioning expenditure in Western Europe to 2040 at around USD 102 billion (Westwood Global Energy Group, 2018[144]), USD 100 billion in the Asia-Pacific region (Slav, 2018[145]), and around USD 40 billion for Australia (Khan, 2018, whereby a substantial proportion of the cost is likely to be borne by the public through tax concessions (Osmundsen and Tveterås, 2003[146]).

The environmental dimension of decommissioning is highly controversial, with decommissioning practice varying considerably across the globe. In regions where decommissioning is performed within a regulatory framework, the regulations often dictate that platforms should not be left standing and have to be removed. In some regions, however, there is a policy to encourage platforms to be left in place where appropriate (e.g. United States); in others (e.g. OSPAR) derogations are possible but are the exception. In yet others (e.g. Indonesia) no regulatory framework exists.

To a large extent, such differences are due to diverging views on the environmental impacts of partial or complete removal of structures. Indeed, the decision on how to decommission often entails difficult trade-offs. Partial removal of platforms which leaves substructures in place can for example lead to chemical contamination of the natural ecosystem or, in the case of intertidal offshore structures, favour conditions for the spread of invasive species. Complete removal, on the other hand, may result in contamination spreading beyond the site, threats to endangered species, destruction of benthic habitats and disruption of food webs.

At global level, little change to regulatory regimes appears to be on the horizon, with some notable exceptions (see further below). However, at expert level opinion may be shifting. The authors of a recent worldwide survey of experts by the Ecological Society of America (Fowler et al., 2018[147]) suggest that their findings support a growing global concern about the risks of infrastructure removal to the environment and marine ecosystems. While participating experts identified negative impacts for both partial and complete removal options, many considered the mass removal of infrastructure to be a potential source of new large-scale disturbance, and called for decommissioning options to be evaluated against a wider range of environmental issues, including biodiversity enhancement and provision of reef habitat, and protection from trawling.

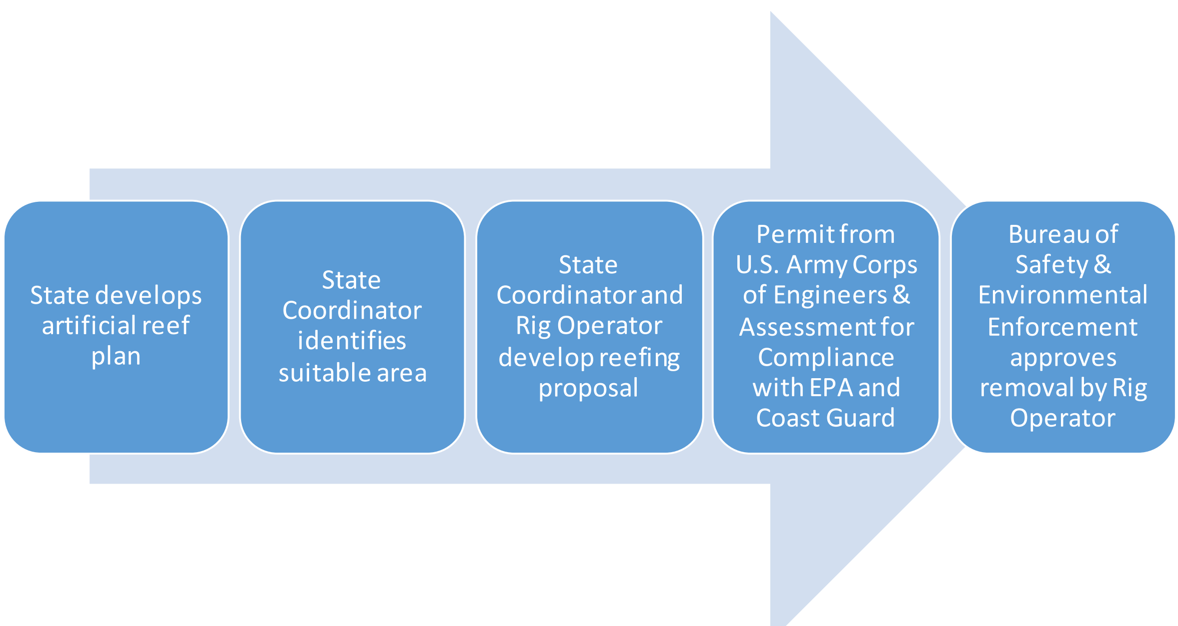
In the final analysis, however, every case of decommissioning is governed by its own geophysical, financial, regulatory, technical and environmental specificities.

### *2.5.2. Converting oil and gas platforms into artificial reefs*

Much as a result of the growing awareness of environmental impacts, but also of the possibilities opening up for ecosystem restoration, interest has been growing in recent years in converting redundant oil and gas platforms into artificial reefs.

Artificial reefs as such have been employed for centuries. A more recent phenomenon however is the design and implementation of plans and programmes to permit and indeed encourage the conversion of offshore structures into artificial reefs, known as rig-to-reef projects. A few such projects have been initiated in for example Thailand, Malaysia and Brunei. But it is in the United States that they are most firmly established, especially in the Gulf of Mexico (Figure 2.5). Indeed, the United States hosts the largest rigs-to-reefs project in the world, namely the Louisiana Artificial Reef Program. Responsibility for decommissioning offshore platforms lies with the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEM), in consultation with state authorities and several federal agencies including the Environmental Protection Agency, NOAA, the Army Corps of Engineers, Fisheries, and the Coast Guard.

**Figure 2.5. How the Rigs-to-Reefs Programme works in the United States**




*Source*: Grasso (2017[148]) *Rigs-to-Reefs Program*, presentation at the OECD Workshop on Innovation for a Sustainable Ocean Economy, October 10-11, 2017, Naples, Italy.

Not all platforms are suitable for conversion. Eligibility for transformation is subject to engineering standards, and numerous criteria play into the decision making process, including the size, structural integrity and location of the platform. In general, the preferred candidates for reefing are complex, stable and clean structures (BSEE, 2015[149]). By 2016, a total of 516 platforms had been converted into reefs, equivalent to around 11% of all platforms decommissioned in the Gulf of Mexico since 1987 (Grasso, 2017[148]).

United States practice offers insights into how savings and economic benefits come into play in the conversion process. For the oil and gas company, the economic incentive consists in the difference between complete removal of the platform and only partial removal for the purposes of reef conversion. The monetary benefit for the environment is that around half of that saving by the oil and gas company goes to the government's artificial reef programme to support the creation of the reef.

*Assessing the ecosystem benefits of rig-to-reef programmes*

How successful so far are rig-to-reef programmes in terms of enhancing or restoring fish and mollusc populations and biodiversity more generally? As noted above, the most comprehensive platform conversion programme has been conducted in United States waters (Gulf of Mexico and Pacific), where it has generated considerable research into this question. For the Gulf of Mexico, it appears that the number of structures on a given reefing site may have considerable impacts on the density of some species (Ajemian et al., 2015[150]), in this particular case on the stocks of economically important red snapper. (Claisse et al., 2014[151]) focussed on waters off the coast of California to compare annual secondary production of fish communities on oil and gas structures to those on natural reefs as well as to secondary production estimates of fish communities from other marine ecosystems. (Secondary production is the formation of new animal biomass from growth for all individuals in a given area during some period of time). They found that "oil and gas platforms off the coast of California have the highest secondary fish production per unit area of seafloor of any marine habitat that has been studied, about an order of magnitude higher than fish communities from other marine ecosystems."

However, Caisse et al (2014[151]) also raise the much-debated question of whether these structures produce a net addition to fish populations in the area, or whether they merely attract existing fish populations from the surrounding area. (This is important since such an accumulation of fish around hard structures may attract more intensive fishing, possibly leading to over-exploitation of stocks in the long term.) In the case of Californian waters, they concluded that "the platform was not drawing fish away from recruiting to other natural habitats, but providing a net increase in recruitment." They noted however that this finding was unlikely to apply to all species and all platforms. For the Mediterranean's largest artificial reef (Cresson, Ruitton and Harmelin-Vivien, 2014[152]), also found that non-natural reefs can contribute to local secondary production. Jagerroos and Krause (2016[138]) too confirm that new reef habitat indisputably increases the abundance of the local fish and invertebrate communities by functioning as a fish aggregation device, but also they raise the issue of "attraction" versus "stock enhancement".

As indicated earlier, not many regions of the world have decommissioning regulations in place, as in the United States, which take a flexible if not favourable approach to rig-to-reef transformation. The North Sea as part of OSPAR is a case in point, where there has never been a rigs-to-reef programme. However, in recent years a series of scientific studies have indicated that rig conversion to reefs may well be an appropriate strategy for fish conservation in the North Sea, as it can have positive effects on deep-sea benthic communities, function as safe harbours for some fish stocks, and host cold-water coral colonies. The upcoming stream of decommissioning projects provides an opportunity to initiate the creation of large-scale reef systems to benefit ocean life (Jørgensen, 2012[153]). As of 2017 no change to OSPAR guidelines is in sight, but pressure is growing from industry, the scientific community and conservationist groups in support of reusing rigs for reefs in the North Sea; see for example Porritt (2017[154]).

It may however prove difficult to bring about significant widespread change. The Norwegian shelf, for example, currently counts 12 concrete facilities, 23 steel floating facilities and 59 steel facilities resting on the seabed, in addition to which there are nearly 400 subsea installations. The authorities have at present approved a total of about 20 decommissioning plans, six of them in the last two years. Over the next five years, up to one-quarter of the fields currently on stream could be closed. But the rules and regulations governing the Norwegian Continental shelf dictate that facilities must be removed in their entirety; only in extremely limited cases can they be abandoned on the field once they have reached the end of their useful life (Norsk Petroleum, 2018[155]). Some margin of manoeuvre may be found in the case of deep-sea oil and gas fields deploying floating installations. The anchoring structures and cable connections could be used for offshore wind farms, or indeed for future deep-sea fish farming.

What emerges from the many studies conducted so far then is that, while the United States experience in particular seems to have been broadly very positive, it remains unclear whether that experience is easily transferable to other regions, locations, and other environments (Techera and Chandler, 2015[156]). As Jagerroos and Krause (2016[138]) note, some offshore platforms that have been in operation for many years have not fostered the diversity of benthic or fish communities comparable to that which can be found on some natural reefs. Indeed, every site reveals different characteristics in terms of marine life, substrate, currents, proximity to natural reefs, and so on (Lyons et al., 2013[157]).

### *A growing role for science in assessing suitability for rig conversion*

The widespread scientific view today is that rig conversion programmes can only be viable after a thorough prior assessment of the many factors and criteria determining their success. These include the composition of marine life on the site but also further afield, the environmental risks, biodiversity conservation issues, questions of location, priority setting, potential benefits and trade-offs, and matters of stakeholder involvement.

This applies no less to the North Sea for which there is a serious lack of data to understand how man-made structures interact and influence its ecosystems (UK Department for Business, 2018[158]) and for which major international research efforts are required. The European-financed INSITE project is one such undertaking. Its aim is to help establish the magnitude of the effects of man-made structures on the North Sea ecosystem, considered on different time and space scales, and to establish to what extent, if any, the man-made structures in the North Sea represent a large inter-connected hard substrate ecosystem (INSITE International Scientific Advisory Board ISAB, 2018[159]). Results so far indicate that oil and gas structures do indeed create a network of hard substrate ecosystems for certain species, and that they may act as bridges (via larval dispersion) between otherwise distinct networks, be they in the deep sea, in fjords or in marine protected coral areas (Henry, 2017[160]). In practical terms, the work to date has shown that the network analysis modelling tools used by the project could be useful in supporting decisions on decommissioning. It also demonstrated the value of DNA barcoding and population fingerprinting in supporting connectivity modelling for specific species.

Other regions of the world too are becoming increasingly aware of the potential benefits of rig conversion on the one hand, but also of the scientific research effort required on the other. In Australia, for example, the National Offshore Petroleum Safety and Environmental Management Authority has been exploring such decommissioning options, and considerable scientific analysis is under way into rig-to-reef solutions, not least in light of the water depths at which many oil and gas facilities operate, and also in view of the uncertainties surrounding monitoring obligations. Under the new decommissioning guidelines published in January 2018, "options other than complete removal may be considered, however the titleholder must demonstrate that the alternative decommissioning approach delivers equal or better environmental, safety and well integrity outcomes compared to complete removal" (Department of Industry of the Australian Government, 2018[161]).

Also, in January 2018 the Western Australia Marine Science Institute published its findings from a wide ranging stakeholder consultation on decommissioning issues (Shaw J.L., Seares P. and Newman S.J., 2018[162]). Among the headline implications drawn from the project was confirmation that:

- "there are knowledge gaps that need to be addressed through science before decision-makers and stakeholders are able to efficiently and effectively consider the full range of decommissioning options as a matter of normal practice
- Confidence of short and long term environmental risk and/or acceptability of different decommissioning options is the overriding priority for stakeholders".

In Southeast Asia around half of the 1 700 oil and gas facilities in operation are more than 20 years old and approaching retirement, and studies are under way in several countries on the feasibility of converting platforms into artificial reefs (Jagerroos and R Krause, 2016[138]).

### *2.5.3. From offshore wind platforms to reefs*

There is also potential for transforming fixed-bottom offshore wind platforms into artificial reefs. As pointed out previously, the offshore wind industry has witnessed spectacular growth over the last couple of decades, from almost nothing to a total capacity of 14 GW in 2016. Growth in the medium-term future is also well on track, with total global capacity expected to triple to well over 40 GW by 2022. The longer-term prospects suggest a further tripling of capacity to around 120 GW by 2030, the vast majority of which will be fixed-bottom installations (GWEC Global Wind Energy Council, 2017[66]).

Offshore wind installations have an expected service life of around 25 years. Those that started operating in the early years of the 21st century are expected to be decommissioned in the course of the 2020s. However, it will be a number of years still before decommissioning will be required on a major scale. When, and how many, will depend on a variety of factors, including the advent of new technologies, the identification of more suitable sites, and the cost of equipment upgrades, all of which may render many existing installations uneconomical sooner rather than later (International Energy Agency, 2018[139]).

In light of those prospects, and reflecting the largely positive experience of North American conversion of oil and gas installations into artificial reefs, attention is now turning to the potential for converting also offshore wind platforms into artificial reefs. For legal, financial and environmental reasons, decommissioning requirements are usually an integral part of licensing and consent for all marine developments, and offshore wind is no exception – the options for offshore wind structures being either full removal, or partial removal leaving some elements in place. While the overall structure of offshore wind platforms is different from that of offshore oil and gas rigs, it is thought that the general principles of conversion into artificial reefs apply, including the potential benefits to ecosystem conservation and development, fisheries and recreational activities. A major difference does pertain, however, insofar as oil and gas rigs may be installed in deep water, thereby presenting fewer navigational risks than wind farms located in shallow waters. But it can be argued that such risks may be outweighed not only by the ecosystem benefits attached to partial removal, but also by the lower energy and labour costs as well as reduced safety risks compared to full removal (Smyth et al., 2015[142]).

Similar to rigs-to-reefs, there are issues around the net benefits of offshore wind platform conversion that would accrue to the ecosystem in terms of new marine life production. To date, very few wind farms have been decommissioned, and so evidence is limited. However, numerous studies indicate increased species abundance around offshore wind foundations, and they are typically associated with positive effects for the local ecosystem; see for example (Bergström et al., 2014[163]). Using improved data and advanced modelling techniques, some scientists have recently begun to link the projected expansion of offshore wind farms with future impacts on certain marine species. Slavik et al (2018[164]), for example, anticipate that on completion of all planned offshore wind installations in the southern North Sea, the overall abundance of the blue mussel will have increased by more than 40%, providing an additional food source (also for some crustaceans), and benefitting ecosystem functioning thanks to their filtering of phytoplankton. Examining offshore wind projects for the Bay of Seine (English Channel) ecosystem, Raoux et al. (2017[165])) projected the potential impacts of benthos and fish aggregation resulting from the installation of the concrete piles and the turbine scour protections. Their results suggest an increase in total ecosystem activity as well as in some fish species, marine mammals and seabirds as a reaction to the biomass aggregation around the infrastructures.

What is clear already at this early stage is that the long-term effects of offshore wind farms on local marine ecosystems as well as on ecosystems further afield are still unknown. If the environmental and economic potential of decommissioned offshore wind farms as artificial reefs is to be fully captured, much more scientific evidence will need to be gathered and evaluated.

### *2.5.4. Concluding observations*

Experience to date, gathered primarily in the Gulf of Mexico and the Pacific since 1987, suggests that only a fraction (around 10%) of oil and gas rigs is suitable for conversion to artificial reefs. Nonetheless, in light of the thousands of rigs to be decommissioned in the coming decades around the world, the number of potential future conversions is significant. Yet, while the United States has accumulated some 30 years of experience with rig-to-reef conversions, most other areas of the globe have been slow to follow, not least because rig-to-reef conversion is not easily transferable from one region to another. Indeed, suitability of rig-to-reef conversion is highly site-specific. Moreover, in many cases, the concern has prevailed that leaving part of the rig infrastructure in place risks serious pollution of the marine environment and that complete removal of the infrastructure should be required; in many other cases, no regulatory framework even exists and needs to be developed. However, the decommissioning issue is increasingly controversial. Support among marine scientists and conservationists is growing in favour of the view that in some instances, complete removal of the platform may cause more harm to the marine ecosystem than leaving the lower structure in place, and that, unless serious pollution risks exist or maritime traffic safety is threatened, some consideration should be given to partial removal.

The economic effects of only partial removal tend to be significant and immediate. The oil and gas companies (and, in the longer term future, offshore wind operators) stand to make significant savings from the reduced decommissioning operation. Governments do however have the option – as they do in the United States, for example – of requiring the companies to pay a specified share of those savings into a fund for reef conversion. (It should be noted however that governments may still be open to criticism from conservationist quarters for allowing oil and gas companies to gain financially from such a reduction in clean-up effort.) There are also likely to be positive effects for the marine environment resulting from less disturbance of the seabed and the water column, which can translate into improved stocks of fish, molluscs and so on.

A potentially positive long-term economic contribution may also be associated with the decision to convert to artificial reefs. Healthy artificial-reef ecosystems can make for more productive commercial fisheries, attract tourism, diving, and recreational fishing, while the decommissioned structure itself may come to serve multiple alternative purposes in support, for example, of aquaculture facilities or marine renewable energy (OECD, 2016[11]). Moreover, there are potential positive spill-overs for other sectors. For example, specialised engineering companies stand to profit from the business generated by the creation of the artificial reefs; see for example Smyth et al (2015[142]), on subsea eco-engineering, and Offshore Digital Magazine (2017[166]), on emerging rigs-to-reefs business partnerships. And even insurance and re-insurance companies look set to engage in the business of ecosystem resilience and restoration (Leber, 2018[167])).

In addition, the growing volume of scientific assessment, inspection and monitoring involved in the decision-making and implementation of rig and (eventually) wind turbine conversions promises to offer considerable opportunities for the owners and operators of AUVs, ROVs and other subsea vehicles. The sector, while still small, is currently expanding rapidly. The latest world AUV forecast (Westwood Global Energy Group, 2018[44]) for example, sees total global demand increasing by almost 40% between 2018 and 2022. Demand growth in the research sector is still modest, but is nonetheless expected to see its share of total demand reach 25% by 2022. Commercial demand should see the fastest growth rates, expanding by 74% over the next five years.

Rigs-to-reef programmes and renewables-to-reef projects are at very different stages of development. Yet both offer long-term potential for synergies between economic gain and ecosystem benefit. Neither will be able to unfold that potential to its full extent unless long-term strategies, appropriate incentives and effective regulatory frameworks are put in place by public authorities working closely with the private sector and the many other stakeholders concerned. Such strategic policy decisions and collective actions, however, need to be founded on the best possible scientific evidence with respect both to the environmental issues surrounding the debate of partial versus complete removal of infrastructures, and to the question of the successful creation and long-term viability of artificial reefs. As this case study has endeavoured to show, much work is still required from the scientific community to deliver that evidence.

## Notes

1. Advances in other technologies, e.g. drone technology, could also contribute to reduced inspection costs.

2. Significant moves are also being made in bringing salmon farming onshore with the help of advances in such techniques as land-based Recycling Aquaculture Systems. These technologies are not addressed in this report since its focus is specifically on production in the marine environment.

3. Much of the current evidence suggests that under a number of climate change scenarios, harmful algal bloom incidents may increase. However, more research into the link between climate change and harmful algae is required. See for example (United States Environmental Portection Agency, 2013[180]).

4. It is worth noting that genetically modified salmon is already on the marketplace and is being presented as one of the solutions needed to make land-based salmon farming profitable (e.g. AquaBounty's AquaAdvantage salmon, where a Chinook growth hormone gene has been integrated into the genome of an Atlantic salmon).

5. In South America, infectious salmon amenia cut the salmon harvest in Chile by 60% between 2008 and 2010. Chile was also at the centre of massive outbreaks of sea lice in 2007 which caused economic losses in the order of USD 2 billion (Ottinger, Clauss and Kuenzer, 2016[104]). In Europe, too, sea lice is proving a persistent challenge – for example, in 2011 they are estimated to have caused production losses of around USD 436 million, equivalent to 9% of total revenues of Norwegian fish farmers (Abolofia, Asche and Wilen, 2017[173]). In Asia, among the most potent diseases are the Whitespot Syndrome Virus and the Yellowhead Virus, which have triggered crop losses in shrimp farming running into millions of USD – in the mid-1990s the Whitespot Syndrome Virus was responsible for losses in Bangladesh of almost 45% of total shrimp production. Other cases of catastrophic disease outbreaks have been reported from Thailand, Vietnam, Peru, Nicaragua and Taiwan (Ottinger, Clauss and Kuenzer, 2016[104]). Climate change is set to complicate matters yet further. In Northern European waters, for example, rising ocean temperatures over the longer term are likely to lead to changes in the panorama of diseases affecting finfish, rendering them less vulnerable to some harmful viruses and bacteria but more vulnerable to others. In the case of sea lice, warmer water is likely to lead to increased infestations of the parasite (Bergh et al., 2017[172])

6. Initially, wild cleaner fish were used, but the resultant growing pressure on wild stocks of the species plus the overriding need to deal with recurring sea lice outbreaks led the salmon farming community to take action by developing cleaner-fish aquaculture. Whereas in 2012 farmed cleaner fish accounted for only a minute fraction of total wrasse and lumpfish use, the share had grown to 44% by 2016 (Norwegian Directorate for Fisheries). Over the same period the number of companies licensed to sell farmed cleaner fish rose from 5 to 24, and the value of those sales from NOK 7 million (about EUR 1 million) to NOK 304 million (about EUR 33 million). The total value of wild and farmed cleaner fish together was estimated at NOK 652 million (about EUR 70 million) in 2016. Research and

development in cleaner fish has accelerated remarkably, and projects are currently running in Scotland, Ireland, Faroe Islands and Iceland. The Scottish Aquaculture Innovation Centre, for example, is collaborating on several projects aimed at *inter alia* scaling up the use of cleaner fish, improving cleaner fish vaccination, ensuring the sustainable supply and deployment of lumpsuckers, and enhancing their health and welfare (SAIC Scottish Aquaculture Innovation Centre, 2018[171]).

7. Alone in Norway there are currently 104 applications under way for innovation development licenses, ranging from coastal closed systems, to vessel re-use and long-ship type structures with no bottom (Bjelland H., 2018[170]).

8. It is a huge semi-submersible structure, anchored to the sea bed and suitable for water depths of 100 to 300 m, and big enough to produce1.6 million salmon of 5 kg in weight. The highly sophisticated technology is closely aligned to the concept of precision fish farming (Føre et al., 2018[102]). It brings together marine engineering, marine cybernetics and marine biology via a "big data" approach. The structure combines innovations from different parts of the enterprise and from various sectors. For example, its extensive subsea sensor suite comes from the maritime business and contains highly sensitive echo sounders originally developed to detect oil and gas leaks but deployed here to detect fish feed pellets. Feeding is much more precise so as to leave a smaller environmental footprint, relying heavily on bio-cybernetics to model behaviour and mathematical modelling for analysis of the metabolism. Among the next objectives are improved situational awareness and visualisation of fish, both capabilities among the most needed for all autonomous systems (Hukkelas, 2018[178]).

9. This is a complete turnkey farm system that can be scaled up incrementally as learning from experience improves and capital investment becomes available. Feeding and monitoring are automated, the data being transmitted to shore and to service vessels (Kelly, 2018[179]).

## References


Abolofia, J., F. Asche and J. Wilen (2017), "The Cost of Lice: Quantifying the Impacts of Parasitic Sea Lice on Farmed Salmon", *Marine Resource Economics*, Vol. 32/3, pp. 329-349, http://dx.doi.org/10.1086/691981. [175]

Ajemian, M. et al. (2015), "An Analysis of Artificial Reef Fish Community Structure along the Northwestern Gulf of Mexico Shelf: Potential Impacts of "Rigs-to-Reefs" Programs", *PLOS ONE*, Vol. 10/5, p. e0126354, http://dx.doi.org/10.1371/journal.pone.0126354. [150]

Anderson, D. and J. Rense (2016), *Harmful Algal Blooms Assessing Chile's Historic HAB Events of 2016, A Report Prepared for the Global Aquaculture Alliance*, https://www.aquaculturealliance.org/wp-content/uploads/2017/05/Final-Chile-report.pdf. [109]

Azevedo, A. et al. (2017), "An oil risk management system based on high-resolution hazard and vulnerability calculations", *Ocean & Coastal Management*, Vol. 136, pp. 1-18, http://dx.doi.org/10.1016/J.OCECOAMAN.2016.11.014. [20]

Bastos Gomes, G. et al. (2017), "Use of environmental DNA (eDNA) and water quality data to predict protozoan parasites outbreaks in fish farms", *Aquaculture*, Vol. 479, pp. 467-473, http://dx.doi.org/10.1016/J.AQUACULTURE.2017.06.021. [124]

Batista, W. et al. (2017), "Which Ballast Water Management System Will You Put Aboard? Remnant Anxieties: A Mini-Review", *Environments*, Vol. 4/3, p. 54, http://dx.doi.org/10.3390/environments4030054. [87]

Bawat (2018), *Ballast Water Management System for ships and vessels*, https://www.bawat.com/ship-bwms/ship-bwms. [92]

Bento, N. and M. Fontes (2017), *Direction and legitimation in system upscaling - planification of floating offshore wind*, http://dx.doi.org/10.15847/dinamiacet-iul.wp.2017.01. [77]

Bergh, O. et al. (2017), *Impact of global warming on diseases in aquaculture*, European Aquaculture Society - Meeting Abstract, https://www.was.org/easonline/AbstractDetail.aspx?i=8583. [174]

Bergström, L. et al. (2014), "Effects of offshore wind farms on marine wildlife—a generalized impact assessment", *Environmental Research Letters*, Vol. 9/3, p. 034012, http://dx.doi.org/10.1088/1748-9326/9/3/034012. [163]

Besson, M. et al. (2017), "Effect of production quotas on economic and environmental values of growth rate and feed efficiency in sea cage fish farming", *PLOS ONE*, Vol. 12/3, p. e0173131, http://dx.doi.org/10.1371/journal.pone.0173131. [111]

Bjelland H. (2018), *Current challenges and future opportunities for exposed salmon farming in Norway, presentation at Oceanology International 2018*, https://www.arcticfrontiers.com/wp-content/uploads/downloads/2018/Arctic%20Frontiers%20Science/Presentations/23%20January%202018/Aquaculture%20in%20the%20High%20North%20in%20times%20of%20change/1500%20Bjelland_Hans.pdf (accessed on 05 December 2018). [172]

Boschen, R. et al. (2016), "A primer for use of genetic tools in selecting and testing the suitability of set-aside sites protected from deep-sea seafloor massive sulfide mining activities", *Ocean & Coastal Management*, Vol. 122, pp. 37-48, http://dx.doi.org/10.1016/J.OCECOAMAN.2016.01.007. [27]

Bricker, S. et al. (2016), "Integration of ecosystem-based models into an existing interactive web-based tool for improved aquaculture decision-making", *Aquaculture*, Vol. 453, pp. 135-146, http://dx.doi.org/10.1016/J.AQUACULTURE.2015.11.036. [107]

Brinkmeyer, R. (2016), "Diversity of bacteria in ships ballast water as revealed by next generation DNA sequencing", *Marine Pollution Bulletin*, Vol. 107/1, pp. 277-285, http://dx.doi.org/10.1016/J.MARPOLBUL.2016.03.058. [94]

BSEE (2015), *Rigs to Reefs | Bureau of Safety and Environmental Enforcement*, https://www.bsee.gov/what-we-do/environmental-focuses/rigs-to-reefs. [149]

Business Wire (2016), *Global Medicines for Aquaculture Market Report 2016 - Analysis, Technologies & Forecasts - Research and Markets | Business Wire*, https://www.businesswire.com/news/home/20160627006068/en/Global-Medicines-Aquaculture-Market-Report-2016. [127]

Carbon Trust and Offshore Renewable Energy Catapult (2017), *Floating Wind Joint Industry Project: Policy and Regulatory Appraisal*, https://www.carbontrust.com/media/673978/wp1-flw-jip-policy-regulatory-appraisal_final_170120_clean.pdf (accessed on 05 December 2018). [76]

Catapult and Carbon Trust (2017), *Floating Wind Joint Industry Project: Policy and Regulatory Appraisal*, Carbon Trust and Catapult Offshore Renewable Energy, https://www.carbontrust.com/media/673978/wp1-flw-jip-policy-regulatory-appraisal_final_170120_clean.pdf. [62]

Chardard, Y. (2017), *UTOFIA – A novel solution to underwater 3D real time imaging using range gating technology*. [36]

Cimino, R. (2017), *Decommissioning infrastructures at sea: reducing environmental impact; enhancing blue growth opportunities*. [140]

Claisse, J. et al. (2014), "Oil platforms off California are among the most productive marine fish habitats globally.", *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 111/43, pp. 15462-7, http://dx.doi.org/10.1073/pnas.1411477111. [151]

Clarksons Research (2017), *Ballast Water Management Update*, http://www.clarksons.net/docdata/public/newsdownloads/bwms_update.pdf. [98]

Colefax, A., P. Butcher and B. Kelaher (2018), “The potential for unmanned aerial vehicles (UAVs) to conduct marine fauna surveys in place of manned aircraft”, *ICES Journal of Marine Science*, Vol. 75/1, pp. 1-8, http://dx.doi.org/10.1093/icesjms/fsx100. [37]

Copernicus (2016), *Forecasting Harmful Algal Blooms for fish and shellfish farmers The ASIMUTH project*, http://ec.europa.eu/fisheries/documentation/publications/2015-aquaculture-facts_en.pdf.. [110]

Council of Canadian Academies (2013), *Ocean Science in Canada: Meeting the Challenge, Seizing the Opportunity*, Expert Panel on Canadian Ocean Science, Ottawa, https://www.scienceadvice.ca/wp-content/uploads/2018/10/oceans_fullreporten.pdf. [1]

Council of Canadian Academies (2013), *Ocean Science in Canada: Meeting the Challenge, Seizing the Opportunity (2013) | Science-Metrix*, http://www.science-metrix.com/?q=en/publications/reports/ocean-science-in-canada-meeting-the-challenge-seizing-the-opportunity-2013. [176]

Cresson, P., S. Ruitton and M. Harmelin-Vivien (2014), “Artificial reefs do increase secondary biomass production: mechanisms evidenced by stable isotopes”, *Marine Ecology Progress Series*, Vol. 509, pp. 15-26, http://dx.doi.org/10.3354/meps10866. [152]

Cutter, G., K. Stierhoff and D. Demer((n.d.)), “Remote sensing of habitat characteristics using echo metrics and image-based seabed classes”, http://dx.doi.org/10.1093/icesjms/fsw024. [33]

Dadar, M. et al. (2017), “Advances in Aquaculture Vaccines Against Fish Pathogens: Global Status and Current Trends”, *Reviews in Fisheries Science & Aquaculture*, Vol. 25/3, pp. 184-217, http://dx.doi.org/10.1080/23308249.2016.1261277. [126]

Darling, J. et al. (2017), “Recommendations for developing and applying genetic tools to assess and manage biological invasions in marine ecosystems”, *Marine Policy*, Vol. 85, pp. 54-64, http://dx.doi.org/10.1016/J.MARPOL.2017.08.014. [26]

Davidson, I. et al. (2017), “Pioneering patterns of ballast treatment in the emerging era of marine vector management”, *Marine Policy*, Vol. 78, pp. 158-162, http://dx.doi.org/10.1016/J.MARPOL.2017.01.021. [90]

Davidson, I. et al. (2016), “Mini-review: Assessing the drivers of ship biofouling management – aligning industry and biosecurity goals”, *Biofouling*, Vol. 32/4, pp. 411-428, http://dx.doi.org/10.1080/08927014.2016.1149572. [171]

Davidson, K. et al. (2016), “Forecasting the risk of harmful algal blooms”, *Harmful Algae*, Vol. 53, pp. 1-7, http://dx.doi.org/10.1016/j.hal.2015.11.005. [86]

Defoirdt, T., P. Sorgeloos and P. Bossier (2011), “Alternatives to antibiotics for the control of bacterial disease in aquaculture”, *Current Opinion in Microbiology*, Vol. 14/3, pp. 251-258, http://dx.doi.org/10.1016/j.mib.2011.03.004. [131]

Department of Industry of the Australian Government (2018), *Offshore Petroleum Decommissioning Guideline*, http://www.nopta.gov.au.. [161]

Dooly, G. et al. (2016), "Unmanned vehicles for maritime spill response case study: Exercise Cathach", *Marine Pollution Bulletin*, Vol. 110/1, pp. 528-538, http://dx.doi.org/10.1016/j.marpolbul.2016.02.072. [39]

Dossou, S. et al. (2018), "Effect of partial replacement of fish meal by fermented rapeseed meal on growth, immune response and oxidative condition of red sea bream juvenile, Pagrus major", *Aquaculture*, Vol. 490, pp. 228-235, http://dx.doi.org/10.1016/J.AQUACULTURE.2018.02.010. [118]

Dvorak, P. (2018), *Riding the waves of complexity in floating offshore wind*, https://www.windpowerengineering.com/projects/offshore-wind/riding-the-waves-of-complexity-in-floating-offshore-wind/. [64]

European Marine Board (2013), *Navigating the Future*, Position Paper 20, March, http://www.marineboard.eu. [3]

European Marine Board (2013), *Navigating the future (position paper 20)*. [177]

FAO (2018), *The State of World Fisheries and Aquaculture: Meeting the Sustainable Development Goals*, http://www.fao.org/publications. [101]

FAO (2017), "FAO Aquaculture Newsletter", Vol. No. 56/April, http://www.fao.org/3/a-i7171e.pdf. [114]

Fernandes, J. et al. (2016), "Costs and benefits to European shipping of ballast-water and hull-fouling treatment: Impacts of native and non-indigenous species", *Marine Policy*, Vol. 64, pp. 148-155, http://dx.doi.org/10.1016/J.MARPOL.2015.11.015. [95]

Fernandes, J. et al. (2016), "Costs and benefits to European shipping of ballast-water and hull-fouling treatment: Impacts of native and non-indigenous species", *Marine Policy*, Vol. 64, pp. 148-155, http://dx.doi.org/10.1016/J.MARPOL.2015.11.015. [85]

Fernandez-Ordonez, Y., J. Soria-Ruiz and C. Medina-Ramirez (2015), *Use of satellite image data to locate potential aquaculture facilities*, https://www.researchgate.net/publication/304154730_Use_of_satellite_image_data_to_locate_potential_aquaculture_facilities. [48]

Føre, M. et al. (2018), "Precision fish farming: A new framework to improve production in aquaculture", *Biosystems Engineering*, Vol. 173, pp. 176-193, http://dx.doi.org/10.1016/j.biosystemseng.2017.10.014. [104]

Forshaw, K. (2018), *Linking Ocean Sustainability and Innovation*. [38]

Fowler, A. et al. (2018), "Environmental benefits of leaving offshore infrastructure in the ocean", *Frontiers in Ecology and the Environment*, Vol. 16/10, pp. 571-578, http://dx.doi.org/10.1002/fee.1827. [147]

Fraunhofer (2016), *Long-lasting rust protection for offshore wind turbines*, https://www.fraunhofer.de/en/press/research-news/2016/February/long-lasting-rust-protection-for-offshore-wind-turbines.html. [72]

Froehlich, H. et al. (2017), "Offshore Aquaculture: I Know It When I See It", *Frontiers in Marine Science*, Vol. 4, p. 154, http://dx.doi.org/10.3389/fmars.2017.00154. [135]

Gallego, A. et al. (2017), "Large scale three-dimensional modelling for wave and tidal energy resource and environmental impact: Methodologies for quantifying acceptable thresholds for sustainable exploitation", *Ocean & Coastal Management*, Vol. 147, pp. 67-77, http://dx.doi.org/10.1016/j.ocecoaman.2016.11.025. [55]

Gates, A. (2018), *Interspill 2018 Application of Marine Autonomous Systems to oil spill response and monitoring Conference Stream: Surveillance, Modelling and Visualisation (SMV)*, http://www.interspill.org/previous-events/2018/14March2018/3-Situational-Awareness/Application-of-Marine-Autonomous-Systems-A-Gates-NOC-and-S-Hall-OSRL.pdf. [40]

Gentry, R. et al. (2017), "Mapping the global potential for marine aquaculture", *Nature Ecology & Evolution*, Vol. 1/9, pp. 1317-1324, http://dx.doi.org/10.1038/s41559-017-0257-9. [133]

Geoffroy, M. et al. (2016), "AUV-based acoustic observations of the distribution and patchiness of pelagic scattering layers during midnight sun", *ICES Journal of Marine Science: Journal du Conseil*, Vol. 74/9, p. fsw158, http://dx.doi.org/10.1093/icesjms/fsw158. [30]

Global Ocean Commission (2014), *From Decline to Recovery A Rescue Package for the Global Ocean Contents Letter from the Co-chairs Understanding the Global Ocean Shifting From Continued Decline to a Cycle of Recovery Proposals for Action Annexes*, https://www.iucn.org/sites/dev/files/import/downloads/goc_full_report_1.pdf. [178]

Gomez, F. et al. (2017), "Intraseasonal patterns in coastal plankton biomass off central Chile derived from satellite observations and a biochemical model-NC-ND license (http:// creativecommons.org/licenses/by-nc-nd/4.0/)", http://dx.doi.org/10.1016/j.jmarsys.2017.05.003. [23]

Grasso, M. (2017), *Rigs to Reefs Program*. [148]

Grave, K. and E. Oslo (2016), *Report Use of Antibiotics in Norwegian Aquaculture Report from The Norwegian Veterinary Institute Use of Antibiotics in Norwegian Aquaculture on behalf of Norwegian Seafood Council*, https://seafood.no/contentassets/c5a14b9acf3b4f1b9753263586513a68/use-of-antibiotics-in-norwegian-aquaculture.pdf. [129]

Grealis, E. et al. (2017), "The economic impact of aquaculture expansion: An input-output approach", *Marine Policy*, Vol. 81, pp. 29-36, http://dx.doi.org/10.1016/J.MARPOL.2017.03.014. [136]

Guichoux, Y. (2018), *Omni-situ surface currents: a transformative approach to measure ocean surface currents using AIS data*. [21]

GWEC Global Wind Energy Council (2017), *Global wind report: Opening up new markets for business*, http://www.gwec.net. [66]

Heath, M. et al. (2017), "Modelling the sensitivity of suspended sediment profiles to tidal current and wave conditions", *Ocean & Coastal Management*, Vol. 147, pp. 49-66, http://dx.doi.org/10.1016/J.OCECOAMAN.2016.10.018. [54]

Henry, L. (2017), *ANChor Summary Report*, https://s3-eu-west-1.amazonaws.com/static.insitenorthsea.org/files/INSITE-ANChor-Summary-Report-v1.0.pdf. [160]

Henry, M. et al. (2015), "Review on the use of insects in the diet of farmed fish: Past and future", *Animal Feed Science and Technology*, Vol. 203, pp. 1-22, http://dx.doi.org/10.1016/J.ANIFEEDSCI.2015.03.001. [117]

Hill, J. (2018), *Hywind Scotland, World's First Floating Wind Farm, Performing Better Than Expected | CleanTechnica*, https://cleantechnica.com/2018/02/16/hywind-scotland-worlds-first-floating-wind-farm-performing-better-expected/. [63]

Höfling, H. (2016), "Cost of Renewable energy – how expensive is green electricity really?", *Fokus Volkswirtschaft* , Vol. 45/6 October 2015. [79]

Hukkelas, T. (2018), *Ocean Farm 1: The world's first "smart" fish farm*. [179]

Hurley, W. (2018), *The fundamental importance of mooring systems*, http://www.rechargenews.com. [81]

IEA (2018), *Renewables 2018: Analysis and Forecasts to 2023*, IEA, Paris, https://dx.doi.org/10.1787/re_mar-2018-en. [59]

IEA (2018), *The future of petrochemicals: Towards more sustainable plastics and fertilisers*, IEA, Paris, https://dx.doi.org/10.1787/9789264307414-en. [7]

IHS Markit (2016), *Decommissioning of Aging Offshore Oil and Gas Facilities Increasing Significantly, with Annual Spending Rising to $13 Billion by 2040, IHS Markit Says | IHS Online Newsroom*, https://news.ihsmarkit.com/press-release/energy-power-media/decommissioning-aging-offshore-oil-and-gas-facilities-increasing-si. [141]

IMO (2018), *Invasive Aquatic Species (IAS)*, http://www.imo.org/en/OurWork/Environment/BallastWaterManagement/Pages/AquaticInvasiveSpecies(AIS).aspx. [84]

IMO (2017), *Global treaty to halt invasive aquatic species enters into force*, Briefing, http://www.imo.org/en/MediaCentre/PressBriefings/Pages/21-BWM-EIF.aspx. [88]

Innes, J., R. Martini and A. Leroy (2017), "Red tape and administrative burden in aquaculture licensing", *OECD Food, Agriculture and Fisheries Papers*, No. 107, OECD Publishing, Paris, https://dx.doi.org/10.1787/7a56bfbc-en. [103]

INSITE International Scientific Advisory Board ISAB (2018), *The Influence of Man-made Structures in the North Sea (INSITE) Synthesis and Assessment of Phase 1*, https://s3-eu-west-1.amazonaws.com/static.insitenorthsea.org/files/INSITE-ISAB-Synthesis-Report-Phase-1-final.pdf. [159]

International Energy Agency (2018), *Offshore Energy Outlook*, http://www.iea.org/t&c/. [139]

International Transport Forum (2018), *Data sharing in the maritime logistics chain (draft paper)*. [41]

IOC (2018), *Roadmap for the UN Decade of Ocean Science for Sustainable Development*, Intergovernmental Oceanographic Commission (IOC) , Fifty-first Session of the Executive Council UNESCO, Paris, 3–6 July 2018. [10]

IOC (2017), *Global Ocean Science Report : The Current Status of Ocean Science Around the World*, , Intergovernmental Oceanographic Commission, UNESCO Publishing, https://unesdoc.unesco.org/ark:/48223/pf0000250428. [6]

IPCC (2018), *The Ocean and Cryosphere in a Changing Climate*, Special Report Webpage, https://www.ipcc.ch/report/srocc/ (accessed on 16 June 2018). [9]

Jagerroos, S. and P. R Krause (2016), "Rigs-To-Reef; Impact or Enhancement on Marine Biodiversity", *Journal of Ecosystem & Ecography*, Vol. 6/2, pp. 1-9, http://dx.doi.org/10.4172/2157-7625.1000187. [138]

James, E., S. Benjamin and M. Marquis (2018), "Offshore wind speed estimates from a high-resolution rapidly updating numerical weather prediction model forecast dataset", *Wind Energy*, Vol. 21/4, pp. 264-284, http://dx.doi.org/10.1002/we.2161. [69]

Jha, S. et al. (2017), "Renewable energy: Present research and future scope of Artificial Intelligence", *Renewable and Sustainable Energy Reviews*, Vol. 77, pp. 297-317, http://dx.doi.org/10.1016/j.rser.2017.04.018. [47]

Joffre, O. et al. (2017), "How is innovation in aquaculture conceptualized and managed? A systematic literature review and reflection framework to inform analysis and action", *Aquaculture*, Vol. 470, pp. 129-148, http://dx.doi.org/10.1016/J.AQUACULTURE.2016.12.020. [105]

Jørgensen, D. (2012), "OSPAR's exclusion of rigs-to-reefs in the North Sea", *Ocean & Coastal Management*, Vol. 58, pp. 57-61, http://dx.doi.org/10.1016/j.ocecoaman.2011.12.012. [153]

Kadiyala, A., R. Kommalapati and Z. Huque (2017), "Characterization of the life cycle greenhouse gas emissions from wind electricity generation systems", *International Journal of Energy and Environmental Engineering*, Vol. 8/1, pp. 55-64, http://dx.doi.org/10.1007/s40095-016-0221-5. [61]

Kausche, M. et al. (2018), "Floating offshore wind - Economic and ecological challenges of a TLP solution", *Renewable Energy*, Vol. 126, pp. 270-280, http://dx.doi.org/10.1016/J.RENENE.2018.03.058. [73]

Kelly, D. (2018), *InnovaSea: phased development of an open ocean aquaculture farm*. [180]

Kim, H. et al. (2017), "Remote sensing and water quality indicators in the Korean West coast: Spatio-temporal structures of MODIS-derived chlorophyll-a and total suspended solids", *Marine Pollution Bulletin*, Vol. 121/1-2, pp. 425-434, http://dx.doi.org/10.1016/j.marpolbul.2017.05.026. [24]

King D.M. et al. (2012), "(PDF) Preview of global ballast water treatment markets", *Journal of Marine Engineering, Science and Technology*, Vol. 11/1, pp. 3-15, https://www.researchgate.net/publication/290997328_Preview_of_global_ballast_water_treatment_markets. [96]

King, D. (2016), *Ocean Health and the Economics of Global Ballast Water Regulations*, International Network for Environmental Compliance and Enforcement (INECE), https://inece.org/library/. [83]

Kleitou, P., D. Kletou and J. David (2018), "Is Europe ready for integrated multi-trophic aquaculture? A survey on the perspectives of European farmers and scientists with IMTA experience", *Aquaculture*, Vol. 490, pp. 136-148, http://dx.doi.org/10.1016/J.AQUACULTURE.2018.02.035. [123]

Komen, H. et al. (2017), "Impact of selective breeding on European aquaculture", *Aquaculture*, Vol. 472, pp. 8-16, http://dx.doi.org/10.1016/j.aquaculture.2016.03.012. [112]

Kongsberg (2017), *Underwater Science Products: Technology for Sustainable Fisheries*. [46]

Kroodsma, D. et al. (2018), "Tracking the global footprint of fisheries", *Science*, Vol. 359/6378, pp. 904-908, http://dx.doi.org/10.1126/science.aao5646. [22]

Kubryakov, A. et al. (2018), "Reconstructing Large- and Mesoscale Dynamics in the Black Sea Region from Satellite Imagery and Altimetry Data—A Comparison of Two Methods", *Remote Sensing*, Vol. 10/2, p. 239, http://dx.doi.org/10.3390/rs10020239. [50]

Kulkarni, S., M. Deo and S. Ghosh (2018), "Framework for assessment of climate change impact on offshore wind energy", *Meteorological Applications*, Vol. 25/1, pp. 94-104, http://dx.doi.org/10.1002/met.1673. [57]

Kulkarni, S., M. Deo and S. Ghosh (2018), "Framework for assessment of climate change impact on offshore wind energy", *Meteorological Applications*, Vol. 25/1, pp. 94-104, http://dx.doi.org/10.1002/met.1673. [70]

Lader, P. et al. (2017), *Classification of Aquaculture Locations in Norway With Respect to Wind Wave Exposure*, ASME, http://dx.doi.org/10.1115/OMAE2017-61659. [58]

Latarche, M. (2017), "What ballast water technologies are available?", *ShipInsight* 10 April 2017, https://shipinsight.com/what-ballast-water-technologies-are-available. [89]

Leber, J. (2018), *Global Insurance Industry Steps Up to Turn Ocean Risk Into — Oceans Deeply*, https://www.newsdeeply.com/oceans/articles/2018/05/15/global-insurance-industry-steps-up-to-turn-ocean-risk-into-resilience. [167]

Linder M. (2017), *Economic Impact of Global Standards - Ballast Water Treatment*, http://injapan.no/wp-content/uploads/2017/01/7-Mr.-Martin-Linder-Optimarin-Ballast-Water-Treatment.pdf (accessed on 05 December 2018). [97]

Li, P. et al. (2016), "Offshore oil spill response practices and emerging challenges", *Marine Pollution Bulletin*, Vol. 110/1, pp. 6-27, http://dx.doi.org/10.1016/J.MARPOLBUL.2016.06.020. [13]

López-Cortés, X. et al. (2017), "Fast detection of pathogens in salmon farming industry", *Aquaculture*, Vol. 470, pp. 17-24, http://dx.doi.org/10.1016/J.AQUACULTURE.2016.12.008. [128]

Lyons, Y. et al. (2013), *International Workshop on Rigs-toReefs: Prospects for large artificial reefs in tropical South East Asia – Is there life after oil?*, https://cil.nus.edu.sg/wp-content/uploads/2015/03/Executive-Summary.pdf. [157]

Martignac, F. et al. (2015), "The use of acoustic cameras in shallow waters: new hydroacoustic tools for monitoring migratory fish population. A review of DIDSON technology", *Fish and Fisheries*, Vol. 16/3, pp. 486-510, http://dx.doi.org/10.1111/faf.12071. [29]

Maw, M. et al. (2018), "A Changeable Lab-on-a-Chip Detector for Marine Nonindigenous Microorganisms in Ship's Ballast Water", *Micromachines*, Vol. 9/1, p. 20, http://dx.doi.org/10.3390/mi9010020. [93]

McKenna, R., P. Ostman v.d. Leye and W. Fichtner (2016), "Key challenges and prospects for large wind turbines", *Renewable and Sustainable Energy Reviews*, Vol. 53, pp. 1212-1221, http://dx.doi.org/10.1016/J.RSER.2015.09.080. [71]

Miller, P. (2018), *Satellite based harmful algal bloom and water quality monitoring for coastal and offshore aquaculture farms to support management decisions*. [51]

Mussells, O., J. Dawson and S. Howell (2017), "Navigating pressured ice: Risks and hazards for winter resource-based shipping in the Canadian Arctic", *Ocean & Coastal Management*, Vol. 137, pp. 57-67, http://dx.doi.org/10.1016/J.OCECOAMAN.2016.12.010. [19]

Myhr, A. et al. (2014), "Levelised cost of energy for offshore floating wind turbines in a life cycle perspective", *Renewable Energy*, Vol. 66, pp. 714-728, http://dx.doi.org/10.1016/J.RENENE.2014.01.017. [78]

National Research Council (2015), *Sea Change: 2015-2025 Decadal Survey of Ocean Sciences*, National Academies Press, Washington, DC, http://dx.doi.org/10.17226/21655. [2]

Nevalainen, M., I. Helle and J. Vanhatalo (2017), "Preparing for the unprecedented — Towards quantitative oil risk assessment in the Arctic marine areas", *Marine Pollution Bulletin*, Vol. 114/1, pp. 90-101, http://dx.doi.org/10.1016/J.MARPOLBUL.2016.08.064. [18]

Norris, A. (2017), "Application of genomics in salmon aquaculture breeding programs by Ashie Norris", *Marine Genomics*, Vol. 36, pp. 13-15, http://dx.doi.org/10.1016/j.margen.2017.11.013. [125]

Norsk Petroleum (2018), *Cessation and decommissioning - Norwegianpetroleum.no*, https://www.norskpetroleum.no/en/developments-and-operations/cessation-and-decommissioning/. [155]

Norwegian Directorate of Fisheries (2018), *Cleanerfish (Lumpfish and Wrasse)*, https://www.fiskeridir.no/English/Aquaculture/Statistics/Cleanerfish-Lumpfish-and-Wrasse. [132]

OECD (2018), *Improving Markets for Recycled Plastics: Trends, Prospects and Policy Responses*, OECD Publishing, Paris, https://dx.doi.org/10.1787/9789264301016-en. [8]

OECD (2017), *Analysis of selected measures promoting the construction and operation of greener ships*, OECD, Paris, http://www.oecd.org/sti/shipbuilding. [99]

OECD (2017), *Analysis of Selected Measures Promoting the Construction and Operation of Greener Ships*, OECD, Paris. [100]

OECD (2017), *Analysis of Selected Measures Promoting the Construction and Operation of Greener Ships*, OECD Council Working Party on Shipbuilding (WP6), Paris, http://www.oecd.org/sti/shipbuilding. [168]

OECD (2016), *The Ocean Economy in 2030*, OECD Publishing, Paris, https://dx.doi.org/10.1787/9789264251724-en. [11]

OECD/FAO (2018), *OECD-FAO Agricultural Outlook 2018-2027*, OECD Publishing, Paris/FAO, Rome, https://dx.doi.org/10.1787/agr_outlook-2018-en. [102]

Offshore Digital Magazine (2017), *Xodus, Subcon form 'rigs to reef' decommissioning partnership - Offshore*, https://www.offshore-mag.com/articles/2017/11/xodus-subcon-form-rigs-to-reef-decommissioning-partnership.html. [166]

offshoreWIND.biz (2018), *ORE Catapult Shares Offshore Wind Vision | Offshore Wind*, https://www.offshorewind.biz/2018/02/26/ore-catapult-shares-offshore-wind-vision/. [170]

offshoreWIND.biz (2017), *BNEF: 237MW of Floating Offshore Wind by 2020 | Offshore Wind*, https://www.offshorewind.biz/2017/03/20/bnef-237mw-of-floating-offshore-wind-by-2020/. [65]

OFS Research/Westwood Global Energy Group (2018), *World Offshore Maintenance, Modifications & Operations 2018-2022*, https://www.westwoodenergy.com/product/world-offshore-maintenance-modifications-operations-market-forecast-2018-2022/?utm_source=iContact&utm_medium=email&utm_campaign=2_OFS+Research&utm_content=. [137]

Osmundsen, P. and R. Tveterås (2003), "Decommissioning of petroleum installations—major policy issues", *Energy Policy*, Vol. 31/15, pp. 1579-1588, http://dx.doi.org/10.1016/S0301-4215(02)00224-0. [146]

Ottinger, M., K. Clauss and C. Kuenzer (2016), "Aquaculture: Relevance, distribution, impacts and spatial assessments – A review", *Ocean & Coastal Management*, Vol. 119, pp. 244-266, http://dx.doi.org/10.1016/J.OCECOAMAN.2015.10.015. [106]

Oyinlola, M. et al. (2018), "Global estimation of areas with suitable environmental conditions for mariculture species", *PLOS ONE*, Vol. 13/1, p. e0191086, http://dx.doi.org/10.1371/journal.pone.0191086. [134]

Pereira, N. et al. (2016), "Challenges to implementing a ballast water remote monitoring system", *Ocean & Coastal Management*, Vol. 131, pp. 25-38, http://dx.doi.org/10.1016/J.OCECOAMAN.2016.07.008. [28]

Perez-Velazquez, M. et al. (2018), "Partial replacement of fishmeal and fish oil by algal meals in diets of red drum Sciaenops ocellatus", *Aquaculture*, Vol. 487, pp. 41-50, http://dx.doi.org/10.1016/J.AQUACULTURE.2018.01.001. [116]

Pezy, J., A. Raoux and J. Dauvin (2018), "An ecosystem approach for studying the impact of offshore wind farms: a French case study", *ICES Journal of Marine Science*, http://dx.doi.org/10.1093/icesjms/fsy125. [82]

Porritt, J. (2017), *Decommissioning in the North Sea: Rigs, Reefs, but not much Realism | Jonathon Porritt*, 20.02.2017, http://www.jonathonporritt.com/blog/decommissioning-north-sea-rigs-reefs-not-much-realism. [154]

Raoux, A. et al. (2017), "Benthic and fish aggregation inside an offshore wind farm: Which effects on the trophic web functioning?", *Ecological Indicators*, Vol. 72, pp. 33-46, http://dx.doi.org/10.1016/j.ecolind.2016.07.037. [165]

Renewable Energy Agency, I. (2016), *Floating Foundations: A Game Changer for Offshore Wind Power*, https://www.irena.org/DocumentDownloads/Publications/IRENA_Offshore_Wind_Floating_Foundations_2016.pdf. [67]

Research and Markets (2017), *Aquafeed Market by End User, Ingredient, Additive, and Region - Global Forecast to 2022*, April, https://www.researchandmarkets.com/research/vlhxv6/aquafeed_market. [122]

SAIC Scottish Aquaculture Innovation Centre (2018), *Innovation and the Ripple Effect*, http://scottishaquaculture.com/innovation-and-the-ripple-effect/. [173]

SeaTwirl (2018), *SeaTwirl is developing a floating wind turbine, VAWT, for the ocean.*, https://seatwirl.com/. [74]

Shafait, F. et al. (2016), "Fish identification from videos captured in uncontrolled underwater environments", *ICES Journal of Marine Science: Journal du Conseil*, Vol. 73/10, pp. 2737-2746, http://dx.doi.org/10.1093/icesjms/fsw106. [31]

Shaw J.L., Seares P. and Newman S.J. (2018), *Decommissioning offshore infrastructure: a review of stakeholder views and science priorities Decommissioning offshore infrastructure: a review of stakeholder views and science prioritiesau/decommissioning-offshore-infrastructure-review-stakeholder-views-and-science-priorities)*, WAMSI, Perth, Western Australia, http://www.wamsi.org.au/decommissioningoffshore-infrastructure-review-stakeholder-views-and-science-priorities (accessed on 05 December 2018). [162]

Shaw, J., P. Seares and S. Newman (2018), *Decommissioning offshore infrastructure: a review of stakeholder views and science priorities*, WAMSI, Perth, Western Australia, http://www.wamsi.org.au/decommissioning-offshore-infrastructure-review-stakeholder-views-and-science-priorities. [143]

Shepherd, C., O. Monroig and D. Tocher (2017), "Future availability of raw materials for salmon feeds and supply chain implications: The case of Scottish farmed salmon", *Aquaculture*, Vol. 467, pp. 49-62, http://dx.doi.org/10.1016/j.aquaculture.2016.08.021. [115]

Siddiqui, S. et al. (2018), "Automatic fish species classification in underwater videos: exploiting pre-trained deep neural network models to compensate for limited labelled data", *ICES Journal of Marine Science*, Vol. 75/1, pp. 374-389, http://dx.doi.org/10.1093/icesjms/fsx109. [35]

Side, J. et al. (2017), "Developing methodologies for large scale wave and tidal stream marine renewable energy extraction and its environmental impact: An overview of the TeraWatt project", *Ocean & Coastal Management*, Vol. 147, pp. 1-5, http://dx.doi.org/10.1016/J.OCECOAMAN.2016.11.015. [52]

Singha, S. and R. Ressel (2016), "Offshore platform sourced pollution monitoring using space-borne fully polarimetric C and X band synthetic aperture radar", *Marine Pollution Bulletin*, Vol. 112/1-2, pp. 327-340, http://dx.doi.org/10.1016/J.MARPOLBUL.2016.07.044. [12]

Slav, I. (2018), *Asian Oil Companies Face $100B Well Decommissioning Bill | OilPrice.com*, 1 February 2018, https://oilprice.com/Latest-Energy-News/World-News/Asian-Oil-Companies-Face-100B-Well-Decommissioning-Bill.html (accessed on 05 December 2018). [145]

Slavik, K. et al. (2018), *The large-scale impact of offshore wind farm structures on pelagic primary productivity in the southern North Sea*, Springer International Publishing, http://dx.doi.org/10.1007/s10750-018-3653-5. [164]

Smyth, K. et al. (2015), "Renewables-to-reefs? – Decommissioning options for the offshore wind power industry", *Marine Pollution Bulletin*, Vol. 90/1-2, pp. 247-258, http://dx.doi.org/10.1016/J.MARPOLBUL.2014.10.045. [142]

Spaulding, M. (2017), "State of the art review and future directions in oil spill modeling", *Marine Pollution Bulletin*, Vol. 115/1-2, pp. 7-19, http://dx.doi.org/10.1016/J.MARPOLBUL.2017.01.001. [17]

Strong, J. and M. Elliott (2017), "The value of remote sensing techniques in supporting effective extrapolation across multiple marine spatial scales", *Marine Pollution Bulletin*, Vol. 116/1-2, pp. 405-419, http://dx.doi.org/10.1016/J.MARPOLBUL.2017.01.028. [16]

Taninoki Ryota, K. et al. (2017), "Dynamic Cable System for Floating Offshore Wind Power Generation", *SEI Technical Review*, Vol. 84/April, pp. 53-58, http://www.abysse.co.jp/japan/index.html. [75]

Techera, E. and J. Chandler (2015), "Offshore installations, decommissioning and artificial reefs: Do current legal frameworks best serve the marine environment?", *Marine Policy*, Vol. 59, pp. 53-60, http://dx.doi.org/10.1016/J.MARPOL.2015.04.021. [156]

Thanigaivel, S. et al. (2016), "Seaweeds as an alternative therapeutic source for aquatic disease management", *Aquaculture*, Vol. 464, pp. 529-536, http://dx.doi.org/10.1016/j.aquaculture.2016.08.001. [130]

Thomson, C. and G. Harrison (2015), *Life cycle costs and carbon emissions of wind power: Executive Summary Key Points*, http://www.climatexchange.org.ukhttp://www.climatexchange.org.uk/index.php/download_file/554/http://www.climatexchange.org.uk/index.php/download_file/555/. [60]

Tornero, V. and G. Hanke (2016), "Chemical contaminants entering the marine environment from sea-based sources: A review with a focus on European seas", *Marine Pollution Bulletin*, Vol. 112/1-2, pp. 17-38, http://dx.doi.org/10.1016/J.MARPOLBUL.2016.06.091. [15]

Torrecillas, S. et al. (2017), "Combined replacement of fishmeal and fish oil in European sea bass (Dicentrarchus labrax): Production performance, tissue composition and liver morphology", *Aquaculture*, Vol. 474, pp. 101-112, http://dx.doi.org/10.1016/J.AQUACULTURE.2017.03.031. [119]

Trenkel, V., N. Handegard and T. Weber (2016), "Observing the ocean interior in support of integrated management", *ICES Journal of Marine Science: Journal du Conseil*, Vol. 73/8, pp. 1947-1954, http://dx.doi.org/10.1093/icesjms/fsw132. [34]

UK Department for Business, E. (2018), *Oil and gas: decommissioning of offshore installations and pipelines - GOV.UK*, https://www.gov.uk/guidance/oil-and-gas-decommissioning-of-offshore-installations-and-pipelines. [158]

UN General Assembly (2015), *Transforming our world: the 2030 Agenda for Sustainable Development*, A/RES/70/1, https://www.refworld.org/docid/57b6e3e44.html. [169]

Division for Ocean Affairs and the Law of the Sea, O. (ed.) (2017), *The First Global Integrated Marine Assessment*, Cambridge University Press, Cambridge, http://dx.doi.org/10.1017/9781108186148. [4]

United Nations (2016), *Summary of the First Global Integrated Marine Assessment*, http://www.un.org/depts/los/global_reporting/WOA_RPROC/Summary.pdf. [5]

United States Environmental Portection Agency (2013), *Impacts of Climate Change on the Occurrence of Harmful Algal Blooms*, http://go.usa.gov/gYTH. [181]

Venugopal, V., R. Nemalidinne and A. Vögler (2017), "Numerical modelling of wave energy resources and assessment of wave energy extraction by large scale wave farms", *Ocean & Coastal Management*, Vol. 147, pp. 37-48, http://dx.doi.org/10.1016/J.OCECOAMAN.2017.03.012. [53]

Wall, C., J. Jech and S. McLean (2016), "Increasing the accessibility of acoustic data through global access and imagery", *ICES Journal of Marine Science: Journal du Conseil*, Vol. 73/8, pp. 2093-2103, http://dx.doi.org/10.1093/icesjms/fsw014. [32]

Wells, M. et al. (2015), *Harmful algal blooms and climate change: Learning from the past and present to forecast the future*, Elsevier, http://dx.doi.org/10.1016/J.HAL.2015.07.009. [108]

Westwood Global Energy Group (2018), *Westwood Insight: Decommissioning – Challenge, Accepted! - Westwood Global Energy Group*, January, https://www.westwoodenergy.com/news/westwood-insight/westwood-insight-decommissioning-challenge-accepted/. [144]

Westwood Global Energy Group (2018), *Westwood Insight: Decommissioning – Challenge, Accepted! - Westwood Global Energy Group*, https://www.westwoodenergy.com/news/westwood-insight/westwood-insight-decommissioning-challenge-accepted/. [43]

Westwood Global Energy Group (2018), *World AUV Market Forecast 2018-2022 - Westwood*, June, https://www.westwoodenergy.com/product/world-auv-market-forecast-2018-2022/. [44]

White, H. et al. (2016), "Methods of Oil Detection in Response to the Deepwater Horizon Oil Spill", *Oceanography*, Vol. 29/3, pp. 76-87, http://dx.doi.org/10.5670/oceanog.2016.72. [14]

Wilby, B. (2016), "AUVs gain momentum in oil and gas operations", *Society of Petroleum Engineers*, Vol. 5/5. [42]

Wind Europe (2017), *Floating Offshore Wind Vision Statement*, https://windeurope.org/wp-content/uploads/files/about-wind/reports/Floating-offshore-statement.pdf. [68]

Wiser, R. et al. (2016), *Forecasting Wind Energy Costs and Cost Drivers: The Views of the World's Leading Experts*, http://eta-publications.lbl.gov/sites/default/files/lbnl-1005717.pdf. [80]

Wollenhaupt, G. (2017), *ABS: Nearly half of ballast water systems 'inoperable' or 'problematic' - Professional Mariner - December/January 2018*, Professional Mariner, http://www.professionalmariner.com/December-January-2018/Ballast-water-systems-inoperable-or-problematic/ (accessed on 05 December 2018). [91]

Wu, W., Y. Zhou and B. Tian (2017), "Coastal wetlands facing climate change and anthropogenic activities: A remote sensing analysis and modelling application", *Ocean & Coastal Management*, Vol. 138, pp. 1-10, http://dx.doi.org/10.1016/J.OCECOAMAN.2017.01.005. [25]

Yıldız, M. et al. (2018), "The effects of fish oil replacement by vegetable oils on growth performance and fatty acid profile of rainbow trout: Re-feeding with fish oil finishing diet improved the fatty acid composition", *Aquaculture*, Vol. 488, pp. 123-133, http://dx.doi.org/10.1016/J.AQUACULTURE.2017.12.030. [120]

Ytrestøyl, T., T. Aas and T. Åsgård (2015), "Utilisation of feed resources in production of Atlantic salmon (Salmo salar) in Norway", *Aquaculture*, Vol. 448, pp. 365-374, http://dx.doi.org/10.1016/J.AQUACULTURE.2015.06.023. [121]

Yue, G. and L. Wang (2017), "Current status of genome sequencing and its applications in aquaculture", *Aquaculture*, Vol. 468, pp. 337-347, http://dx.doi.org/10.1016/J.AQUACULTURE.2016.10.036. [113]

Zborowski, M. (2018), *Total, Google Cloud to Team on AI for Upstream*, 26 April 2018, https://www.spe.org/en/print-article/?art=4144. [45]

Zecchetto, S., Zecchetto and Stefano (2018), "Wind Direction Extraction from SAR in Coastal Areas", *Remote Sensing*, Vol. 10/2, p. 261, http://dx.doi.org/10.3390/rs10020261. [49]

Zheng, C. et al. (2016), "An overview of global ocean wind energy resource evaluations", *Renewable and Sustainable Energy Reviews*, Vol. 53, pp. 1240-1251, http://dx.doi.org/10.1016/J.RSER.2015.09.063. [56]

# 3. Innovation networks in the ocean economy

*The objective of Chapter 3 is to gain an initial understanding of the role that collaboration plays in fostering innovation for the ocean economy. In particular, the OECD has assembled a set of case studies to explore how innovation network centres – in various marine/maritime sectors and diverse countries – organise collaboration among organisations of different types and the benefits achieved in doing so. This chapter presents the results of a survey of ten selected innovation networks in the ocean economy. Taking into account context-specific situations, some preliminary lessons learned on innovation networks for the ocean economy are drawn out for policy makers and practitioners. Further mapping of innovation networks will continue in 2019-20.*

## 3.1. What are ocean economy innovation networks?

The growing pressure to balance growth in the ocean economy with improvements in the health of the marine environment is driving rapid changes in the structure of the ocean economy and its innovation landscape. The broad objective of this chapter is to examine the role that collaboration plays in fostering innovation for the ocean economy. Ocean economy innovation networks are but one construction through which such objectives are being realised and are the focus of this exploratory exercise.

### *3.1.1. Introducing the concept of innovation networks*

The literature has long recognised that organisations do not innovate in isolation but co-operate with external partners throughout the innovation process. Collaborations for innovation may take multiple forms and the term "innovation network" has not been defined precisely as a result. Instead, a range of terminologies and definitions are used frequently and interchangeably depending on the context and specific arrangement under scrutiny. Box 3.1 for example, details the rise of global innovation networks among multinational enterprises.

**Box 3.1. Multinational enterprises and their global innovation networks**

Firms are at the core of many innovation processes (OECD, 2015[1]). The concept of the global innovation network emerged in the business management literature in the 1990s, as a growing number of multinational enterprises from diverse sectors began to internationalise their research and development (R&D) as a result of the globalisation of their operations. One reason for multinational enterprises to locate their R&D facilities abroad is to gain proximity to large and growing markets. Another important factor is access to new pools of engineers and researchers (OECD, 2008[2]). Furthermore, multinational firms have developed strategies to incentivise innovation by shifting away from firm-centric innovation models. New external networks have created links beyond subsidiaries and traditional partners to reach public research institutes, universities and business schools (Nambisan and Sawhney, 2011[3]). Recent OECD evidence points to the growing importance of these networks for innovative activities. Almost two-thirds of international co-inventions during the period 1995 to 2013 were directly linked to the R&D efforts of multinational enterprises, for example (OECD, 2017[4]).

An influential concept related to business innovation is "open innovation" (Chesbrough, 2003[5]). The term describes collaboration that goes beyond traditional supplier-client relationships and introduces firms to broader knowledge bases and new opportunities with less risk. Open innovation contrasts with innovation that is kept internally to a single organisation for the purpose of maintaining a competitive advantage over rivals – i.e. a "closed innovation" process.

One of the more general observations resulting from open innovation frameworks is that innovation can create significant value for actors beyond the innovating organisation. The core concept, again focusing on business communities, is captured by the term "shared-value creation" (Porter and Kramer, 2011[6]). The idea is that business functions best when business practice creates value for all stakeholders, through the satisfaction of immediate business interests but also broader societal and the environmental objectives. This increases the scope of open innovation to include a far broader set of actors, bringing together professionals from various sectors that share common interests and are guided primarily by the ethos of research and development. One driver for such multi-faceted collaboration, between public and private actors and within and between disciplines, could be that much applied research is necessary before the shared economic potential of many innovations is realised (OECD, 2015[1]).

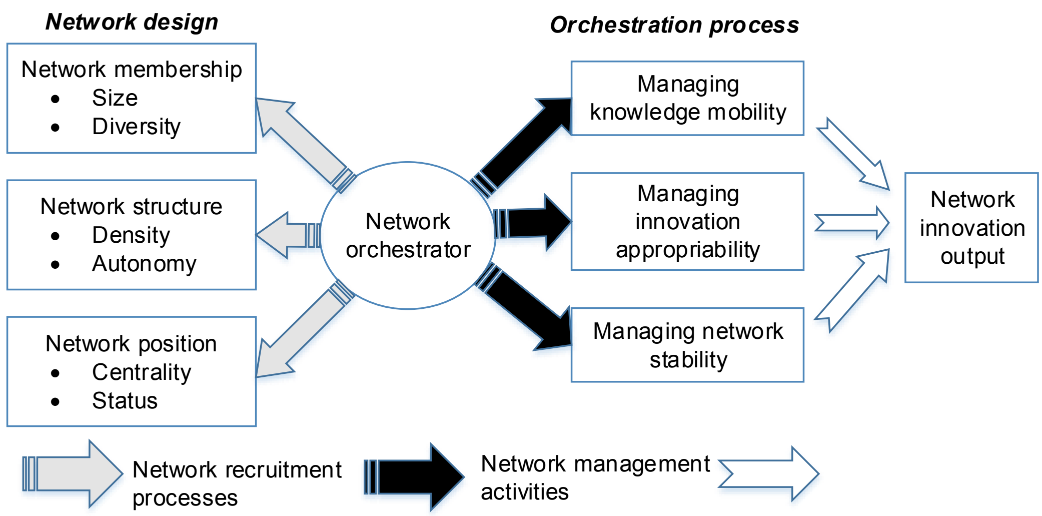
The role that public organisations and policy have to play in nurturing collaboration within the innovation system is a key consideration to many and is, broadly speaking, the subject of this chapter. The OECD, for example, has considered the impact of public policy on innovation collaboration since at least the 1980s (Freeman, 1991[7]) and has investigated collaborations in many forms. Examples of the types of innovation collaborations studied include knowledge networks and markets (OECD, 2012[8]; OECD, 2013[9]), strategic public/private partnerships (OECD, 2008[2]; OECD, 2016[10]) and geographic clusters (OECD, 2009[11]; OECD, 2010[12]; OECD, 2014[13]). Most recently, the fourth edition of the Oslo Manual, the international reference for collecting and using data on innovation, includes guidelines on how to measure knowledge flows and their impacts in systems of innovation (OECD/Eurostat, 2018[14]).

In each incarnation of innovation network studied, different types of organisations collaborate by pooling knowledge and resources with the aim of achieving particular innovative outcomes. Universities and public research institutes, for example, play an increasingly important role in the open innovation strategies of firms both as a source of basic knowledge and as potential collaborators (OECD, 2008[15]). Small and medium sized enterprises (SMEs) are typically involved as both beneficiaries of spill-overs from larger firms and sources of new ideas (Karlsson and Warda, 2014[16]).

There is therefore precedent to the study of innovation networks in the overall economy and a small number of previous studies have focused on innovation networks in the ocean economy in particular. The European Commission has, for example, considered the role of maritime clusters in supporting a productive ocean economy (EC DGMARE, 2008[17]). In North America, Doloreux and Melançon (2009[18]) look at innovation-support organisations in the regional systems of marine science and technology in Canada. A review of maritime innovation networks in Denmark outlines several models of networks utilised by maritime industries, including informal, expert forum, publicly funded and horizontal structures (Perunovic´, Christoffersen and Fürstenberg, 2015[19]).

This chapter is focused, however, on ocean economy innovation networks with publicly (at least partially) funded organisations at their core. The roles and responsibilities of publicly funded organisations in innovation networks vary greatly but, in general, they often play a crucial role in designing networks and orchestrating their activities. There is evidence to suggest that public organisations perform this role more so than private firms, at least at regional levels (Kauffeld-Monz and Fritsch, 2013[20]). A useful framework for considering the role of such an organisation is provided by Dhanaraj and Parkhe (2006[21]). A network "orchestrator" conducts a set of actions on behalf of the rest of the innovation network including designing the network membership, structure and position, and managing various aspects of the networks activities (Figure 3.1). The publicly (at least partially) funded network orchestrator in the networks studied in this chapter will be labelled "innovation network centres" herein.

**Figure 3.1. A framework for orchestration in innovation networks**




*Source*: Adapted from Dhanaraj and Parkhe (2006[21]) *Orchestrating Innovation Networks*.

Organisations forming partnerships through innovation networks tend to share risks and gains while leveraging others R&D budgets and extending business reach. Such factors represent some of the advantages of innovation networks, but there are also possible disadvantages to be considered. They include the extra costs of managing relationships with external partners and the potential leakage of knowledge to competitors. The concentration of knowledge and contacts in closed networks may also prevent new players from entering the innovation field. Another inherent issue concerns the possible growing dependence of smaller players on a given network for access to technology and funds.

An important factor therefore, particularly where public funding is at stake, is the requirement for effective oversight and regular assessment of how innovation networks contribute to innovation outcomes. This aspect is discussed in Section 3.3.

### *3.1.2. Collaboration in the ocean economy via innovation networks*

The objective of this chapter is to gain an initial understanding of the role that collaboration plays in fostering innovation for the ocean economy. In particular, the OECD has assembled a set of case studies to explore how innovation network centres – in various marine/maritime sectors and diverse countries – organise collaboration among organisations of different types and the types of benefits and challenges achieved and faced by doing so.

Ocean economy innovation networks take numerous forms, from loose relationships between various independent actors to relatively formalised associations or consortia pursuing common goals and/or projects. There is no standard model for collaboration and arrangements between partners take many forms. However, while industry clusters tend to be founded upon sector-specific supply linkages in geographical proximity, innovation networks often transcend sectoral boundaries. Cross-sectoral interactions may be pursued through the sharing of facilities, the dissemination of knowledge and expertise, and/or the utilisation of new technologies. Although innovation dynamics cannot be reduced only to the action of one or a few agents, publicly funded organisations often play an important role in federating interested parties and facilitating common projects. For this reason and due to its interest in science and technology policy, the OECD focus is on innovation networks with publicly funded organisations at their core.

It is not the purpose of this chapter to assess directly the impact ocean economy innovation networks have on innovation outcomes, or to evaluate the performance of the centres surveyed. Rather, qualitative benefits associated with this particular form of ocean economy collaboration are discussed.

Central to this research is an OECD exploratory survey of selected publicly funded (at least partially) innovation network centres. A questionnaire requested information regarding basic characteristics (name, location, budget etc.), a broad overview of the network's activities (number of partners, key areas of innovation, types of work carried out etc.), and, finally, specific details concerning particular projects undertaken by the network. The results of this research are summarised in this chapter. The networks surveyed are introduced and the types of benefits thought to be generated by them are described. In addition, a number of challenges are reported. Finally, taking into account context-specific situations, some preliminary lessons learned unique to innovation networks for the ocean economy are drawn out for policy makers and practitioners, as a first step before further OECD mapping of ocean economy innovation networks in 2019 to 2020.

The study focuses on innovation networks with publicly funded organisations at their core. The network centres were identified and contacted by the OECD Secretariat directly or following the advice of the Steering Board members of the OECD's Ocean Economy Group. The present study is therefore limited to a small number of countries and entities. Given the exploratory nature of this work and relatively small sample of networks, the results should be considered indicative of a certain type of innovation activity, rather than an exhaustive summary of networked innovation in the ocean economy, and provide the basis for further study.

## 3.2. Presenting the ten selected innovation networks

Collaboration for innovation occurs in many settings and in many different ways. In order to survey networks of organisations collaborating to produce innovation in the ocean economy, the OECD – in partnership with Marine Scotland – developed a questionnaire to be completed by innovation network centres. The survey aimed to discover the reasons innovation collaboration occurs in the ocean economy, the types of organisations that are drawn to work together and their motivations for sharing innovation outcomes. The results presented below therefore indicate activity among the surveyed innovation network centres only and may not be representative of all innovation networks in the ocean economy. The questionnaire responses are qualitative in nature and yield results that lay the foundations for a deeper exploration of ocean innovation in subsequent studies.

In total, ten innovation network centres based in nine different countries responded to the OECD questionnaire. The vast majority of the selected innovation networks are situated in Europe, with one in Canada (Table 3.1).

**Table 3.1. Selected innovation networks responding to OECD questionnaire**

Innovation network centre name and country of origin

| Name of innovation network | Country |
|---|---|
| Ocean Frontier Institute | Canada |
| Offshoreenergy.dk | Denmark |
| Innovative Business Network (IBN) – Offshore Energy | Belgium (Flanders) |
| Campus mondial de la mer | France |
| Marine Renewable Energy (MaREI) | Ireland |
| EXPOSED Aquaculture | Norway |
| MARE StartUp | Portugal |
| Scottish Aquaculture Innovation Centre | United Kingdom (Scotland) |
| Oceanic Platform of the Canary Islands (PLOCAN) | Spain |
| Marine Autonomous & Robotic Systems Innovation Centre | United Kingdom |

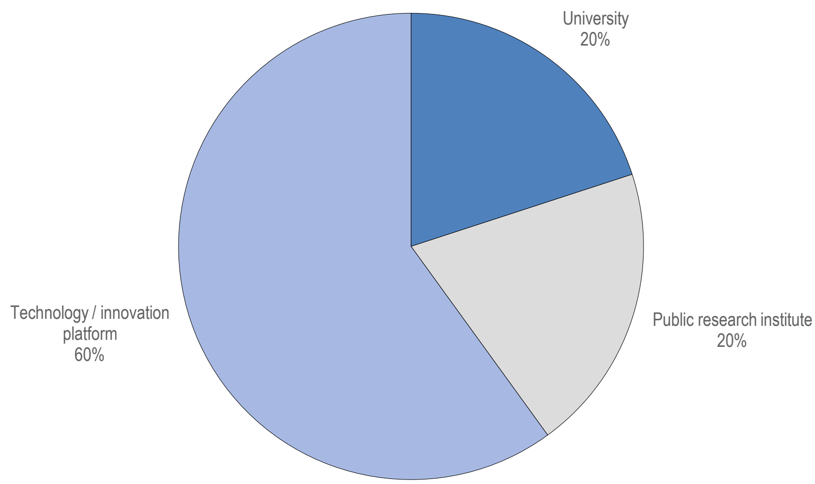
*Source*: Analysis of the OECD *Ocean Economy Innovation Networks Survey* results.

The surveyed network centres differ in the type of public organisation they originate in (Figure 3.2). Labelling the organisation of origin is complicated by the many different types, and definitions, of fully or partially public organisations operating within the innovation system. Broadly speaking, the survey results suggest that there are three types of public organisations from which the innovation network centres originate.

- *Higher Education Institutes (HEIs)* are centres of education and research where students are taught by academics in specialist fields. They can be public or private.
- *Public Research Institutes (PRIs)* are institutions or organisations that meet two important criteria: a) they perform R&D as a primary economic activity (research); and b) are controlled by government (i.e. the formal definition of public sector). PRIs in the government sector may have varying degrees of connection with government departments and agencies.
- A third type of organisation does not fit into either previous category because it may not carry out basic research or teach students. *Technology or innovation hubs* are public organisations tasked with facilitating the transfer of knowledge to practical and commercial uses, or to incubate small technology companies as they seek to grow their markets. Technology/innovation accelerators may be situated at universities and public research institutes, or they could be an institution in their own right

**Figure 3.2. Type of public organisation at centre of the selected innovation networks**

Number of innovation networks according to type of publicly funded centre, as a percentage of total

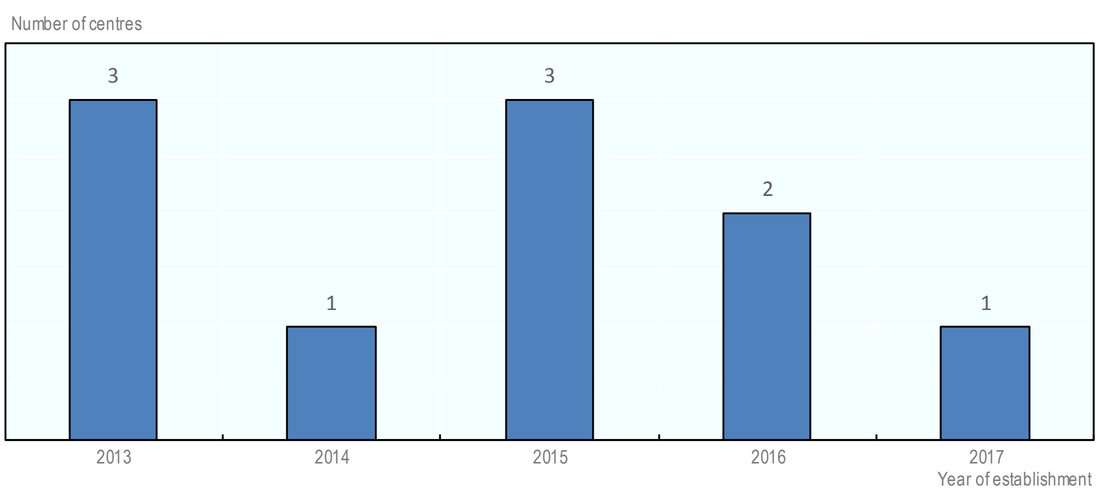



*Source*: Analysis of the OECD *Ocean Economy Innovation Networks Survey* results.

The exact date of the start of an innovation network is not always clear as often collaboration between organisations begins far before an official network is created.[1] However, the surveyed innovation network centres were all recently established, or recognised officially. Two thirds of the centres were officially opened within the last three years (Figure 3.3).

**Figure 3.3. The surveyed innovation network centres were established or recognised as innovation networks recently**

Number of innovation network centres according to the year in which they were established




*Source*: Analysis of the OECD *Ocean Economy Innovation Networks Survey* results.

The majority of the centres are small in terms of direct staffing. The smallest centre has three staff members who dedicate half of their time to its operation, for a total of 1.5 full time equivalent (FTE) employees. The largest centre has over 200 FTE employees (Table 3.2).

**Table 3.2. Number of staff employed by innovation network centres**

Number of innovation network centres according to staffing level, full time equivalents

| Number of staff | 1-5 | 6-10 | 10+ |
|---|---|---|---|
| Number of centres | 3 | 4 | 3 |

*Source*: Analysis of the OECD *Ocean Economy Innovation Networks Survey* results.

In summary, the OECD survey reveals that the selected networks with (at least partially) publicly funded organisations at their core tend to have originated in universities, public research institutes and technology/innovation accelerators, or in any combination of two or more. All of the centres responding to the questionnaire were established or recognised as such less than six years ago, with two-thirds of the total having been established since 2015. Finally, the majority of the network centres have less than 10 FTE employees, with a third employing less than five directly.

### *3.2.1. Structural characteristics of the surveyed innovation network centres and their operations*

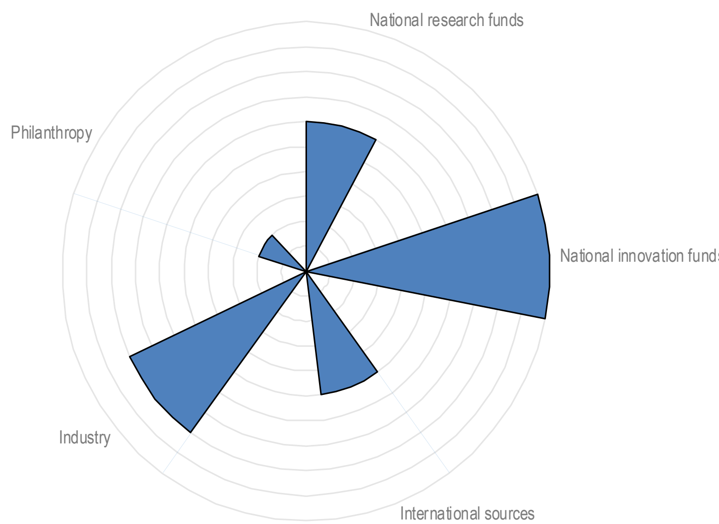
While the surveyed network centres originate in a range of different organisations, the funding for the centres' operations comes from several sources. All of the centres' governance structures resemble each other and they tend to play similar roles on behalf of their networks. This suggests that the innovation network centres have similar structural characteristics, no matter where they are situated or what area of the ocean economy they focus on. The three structural similarities are described below in more detail.

#### *Sources of funding*

There are five categories of funding source contributing to the operations of the surveyed innovation network centres by, for example, paying the salaries of the centre's staff (Figure 3.4). The main sources of funding are national innovation funds, industry contributions and national research funds. All of the network centres receive funding from national level innovation funds, eight of the ten network centres receive contributions from industry and six from national research funds. Less common however are international and philanthropic funding sources, which may represent potential development opportunities for the future.

**Figure 3.4. Several sources of funding are common among surveyed innovation network centres**

Number of innovation network centres mentioning a source of funding in questionnaire responses



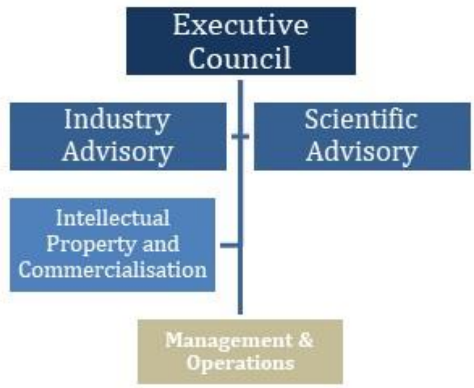

*Note*: Each ring represents one innovation network centre.
*Source*: Analysis of the OECD *Ocean Economy Innovation Networks Survey* results.

### *Governance structure*

The surveyed innovation network centres tend to have similar governance structures, no matter their size, the organisations in which they originate or their sources of funding (Figure 3.5). Every centre has a management and operations layer made up of directors and managerial staff working day-to-day on running the centres' activities. Providing strategic direction to the management team are often a set of committees. At the top of the structure is an executive committee consisting of people from a range of disciplines, ensuring financial accountability and providing general direction on management affairs. Underneath the executive committee can be any number of sub-committees. The role of the sub-committees is more specialised than the executive committee and their membership is normally made up of sectoral experts from diverse marine, scientific and technology domains. A scientific advisory committee provides guidance on research proposals and the general research environment. Industry advisory committees represent relevant industry concerns. An intellectual property and commercialisation committee may also be present to provide guidance on matters concerning the protection of the proceeds of innovation. The members of each committee can either be appointed based on their experience or voted into position by the network through a consortium-type agreement.

An individual network centre may receive oversight from any combination of the types of committees, and the committees overseeing activities in one centre may not necessarily be present in another (Figure 3.6). Most of the surveyed centres have an executive committee (80%) and/or a scientific advisory committee (80%). Slightly less have some form of industry advisory committee (70%) and fewer still have a committee specialising in issues concerning intellectual property and commercialisation (20%). Rather than a separate industry advisory arm, some innovation network centres have industry members sitting directly in their executive committee. Five of the nine members of the Scottish Aquaculture Innovation Centre's Board, for example, are from industry and the centre's ability to align its activities with the needs of its industry partners has been attributed to this setup.

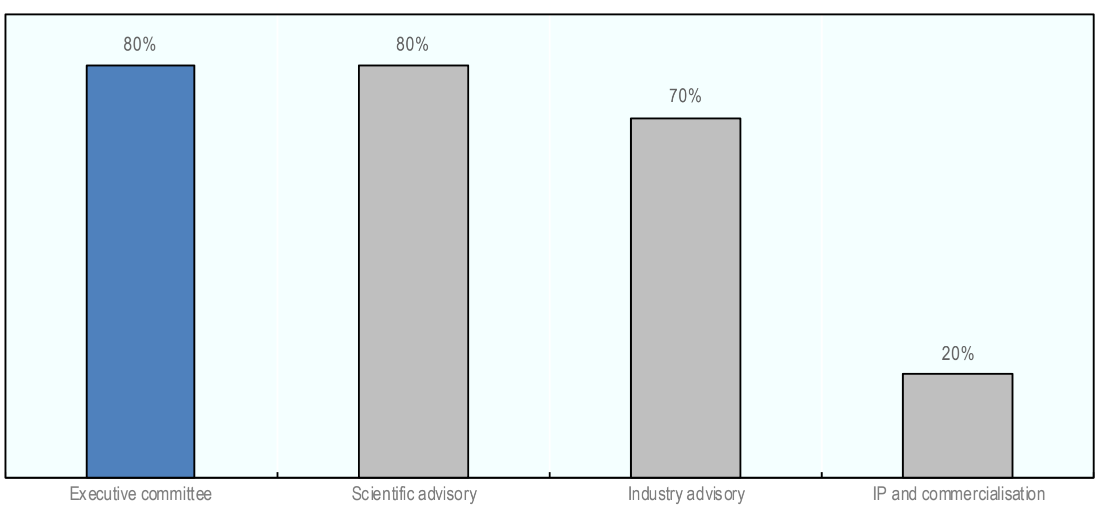
**Figure 3.5. Typical innovation network centre governance structure**




*Note*: Although the types of committees present differ by individual network centres, the diagram illustrates a typical governance structure.
*Source*: Analysis of the OECD *Ocean Economy Innovation Networks Survey* results.

**Figure 3.6. Governance by committee**

Number of surveyed innovation network centres governed by particular types of committee, as a percentage of total




*Note*: The number of centres with an executive committee plus some form of panel advising on scientific and/or industry and/or intellectual property and commercialisation issues are counted.
*Source*: Analysis of the OECD *Ocean Economy Innovation Networks Survey* results.

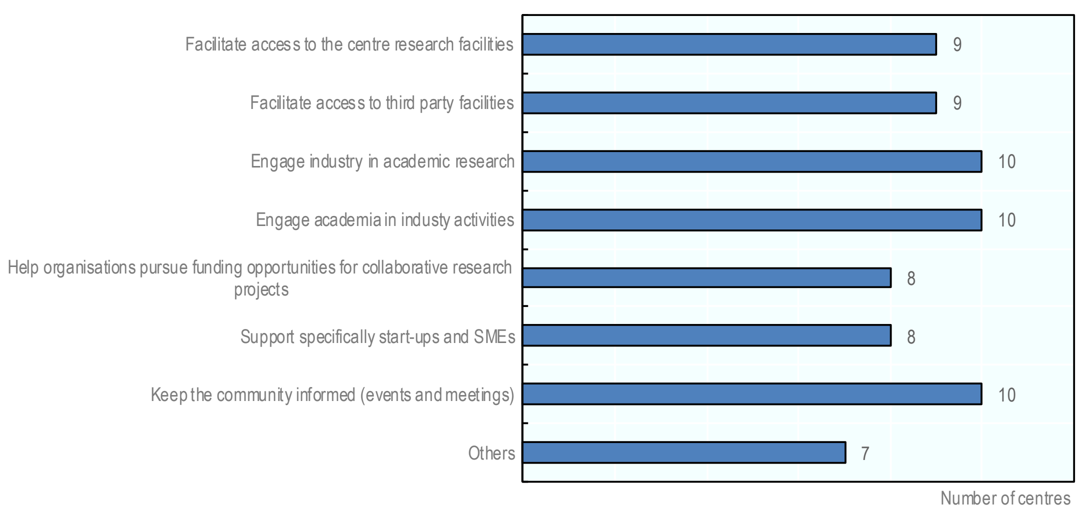
In summary, it is clear from the responses to the survey that governance by committee is a common trait among the surveyed innovation network centres and is likely to produce benefits in the form of effective oversight. Further study would be required to understand the impact of different governance structures on the innovation performance of network centres more precisely, however.

### *Roles of the innovation network centre*

The OECD survey restricted participation to innovation networks with at least partially publicly funded organisations at their core. Beyond this, the network centre could take any form and perform any service on behalf of the network. Perhaps surprisingly then, the questionnaire responses reveal that many of the surveyed innovation network centres perform similar activities (Figure 3.7). All of the network centres engage industry in academic research, engage academia in industry activities, and keep their communities informed of relevant events and meetings. Most of the centres facilitate access to research facilities under control of both the centre and third parties, and provide specific support for start-ups and SMEs. Many assist their partners in pursuing funding opportunities. Other activities include educating the general public on ocean issues, informing network participants of developments in relevant national policy, and delivering training in good management practices.

**Figure 3.7. Activities carried out by surveyed innovation network centres**

Number of innovation network centres that carry out particular duties on behalf of their networks

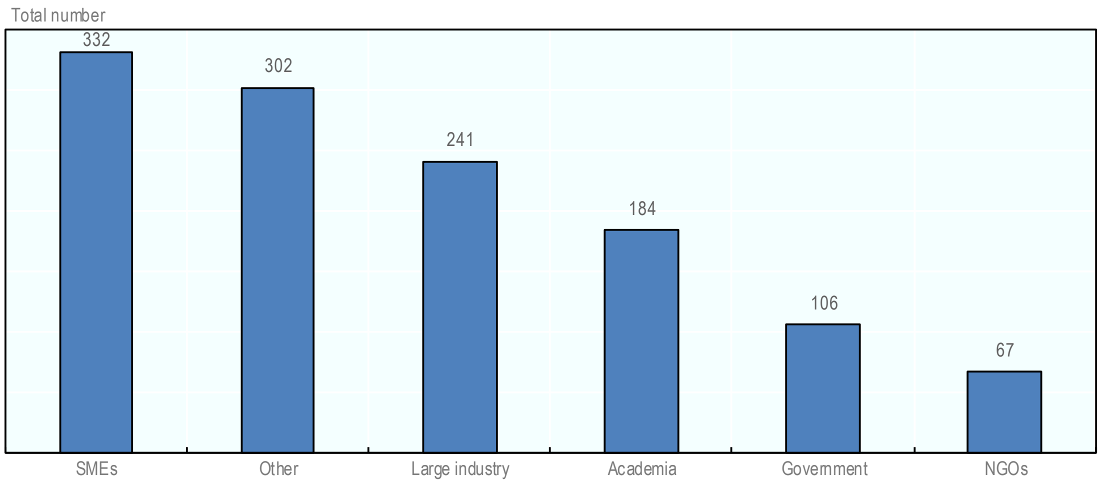



*Source*: Analysis of OECD *Ocean Economy Innovation Network Survey* results.

The results suggest that each partner within an innovation network contributes a specific specialisation that is not present in the expertise of the other collaborators. The organisation type of each partner reflects the expertise brought to the network and suggests why different entities may choose to collaborate. For SMEs, for example, entering a network with collaborators from other sectors may speed up the realisation of a marketable product. For academic institutions, the transfer of knowledge into a new, real-world setting ("technology transfers") may be the desired outcome. The largest share of network partners are from private businesses, with SMEs making up the greatest number of collaborating organisations (Figure 3.8). Additional categories include academia, government and NGOs, while the "other" category consists of a mix of other public or private research institutes and laboratories, or other types of research organisation.

**Figure 3.8. Types of organisations entering innovation networks**

Total number of partners from each category reported by all innovation network centres




*Source*: Analysis of the OECD *Ocean Economy Innovation Networks Survey* results.

### *3.2.2. Innovation focus areas*

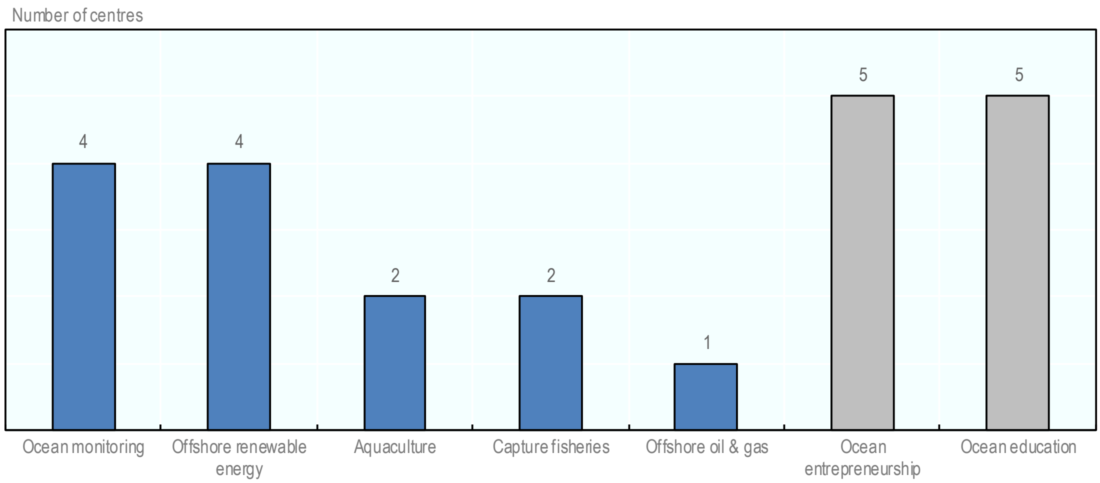
The ocean economy is a broad concept, capturing a wide range of industries, scientific disciplines and technologies. The ten surveyed network centres focus their innovation efforts on varied areas, but the five industries mentioned in the questionnaire responses are aquaculture, wild capture fisheries, ocean monitoring, renewable energy and offshore oil and gas.

- The aquaculture focus concerns the farmed production of seafood and algae in the ocean.
- Wild capture fisheries relates to any innovation concerning commercially harvested fish stocks, including looking at gear technologies to reduce bycatch and protecting endangered species.
- The ocean monitoring focus is concerned with observing the ocean for any purpose, including through the use of technologies such as marine robotics and autonomous systems.
- The renewable energy focus includes offshore wind, tidal, wave and marine thermal energy.
- The offshore oil and gas industry relates to all activities associated with the extraction of fossil fuels from below the seabed.

Two additional focus areas were important for most of the surveyed network centres: ocean entrepreneurship and ocean education. Ocean entrepreneurship concerns any centre that specifically targets collaborating with start-ups or encourages other forms of entrepreneurial activity. The ocean education focus includes any centre that either houses student researchers at its facilities or promotes ocean literacy as part of its core activities (Figure 3.9). Most of the centres focus on multiple areas so any combination of the areas is possible.

**Figure 3.9. Focus areas of surveyed innovation network centres**

Number of innovation network centres focusing on different areas of the ocean economy

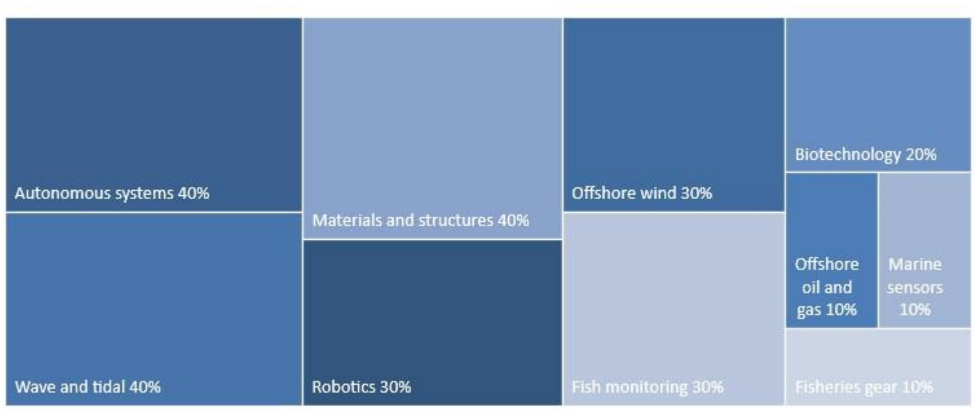



*Note*: Individual innovation network centres may focus on more than one area and therefore the number of focus areas may be greater than the number of innovation network centres.
*Source*: Analysis of the OECD *Ocean Economy Innovation Networks Survey* results.

The innovation network centres taking part in this study are developing a number of different technologies. The responses to the questionnaire have been sifted into ten different technology types. Often centres focused on different areas of the economy are developing different versions of the same technology with specifications suited to their needs (Figure 3.10). The three technologies most apparent among the network centres are autonomous systems, wave and tidal systems, and materials and structures (all with 40%). Robotics, offshore wind and fish monitoring are also important technologies, being developed in 30% of network centres. The remaining technology categories are biotechnology (20%), offshore oil and gas (10%), marine sensors (10%) and fisheries gear (10%).

**Figure 3.10. Ocean innovations occurring in ten different technologies**

Proportion of surveyed innovation network centres developing each technology, as a percentage of total number of network centres

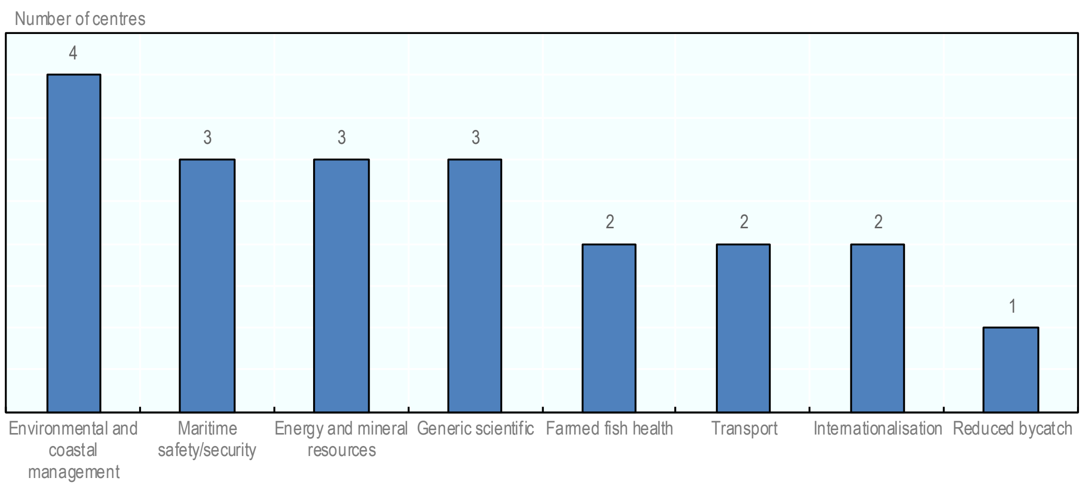



*Source*: Analysis of the OECD *Ocean Economy Innovation Networks Survey* results.

A further point of variation in the questionnaire responses is found in the *purpose* for which innovations are occurring in each focus area. This can be exemplified through marine autonomous vehicles. Autonomous systems are being developed for use in several areas of the ocean economy for multiple purposes, as already seen in Chapter Two. In the aquaculture industry, for example, autonomous underwater vehicles allow the monitoring of fish to continue in the absence of human beings. This has applications in a number of the industry's activities but could be particularly important in rough conditions prevalent in offshore and exposed areas. To follow this line of thinking to its conclusion, the aquaculture industry (focus area) is developing marine autonomous vehicles (technology) in order to improve fish monitoring (purpose) and reduce the risks associated with human presence in aquaculture farms (purpose) (Figure 3.11).

**Figure 3.11. Purpose for innovation**

Number of surveyed innovation network centres with each purpose for innovation




*Note*: Individual innovation network centres may focus on more than one area and therefore the number of focus areas may be greater than the number of innovation network centres.
*Source*: Analysis of the OECD *Ocean Economy Innovation Networks Survey* results.

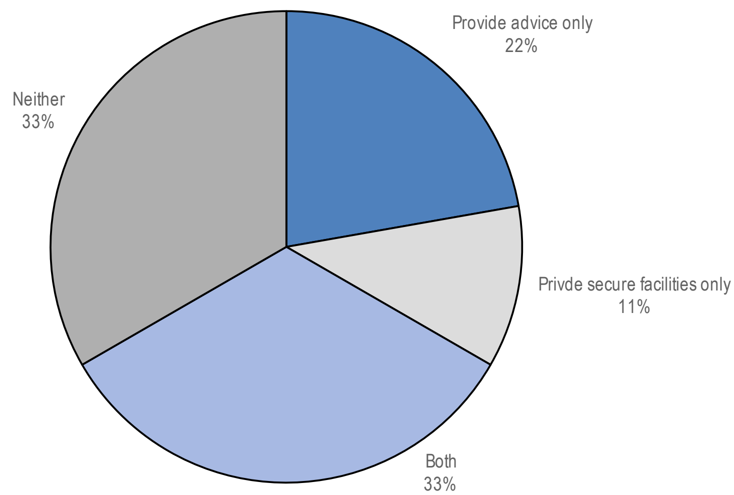
### *3.2.3. Issues concerning knowledge sharing and appropriation*

An important question for organisations entering collaborations is what information (or knowledge) should be shared with other collaborators. Interaction with external parties raises important issues regarding the protection and safeguarding of intellectual assets and intellectual property (patents, trademarks, trade "secrets", etc.). It can create uncertainty about how to appropriate or share the benefits of the collaboration. Tyrrell (2007[22]) identifies intellectual property theft as the most important risk in global innovation networks, with more than 60% of the 300 senior executives questioned indicating intellectual property as the most acute problem in collaborating for innovation.

Varying cases of knowledge sharing were apparent in the innovation network centres surveyed. For some projects, only limited amounts of knowledge need to be shared. In other cases, more efficient outcomes could be achieved by ensuring collaborations are as open as possible. In either case, trust in collaborators is crucial for effective interactions within networks. Without trust, organisations, or even teams within organisations, are unlikely to share their knowledge with each other or enter into arrangements that are anything other than contractual. On the other hand, the free exchange of knowledge may also lead to situations where the security of unrelated intellectual property is compromised. It could therefore be necessary for innovation network centres to put in place policies that safeguard intellectual property within their networks. There are likely to be many possible forms of such a policy. Around a tenth of the surveyed centres provide secure facilities only (meeting rooms, computer equipment etc.) and a fifth provide advice only (Figure 3.12).

**Figure 3.12. Approaches to safeguarding knowledge flows between network members**

Number of surveyed innovation network centres with certain approaches to safeguarding knowledge flows, as a percentage of total responses



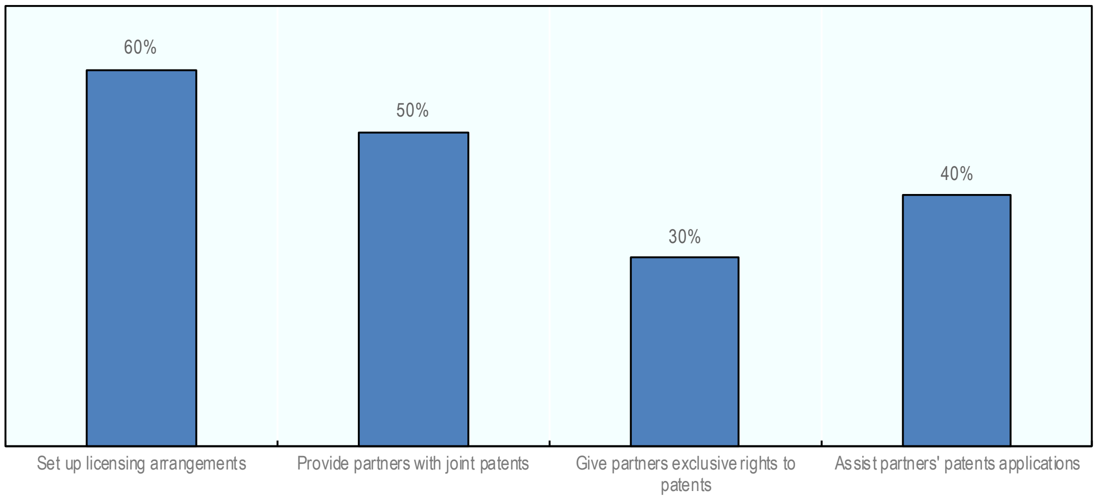

*Note*: The figures represent percentages of total responses to the relevant question in the questionnaire, rather than total number of innovation network centres. Some innovation network centres chose not to respond to the relevant question.
*Source*: Analysis of the OECD *Ocean Economy Innovation Networks Survey* results.

A second issue concerns how the proceeds from innovations are shared among collaborators. The role of the innovation network centre in dealing with the outcomes of innovation will depend on the type of agreements it fosters with the organisations it collaborates with. One way innovation network centres may choose to deal with innovation outcomes is through the use of intellectual property tools, which are an often utilised way for innovators to protect the value of their innovations. Setting up licensing schemes is the most common arrangement, with 60% of the centres having pursued them (Figure 3.13).

Intellectual property tools are often looked at as one measure of innovation performance (e.g. patents, trademarks and industrial designs). Registering intellectual property tools is not necessarily a priority for many of the innovation network centres surveyed. Patents have been registered by 33% of the surveyed networks, and more than half (56%) have not applied for any intellectual property tools thus far (Figure 3.14).

**Figure 3.13. Ways of dealing with innovation outcomes**

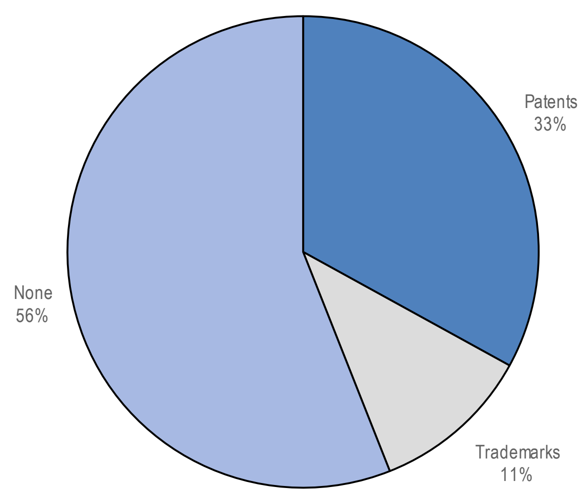
Number of innovation network centres that pursue different intellectual property strategies, as a percentage of total




*Note*: The figures represent percentages of total responses to relevant question in the questionnaire, rather than total number of innovation network centres. Some innovation network centres chose not to respond to the relevant question.
*Source*: Analysis of the OECD *Ocean Economy Innovation Networks Survey* results.

**Figure 3.14. Types of intellectual property tools in place**

Number of surveyed innovation network centres that have used particular intellectual property tools, as a percentage of total responses




*Note*: The figures represent percentages of total responses to the relevant question in the questionnaire, rather than total number of innovation network centres. Some innovation network centres chose not to respond to the question.
*Source*: Analysis of the OECD *Ocean Economy Innovation Networks Survey* results.

## 3.3. The benefits associated with ocean economy innovation networks

There is some ambiguity when trying to measure the benefits associated with innovation networks. The following sections first introduce issues related to evaluation, and then identify a range of qualitative benefits generated by innovation networks, both for network participants and society more generally.[2]

### *3.3.1. Evaluating innovation networks*

Literature assessing the impacts of networked innovation is relatively scarce, and dedicated assessments of public programmes to support innovation networks remain relatively few in number (Cunningham and Ramlogan, 2016[23]).

While studying sector-specific clusters, Porter (1998[24]) suggests that firms are driven to collaborate by access to scientific or technological excellence or by market demand. However, "the mere presence of firms, suppliers, and institutions… creates the potential for economic value, but it does not necessarily ensure the realization of this potential". The benefits derived from innovation networks by organisations participating in them may therefore depend more on intangible factors such as those associated with information flowing more freely and a willingness to align objectives and agendas between otherwise misaligned organisations. Further complicating the analysis of potential benefits is that innovation can create significant value for actors beyond the main innovating organisation, which is one of the more general observations resulting from open innovation frameworks (Chesbrough, 2003[5]; Porter and Kramer, 2011[6]).

Several methodologies with roots in the business literature attempt to tease out such complicated relationships. Value-network analysis, for example, is a theoretical framework for modelling the interactions between stakeholders in a network (den Ouden, 2012[25]; Allee and Schwabe, 2015[26]; Grudinschi et al., 2015[27]). In order to do this effectively, all value flows between all stakeholders both tangible and intangible must be understood, and all relationships and interactions identified.

Assessing the performance and broader impacts of innovation networks is therefore a complex endeavour, typically involving multiple factors. For example, a detailed, national-level assessment of the impact on firm performance of the Danish Innovation Network programme found that, on average, firms involved in sponsored networks had 7% higher labour productivity and 13% higher total factor productivity than similar unparticipating firms (Daly, 2018[28]). The analysis was performed on data collected by Denmark's Agency of Science and Technology and the Danish innovation network surveyed for this chapter, Offshoreenergy.dk, is one of 22 networks examined. Such analysis provides a limited but evidence-based assessment of the impacts of innovation networks from the perspective of the productivity of participating firms.

Evaluating only the potential benefits does not, however, consider the efficiency of public investment and the potential for disadvantages arising as a result of sponsored innovation networks. In general, any factor particular to an innovation network that reduces innovation outcomes when compared to a state where no publicly funded innovation network exists would be considered a disadvantage. In order to ascertain the true societal value of ocean economy innovation networks, the appropriate analysis would therefore entail summarising the cost-effectiveness of programmes designed to encourage innovation networks *and* the costs associated with collaboration more broadly. Ultimately, an assessment of the socioeconomic impacts of innovation networks that balances the full ranges of advantages and disadvantages is necessary.

In this context, preliminary studies of the socioeconomic impacts of ocean economy innovation networks may be useful for framing their future development and ensuring appropriate oversight of public spending. An example of one such review was commissioned by the Scottish Funding Council in order to assess the progress of its Innovation Centres Programme, of which the Scottish Aquaculture Innovation Centre (SAIC) is a product. The independent review of the entire Innovation Centres Programme is wide ranging and covers many issues, including oversight, funding mechanisms and broader impacts. A total of 55 written submissions and 41 interviews were conducted, plus an economic impact assessment commissioned from an external consultancy (EKOS Consultants, 2016[29]).

In particular, the economic impact assessment considered the wider socioeconomic effects of the programme. Estimations of the number of jobs, gross value-added (GVA), wages, turnover and cost-reductions generated by the innovation centres are arrived at. Despite being in the early stages of development, the assessment found evidence of positive net impacts and the potential for future benefits. For example, central case estimates of additional jobs and GVA attributable to the entire Innovation Centre Programme are calculated to be around 330 full-time equivalents and GBP 44.4 million respectively. These results contributed to the recommendations provided by the independent reviewer in their final report, proving the utility of conducting such studies in programme assessment and providing useful background to the implications of innovation networks in a societal context.

### *3.3.2. Benefits for stakeholders involved in ocean economy innovation networks*

To begin to understand the motivations for organisations joining ocean economy innovation networks, the OECD questionnaire asked for information surrounding the contributions and benefits gained according to the organisations participating in at least two projects. Since the organisations involved in networks are highly varied, their respective contributions and the resulting outcomes of their cooperation were very diverse. This section describes qualitatively the benefits accruing to stakeholders involved in networks, as reported by the innovation network centres surveyed.

#### *Co-ordinated approach to ocean research and development across stakeholder communities, and improved cross-sector synergies*

The benefits associated with ocean economy innovation networks are often produced in response to the challenges associated with multi-faceted research and development. For example, a fragmentation in ocean research objectives and efforts is often observed among stakeholders. In response, innovation networks aim to provide a co-ordinated approach across disparate research communities and improve cross-sector synergies. A few illustrations are presented below.

The first challenge summarised here concerns the linkages between research and industry players in new domains of the ocean economy. The centre for Marine and Renewable Energy in Ireland (MaREI) represents a good example of how innovation networks can be utilised to co-ordinate a fragmented research environment, enabling novel approaches to problem solving and boosting the development of new innovations. Headquartered at University College Cork, MaREI is the largest innovation network centre surveyed in this chapter with over 200 staff and a budget in excess of EUR 35 million. It brings together a wide range of research groups, some 45 industry partners, offers testing infrastructure and facilitates innovation in marine renewable energy (MRE) through the co-ordination of efforts among the research and development community. The technologies it develops are aimed at harnessing ocean energy to generate electricity (e.g. offshore wind, tidal stream, ocean current, tidal range, wave, and thermal and salinity gradients.) and are increasingly recognised as opportune for countries looking to shift their energy mix away from fossil fuels. In comparison with more-established ocean-based industries, MRE industries are relatively young and at an early stage of development. With the exception of offshore wind, most MRE technologies have not been proven at a commercial scale and scientific and technical difficulties remain.

A second challenge concerns the growing scientific, technological and logistical complexity of applied research in the ocean economy and ocean environment. A well organised innovation network brings together a diverse range of actors and partners and can strengthen multidisciplinary approaches and activities. It may also enable the exploration of opportunities for combining established with emerging technologies.

**Box 3.2. "Ideation" contributing to ocean innovation**

The "ideation" of ocean innovation can be supported by the right network set-up. Ideation is the creative process of forming and developing new ideas, from the initial conception through to actualising real-world applications. Occasionally, organisations of all types require assistance with taking ideas from "the back of an envelope" to a fully-realised project plan. This can be especially true when uncertainty surrounding the risks associated with investing in research and development (R&D) are particularly large. For example, IBN Offshore Energy, in Flanders, Belgium, facilitates the innovation project planning process for large companies, SMEs, start-ups, R&D intensive and innovation-aware organisations operating in the offshore energy sector. In certain circumstances, the centre simply matches actors for innovative outcomes. In others, the centre will assist collaborators in producing a full project plan for grant applications and other funding schemes. In addition to assistance with the project planning process, the centre provides a range of services on behalf of its networks. Examples of its activities include supporting R&D investments through demonstrating technologies in a commercial setting, creating new value chains by integrating solutions to real problems, rapidly disseminating new scientific knowledge to the market, and representing Flemish concerns in international forums.

To illustrate, most aquaculture at present takes place in coastal waters sheltered from rough conditions. In Norway, where significant parts of the coast are exposed to harsh conditions, this greatly reduces that amount of space available to industrial fish farming. Moving into exposed conditions therefore represents a potential opportunity for the industry. However, the technologies currently available to fish farmers are not suitable for operations in exposed areas. Moreover, the technological and logistical complexity of operating in exposed locations is significantly greater than in sheltered areas (see also Chapter 2 on these challenges). The EXPOSED Aquaculture centre is therefore attempting to foster the innovation required to enable fish farming in exposed locations by matching robust research with industrial applications. EXPOSED aims to deal with the additional complexity through developments aimed at improving safety and reliability in operations, but also in ensuring sustainable production. The types of technologies under development include: autonomous systems and technologies for remote operations, monitoring and decision support for fish, site and operations; structures for exposed locations; and, vessel designs for exposed operations. In addition, the impacts on safety and risk management for human presence in exposed locations, and fish behaviour and welfare in harsh conditions are being researched. To achieve these objectives, the centre brings together a consortium of 14 industry partners and four research institutions. It provides access to exposed sites for testing technology and specialised knowledge required to ensure the tests are robust.

The third challenge is concerned with exploiting the synergies between and across sectors in order to contribute to the creative process of developing new ideas and relevant innovations (see Box 3.2 above for a further example). Three examples from different innovation networks help to demonstrate how networked innovation assists in realising the advantages of cross-sector synergies.

- *Linking with fundamental research:* The Ocean Frontier Institute (OFI), for example, is an international hub for marine research based at Dalhousie and Memorial Universities on the east coast of Canada. OFI's focus is on sustainable development and it encourages strong collaboration across disciplines, especially social and natural sciences, to discover solutions that strengthen the economy and protect the ocean's changing ecosystems. Through education, training, and communication, and by sharing resources and information, OFI's works across two broad areas; (1) key aspects of atmosphere-ocean interactions, resulting ocean dynamics and shifting ecosystems, and (2) effective approaches to resource development that are sustainable, globally competitive, societally acceptable and resilient to change. Geographically, OFI's research covers the North Atlantic and Canadian Arctic Gateway, including the Labrador Sea and eastern portions of the straits of the Canadian Arctic Archipelago.
- *Securing collaboration with other sector-specific networks (drones):* A further example of networks keeping track of innovations and relevant knowledge in related industries is apparent in Denmark. Organisations related to the large and varied offshore energy sector in Denmark collaborate in innovative activity through an innovation network centre called Offshoreenergy.dk. Its members are related to offshore oil and gas and offshore wind and wave energies. The main objective of Offshoreenergy.dk is to facilitate innovation projects and activities between various actors within the Danish offshore industry. Additionally, the centre tracks innovative technologies in other sectors and searches for opportunities for transferring them into the offshore energy industry. Examples include securing collaborations between innovation networks such as those related to the Danish drone industry, in which many SMEs are operating. Creating linkages between the offshore energy sector and the drone industry promises to provide opportunities across many applications, which benefits both sectors simultaneously. Keeping track of relevant innovations, state-of-the-art knowledge and access to testing facilities in related industries are all fundamental benefits associated with innovation networks.
- *Securing collaboration with other sector-specific networks (ICT):* Initiatives that attempt to encourage multidisciplinary and cross-sector research in digital technologies are increasingly important. Digitalisation is enabling advances in many of the technologies mentioned in this book, from autonomous vehicles to better marine sensors. As the ocean economy continues to digitalise, ocean data will grow exponentially beyond what is already collected. This is likely to yield important benefits for understanding the ocean environment and provide opportunities for innovative companies. In order to imagine new uses of digital ocean data, the "Campus mondial de la mer" in Brest, France, has organised an

annual competition called the Ocean Hackathon since 2016 that draws verse diverse research and industry communities together (Box 3.3).

**Box 3.3. Spurring digital innovation in the ocean economy via hackathons**

The "Ocean Hackathon" organised by "Campus mondial de la mer" in Brest, France brings together multi-disciplinary teams from a broad range of backgrounds with the aim of solving challenges based on ocean data. The challenges are varied and designed to generate innovative ideas over one, non-stop, 48 hour period. In 2017, for example, Brittany Ferries, a ferry company based in the surroundings of Brest (Roscoff), tested the potential for virtual reality explanations of the surrounding environment to be provided during their ferry crossings. The 2018 edition, which attracted 86 participants from France, Ireland, Belgium, the United Kingdom and Canada, developed uses of data over a diversity of themes, including: the detection and avoidance of unidentified floating objects, coverage of real-time nautical events, real-time visualisations of satellite observations, shark monitoring, and smartphone identification of algae. Beyond the exploration of innovative uses of ocean data, the Ocean Hackathon provides data engineers and scientists with exposure to organisations collecting and working with data. In addition, the competition attracts data contributions from organisations that would otherwise not allow access to their databases. This provides opportunities for both the data providers and teams with the skills to develop the data into useful products. It also allows the benefits of opening otherwise closed-access data to be tested by their guardians.

### *Facilitation of access to suitable research facilities and specialised knowledge*

The ability to test innovations in a controlled environment removes an important barrier to the development of many ocean economy technologies, via access to suitable research facilities and specialised knowledge, This represent an important *raison d'être* of the innovation networks.

- As an illustration, the recently formed "Campus mondial de la mer" in Brest, at the tip of French Brittany, is building upon existing regional strengths to facilitate further communication, practical co-ordination of joint activities and access to demonstration sites on behalf of its community. The local authorities have nurtured the area's historical association with the ocean through business support organisations and other support services such as technology transfer programmes. The network builds further links between research institutions, such as the French Research Institute for Exploitation of the Sea (Ifremer), traditional ocean-based industries such as fishing fleets, newly established innovative companies and a vibrant university community with strong links to the sea. The result is a strong agglomeration of ocean-related activity directly supporting 65 650 jobs (5% of the total) concentrated around Brest, the largest city on the Brittany coast (ADEUPa, 2018[30]).
- Further south, the Oceanic Platform of the Canary Islands (PLOCAN) is designed to provide the facilities to test innovations for a broad range of activities. Initiated in 2007 to provide the scientific-technological community, both public and private, with the large infrastructure required to develop innovations, PLOCAN has since developed a range of other facilities and services. In addition to the

multi-use platform, which was fixed in location off the north-east coast of Gran Canaria in 2016, PLOCAN contains a 23 $km^2$ offshore test area and a multidisciplinary observatory that is part of the European ocean observatory network. The multi-use platform contains a control tower for monitoring all operations of the platform and the surrounding test site, laboratories and classrooms, an open working area, and a test tank for facilitating sea trials and launching underwater vehicles. PLOCAN also provides a range of services to complement the core testing infrastructure. Such services include assistance with the testing and demonstration infrastructure, management consultancy, and, education and training. For example, the platform hosts an annual training forum for ocean-glider technology. The week-long "Glider School" brings together leading manufacturers of glider technologies and provides students with practical experience through classwork, laboratories and open water sessions, all taking place within the sites facilities.

### *Support for start-ups and SMEs in the ocean economy*

The majority of organisations entering into formal innovation partnerships in the ocean economy are SMEs. However, there are many challenges for start-ups and SMEs, notably in matters of funding, infrastructure and the speed with which they are able to market innovations. The networks often aim to provide support in terms of training, de-risking, marketing and commercialisation, and facilitate funding opportunities for R&D, all by leveraging additional funding from regional, national and international entities.

- As an illustration, in order to capitalise on Portugal's lengthy history of ocean activity and exploration, several universities with links to the ocean economy created MARE-Startup in 2015. The aim of MARE-Startup is to boost ocean entrepreneurship and assist start-ups through a holistic approach. The type of support offered includes access to education and research, but also the provision of advice on business and governance issues. The centre also looks for opportunities more broadly through networks of start-up incubators and centres of excellence in related fields.
- Another example is provided by the Marine Autonomous and Robotics Innovation Centre (MARSIC), in the United Kingdom, which promotes interactions between large, established companies and smaller, innovative organisations. In essence, the innovation network centre acts as an informal financial intermediary. Under MARSIC's model, large companies with an interest in exploiting the next generation of technologies pay a fee to become "Associate Members" of the innovation centre. They do not have the right to a constant presence at the centre but receive access to the "Strategic Partners" – which are organisations, typically SMEs and academic partners, developing new technologies there. The benefits of such an arrangement flow in both directions. Associate Members represent the end-users of ocean technology. They have detailed knowledge of operational needs and are able to influence the direction of innovations accordingly. This increases the chance that the technology developed is useful to them. They also gain early-sight of technological developments enabling them to remain on top of the innovation pipeline and plan accordingly. Strategic Partners, on the other hand, are better able to develop their innovations in-line with the market's needs, improving the likelihood that their technologies are successful when marketed. The support they receive while working at the

innovation centre is funded in part by the membership fees paid by the Associate Members, lowering an important barrier to innovation in smaller enterprises.

- Further north, the Scottish Aquaculture Innovation Centre (SAIC) at the University of Stirling led a pilot project entitled Aquaculture Innovation Network for the Northern Periphery and Arctic (AINNPA), to engage rural and remote SMEs with the aquaculture supply chain. The Northern Periphery and Arctic (NPA) Programme 2014-2020 is fostering cooperation between nine countries in the northern and Arctic regions of the European Union. Funded by the European Regional Development Fund (ERDF), its members include regions in Finland, Sweden, Scotland, Northern Ireland, Republic of Ireland, the Faroe Islands, Iceland, Greenland and Norway. A core objective of the programme is to "use innovation to maintain and develop robust and competitive communities" in often remote locations throughout the NPA. Remotely located SMEs are key to the aquaculture industry across the NPA. Sustainable growth of the sector requires new, innovative products and services. SMEs often experience variable and constraining access to innovation services, however. The AINNPA pilot project addressed this by developing transnational solutions for innovation to aquaculture-facing SMEs and open new markets for innovative SMEs not yet engaged with the aquaculture sector. This was explored by activating international networks for remote SMEs engaged with the aquaculture supply chain, sharing models for delivering innovation services to those SMEs, and combining R&D efforts to develop new products and services for international markets. The intended output from AINNPA is an integrated network of aquaculture innovation services across the participating regions; SME-led prioritisation of regionally relevant aquaculture innovation topics; and new innovative aquaculture products and services. Other project partners include Matis Research and Innovation (Iceland), Bantry Marine Research Station Ltd (Ireland), SINTEF Fisheries and Aquaculture (Norway) and the Aquaculture Research Station of the Faroes (Faroe Islands).

### *3.3.3. Wider benefits associated with ocean economy innovation networks*

In addition to the benefits accruing to organisations that join or are associated with ocean economy innovation networks, the survey reveals a range of broader benefits that spill over to society more generally. The three categories outlined below are framed around the potential for ocean economy innovation networks to contribute to broader societal objectives, such as: building scientific capacity and investing in skills and knowledge for the future; diffusing knowledge between related economic sectors; and, creating more sustainable economic activity.

#### *Ocean economy innovation networks' contribution to building scientific capacity and to investing in skills and knowledge for the future*

The innovation networks surveyed originate in different types of public organisations. Some have grown from technology institutions, others from public research centres and universities. Many driving forces have been highlighted which attempt to explain why these organisations have decided to formalise innovation networks. This, in turn, suggests a multitude of activities and benefits have been targeted. However, a common motivation for the networks related to public research institutes and universities is taking advantage of innovation to improve ocean science. In general, increased scientific capability benefits everyone; whether it be through the better prediction of severe weather events and their impacts, or the intrigue encouraged by learning and understanding more about marine flora and fauna to give but two examples.

Scientific capacity may be increased by innovation in any number of ways. One potential avenue actively pursued by innovation networks is better ocean monitoring. In any case, the ability to measure and observe the ocean is the cornerstone of ocean sciences. Several technologies under development hold the promise of enabling more consistent ocean observations with a more effective cost structure. Marine autonomous vehicles, for example, offer a range of options for monitoring the ocean more efficiently than manned vehicles, operator controlled robotics, buoys and other ocean observation systems. Related advances in marine sensors and instruments, including lab-on-a-chip technology, allow measurements of the marine environment to be taken and processed quicker and with lower power requirements. Further examples of efficiency saving and efficacy boosting ocean observation technologies abound. Advances in this area enable more science to be performed, untold discoveries to be made and new knowledge to be created, leading to greater societal understanding of the ocean.

In addition to technological advances, the innovation networks surveyed are developing approaches to improved ocean monitoring that fall more in the fields of management and international cooperation than R&D. The challenge of building the capacity to monitor the ocean effectively and consistently is complicated by its size and the fact that the high seas are not under individual country jurisdictions. Conducting such activities on a purely unilateral basis is unlikely to be efficient or effective in all situations, but especially for observations occurring outside of a country's exclusive economic zone (EEZ). Working internationally makes sense in this regard and many of the centre's involved in this study are actively pursuing the internationalisation of their networks. Drawing cross-border attention to new technological developments, sharing ship time on research vessels and organising international workshops and conferences, are some examples mentioned in the survey. Such initiatives expand international scientific capacity, spreading the associated societal benefits on a multilateral basis.

A further important point here relates to maintaining a pipeline of appropriately skilled researchers ready to exploit the advanced technologies of tomorrow. This requires foreseeing both technological developments and the volume of new science that is likely to be enabled by them. Incorporating educational opportunities into the innovation process is one way in which the innovation networks surveyed attempt to satisfy such complicating factors. Many facilitate access to funding opportunities for masters and doctoral students, postdoctoral fellows, and for industry professionals to undertake advanced training. Some incorporate students and early-stage researchers into their daily activities by employing them in project positions. Directly developing research capacity with an eye to the future is key and is complemented by the networks' work to strengthen connections between varieties of stakeholders, including through the vocational development of promising professionals. Such efforts increase awareness of innovative business activity among scientists and their students, and vice-versa. When combined with greater emphasis on ocean literacy, which boosts understanding of the ocean among the general population, society's absorption of the benefits yielded by improvements in ocean research is likely to continue apace.

### *Ocean economy innovation networks' contribution to knowledge diffusion beyond the ocean economy*

The previous sections listed a number of activities, such as the facilitation of access to specialised knowledge and bringing innovations out of the laboratory and into the real world. These translate into benefits tilted towards network participants and their immediate stakeholders. The current section focuses on the diffusion of knowledge among typically unrelated areas, thereby stimulating interactions between actors that might not occur otherwise and generating benefits that accrue to society beyond the ocean economy.

Much like all other sectors, the ocean economy is profoundly influenced by enabling technologies that are derived elsewhere. Examples include: broad-based advances in ICTs at the core of marine autonomy – such as machine visual-image processing – with applications across the full spectrum of ocean-based industry and science; the redevelopment of sensors from land-based industry into a product suitable for the offshore fossil fuel industry, such as those used to detect gas leakages from wastewater treatment facilities; and, the use of ultrasound technology and medical diagnostic tools to delouse farmed fish and assess their health, resulting in less damage to the fish or the surrounding environment.

The examples above suggest knowledge exchange between economic sectors offers opportunities for progress in ocean innovation that would not be available should organisations concentrate solely on ocean-related activity. For organisations operating alone, the costs of following the general state of technology may outweigh the potential payoff should a targeted breakthrough prove compatible. Innovation networks therefore play an important role in keeping up-to-date with technology markets and covering a wider range of promising avenues than any organisation could achieve alone. In particular, innovation network centres track technological developments, consider possible ocean applications and communicate advances to their partner organisations, sometimes through dedicated conferences and/or newsletters. This provides benefits to the ocean economy but also the sectors in which alternative technologies originate, contributing to the pool of resources available for progress in society more generally. It should also be noted that innovations may flow in the other direction; from the ocean economy towards other sectors. Here too innovation networks provide a core service by spreading the costs of outreach among multiple parties, an input particularly important for small enterprises without the means to invest in greater exposure individually.

The second element in this category relates to improving policymakers' knowledge of the ocean economy's potential to provide social benefits. Often, ocean-based industries fall under the domain of policies focused more broadly. Ocean and coastal tourism, for example, is likely to be impacted predominantly by policies targeting tourism in general. Advances in aerial drone technology hold great promise across a spectrum of ocean-based industries but the market is poorly regulated and restricted by policies focusing on land-based uses. Marine renewable energies are a clean alternative to fossil fuels and contribute to efforts to decarbonise electricity generation but can be underestimated by decision-makers unaware of their potential. In each of these cases, the nuances associated with ocean-based applications require more attention in policymaking than is afforded by a process that does not distinguish between land-based and ocean economies.

Innovation networks provide a useful platform in this regard. By pooling resources and grouping a variety of actors together, networks are perhaps more visible than individual organisations and are likely to represent a broad range of viewpoints. In marine renewable energies, for example, networks are able to combine expertise in environmental monitoring, perhaps from a research institution, with real-world experience of the energy business, from an energy company, to develop credible siting recommendations. The multi-stakeholder approach provides confidence to policymakers that opportunities are legitimate and provides the voice for a range of communities to communicate the importance of their activities. Ultimately, networked collaboration in the ocean economy creates space for more effective consultation and communication during the policymaking process. Better ocean policies, and the prospects for society to benefit from them, are more likely to be realised as a result.

### *Ocean economy innovation networks' contribution to sustainable economic activity*

The core function of innovation networks is to forge collaborations between distinctly different organisations. The fundamental purpose for encouraging such collaborations, expressed by each of the innovation network centres surveyed, is to harvest the opportunities provided by the ocean in a manner that is both environmentally and economically sustainable. At the most basic level, bringing together a variety of organisations with differing incentives but a common objective – to develop innovations that are adopted in scientific endeavour and/or commercialised – will boost economic activity in the short term. The ocean economy, however, is an interactive system of ocean-based industries and the marine ecosystems upon which they are built. The interdependency of both implies as imperative that economic activity be conducted in such a way that it encourages the conservation and sustainable use of marine ecosystems. Many of the innovations under development and discussed in the examples above, as well as in Chapter 2, are designed with these objectives in mind.

A sustainable ocean economy will provide societal benefits on many levels. Take, for example, the marine renewable energies sector. Any technology under development applicable in this area has the ultimate aim of lowering the levelised cost of renewable energy, thereby reducing the costs to society of an energy system less reliant on emissions of greenhouse gasses and other harmful pollutants. Marine autonomous vehicles are likely to provide the technology required to conduct full water column surveys of the ocean environment at a fraction of the present costs, with the added advantage of reducing the necessity to place humans in dangerous environments. The environmental benefits of such technologies are clear, particularly when applied to scientific uses or renewable energies.

Additionally, innovation specifically in networks has a role to play in the realisation of a sustainable ocean economy in more intangible ways. Matching collaborators with complementary but different expertise is likely to result in development paths that are some combination of the objectives of all parties involved. It could be that, for example, the involvement of marine scientists in projects with potentially adverse environmental impacts results in outcomes more acceptable to society than products resulting from innovative efforts conducted purely by industry. It is also likely that, through the connections made and relationships formed, emerging technologies from other sectors are applied in new ocean settings. This stokes economic activity and opens new markets where no connections existed before. Finally, bridging the gap between academia and business will assist with maintaining a thriving pipeline of workers with skills appropriate for a sustainable ocean economy. Optimising the education system to build the right capacity is, after all, perhaps the most important determinant of long term sustainability of them all.

## 3.4. How to ensure that innovation networks have positive impacts

The ocean economy innovation networks surveyed are different in scope. But they tend to share some common points, including in terms of the challenges they face. The following sections provide an overview of these challenges and suggest some policy options for policymakers wishing to ensure innovation networks are well equipped to operate.

### *3.4.1. The challenges faced by ocean economy innovation networks*

The following four broad challenges reported by the innovation network centres should not be considered exhaustive of the issues faced by ocean economy innovation networks, but provide instead a number of insights into the challenges of collaboration schemes between marine and maritime actors.

#### *1. Taking advantage of the opportunities of a growing ocean economy*

The broad objective of many of the networks is to develop the innovations required to secure an ocean economy that is able to provide the benefits associated with economic growth while conserving and sustainably using marine ecosystems. These aims will also impact upon broader objectives such as efforts to decarbonise the overall economy. Still, many of the opportunities made possible by innovation in the ocean economy are yet to be exploited, or recognised, in their fullest. An example is the marine renewable energies (MREs) sector. Given many countries are attempting to shift their energy mix away from fossil fuels in the medium term, MREs are likely to become increasingly important in the future. There is a general sense, however, that the role that innovation has played in reducing the costs of marine renewable energies – reductions in the costs of offshore wind being particularly impressive – have been overlooked at levels of national policymaking beyond that directly responsible for renewable energy in many parts of the world. Such issues appear of more importance in recently established and/or smaller innovation networks which perhaps do not have the capacity to communicate the outcomes of their work to the appropriate audience. The larger innovation centres, on the other hand, have reported active links with policymakers.

#### *2. Responding to the growing pains of collaboration*

Despite the broad based benefits associated with networked innovation in the ocean economy, some important challenges exist in conducting collaborative activities. Perhaps the greatest relates to a core function of the innovation network centre: to successfully build bridges between a diversity of organisations, with differing purposes and objectives. Often, for example, businesses have shorter time frames in which to conduct R&D than partners based in academic settings. While academics might be most interested in the pursuit of new knowledge, business will place a greater premium on real-world marketability. In certain cases, competing priorities and mismatched notions of time could produce frictions between partners that prove detrimental to innovation. In general then, the innovation network centres work to match compatible organisations and reduce gaps between organisations that may be irreconcilable without the existence of a functioning centre. Relatedly, a balance must be struck between the numbers of each type of collaborating organisation. The strongest networks are likely to contain a range of partner types. It typically falls to the innovation network centre to ensure an appropriate balance is maintained and that relationships are managed accordingly.

*3. Balancing commercial potential and opportunities for more research*

While in many cases mixing and matching different types of organisations is likely to result in better innovations, it is also important to ensure that innovation has commercial potential by being a viable investment and, indirectly, by contributing to a more evidence based policy environment. Often then, industry partners play a role in signalling whether or not R&D is being directed towards problems faced in the ocean economy. Innovation network centres pursue a variety of methods to coordinate this interaction. Some centres build upon a problem statement provided by industry as part of their conditions of service. Others host networking breakfasts and/or actively match potential customers with specific technologies. Such initiatives are clearly worthwhile and assist in the slow grind towards commercial success. However, innovations may also prove suitable for solving problems that are currently unforeseen, and fundamental R&D in this area should not be disregarded. Ultimately then, engaging end-users in the innovation process by actively encouraging them to join innovation networks seems likely to have the greatest impact, regardless of whether a problem statement exists. In this way, potential end-users are able to steer innovation in a useful direction, but may also be inspired to change the way they operate as a result of opportunities only discovered through actively partaking in the innovation process.

*4. Maintaining a culture of innovation in the network*

Finally, it follows that an important contribution of ocean economy innovation networks is to maintain a culture of innovation within and between diverse groups of actors. Key factors deciding success in this regard include upholding a deep understanding of the issues affecting a relevant area of innovation and the development of effective working relationships between collaborating organisations. Innovation network centres play a fundamental role in cultivating such attributes and, in turn, boosting ocean economy innovation. They perform a function that, increasingly, goes to the very heart of the sustainable ocean economy of the future. However, there is room for policy to assist this most important of ocean economy trends. Many of the innovation network centres surveyed operate with a small number of staff, are subject to short funding time frames and are faced with restricted access to trial and demonstration sites, for example. The following sections expand on areas of potential policy improvements so that the opportunities presented by innovation in the ocean economy can be exploited more fully.

### 3.4.2. Policy options to address ocean economy innovation networks

Policymakers looking to encourage and monitor the development of ocean economy innovation networks in their countries may wish to consider the environment under which these networks are operating. In view of the diversity of the ocean economy innovation networks that exist, there is no ‘one size fits all’ policy option. Several options are proposed below to cultivate the potential for ocean economy innovation networks to deliver sustainably into the future.

*1. Assess the performance and evaluate the impacts of innovation networks*

As an important step, independent and credible scrutiny is recommended to ensure that public funds channelled through innovation networks are reaching their target of facilitating cooperation between different stakeholders and leading to innovations. Assessing the performance of the innovation networks over time will contribute to ensuring their effectiveness and sustainability as they mature. The limited number of independent assessments of ocean economy innovation networks that have been carried out, as mentioned in previous sections, have shown the generation of benefits within and beyond the sector under investigation. However, more efforts to assess impacts will be required if their value is to be fully assessed and understood widely.

### *2. Orientate regulation towards innovation*

The relationship between regulation and innovation is often ambiguous. On the one hand, regulation can affect the rate of innovation both positively and negatively. On the other, technological change can render once-effective regulations obsolete. Given this, the regulatory framework should seek to ensure stability as far as possible (to provide private decision makers with a degree of certainty) while being able to adapt to trends in technological development where necessary. This is often a difficult mix of objectives and can be particularly challenging in the ocean economy where safety and environmental concerns are paramount (Box 3.4).

**Box 3.4. Regulatory challenges surrounding marine autonomous vehicles**

An example of the importance of the regulatory environment on the development of technology in ocean economy innovation networks is apparent in projects related to marine autonomy. At present, Marine Autonomous Surface Ships (MASS) are subject to regulation designed for conventional shipping. Regulations designed for ships navigated entirely by on-board seafarers may not be appropriate in all autonomous eventualities and could represent a hindrance to innovation. Furthermore, different rules are likely to be required according to what type of area the vessel is travelling through (coastal, open ocean, shipping lanes, remote locations etc.) and the level of automation utilised (only limited automated functions through to full autonomy). Several industry-led attempts have assessed the effects of the regulatory environment on development in this area (see, for example, Ramboll and CORE Advokatfirma (2017[31]) and UK Maritime Autonomous Systems Working Group (2017[32])). The issue is now under the attention of the UN International Maritime Organisation's Maritime Safety Committee (IMO-MSC). These efforts should be bolstered and extended if investor certainty is to be maximised.

Performance-based regulations are targeted at the consequences of a particular product or service on health, safety and environmental outcomes. They do not specify technical specifications for a particular technology or imply that a particular standard must be achieved (unlike technology-based standards). Because of this, performance-based regulations tend to be technology neutral and provide a degree of flexibility for innovators who are permitted multiple pathways for meeting regulations affecting them. Flexibility, in general, is considered beneficial for innovation as it allows a greater deal of experimentation in R&D. However, if regulation is to encourage innovation then it must be designed with the risks that it may discourage innovation in mind. A great deal of uncertainty surrounds how best this might be achieved (in reality a bit of both impacts are likely to occur), but the inclusion of ocean innovation expertise throughout the design and implementation phases of the regulatory process – and this is already the case for most of the surveyed networks – is likely to increase the chance that regulations result in more innovation rather than less (Box 3.5).

### *3. Consider increased support for technologies in later stages of development*

The high costs associated with early-stage research have led in general governments to offer support for fundamental and applied research. Such funding mechanisms tend to only apply to basic research. Once scientific principles suggest an innovation is possible and a proof-of-concept is achieved, such sources of funding tend to dry up. Just as critical in an ocean technologies path to commercialisation, however, is the process of testing and demonstrating that a product operates effectively (broadly equivalent to technological readiness levels six to nine). The costs of proving a technology is ready for commercialisation are significant and could act as a barrier to innovation. Public support for demonstration and testing tends to be available through various innovation funds and many of the innovation networks surveyed have accessed such sources. In some cases, more support could be provided at the latter stages of technological development, both in terms of facilitating access to finance and the provision of suitable demonstration sites, where proving commercial applicability is key. This could be recognised as an option by administrations looking to support late-stage technological development in the ocean economy.

**Box 3.5. Advanced tools for regulating the aquaculture industry**

**New models for estimating the impact of aquaculture waste on the environment partly supported by the Scottish Aquaculture Innovation Centre (SAIC)**

Waste from aquaculture farms may have significant environmental effects. Licensing new, or re-licensing existing, farms therefore depends on estimating local impact. Since the mid-1990s, sea-bed impact has been estimated with predictive models that simulate the fate of organic material moving from fish enclosures to deposit on the sea-bed, with subsequent bio-degradation and some resuspension. From the mid-1990s, models such as DEPOMOD encapsulated the relevant physics and biology. Predictions based on physical measurements could be checked against surveyed sea-bed biology. Consequent elaboration of the models helped ensure their wide international application. Progress was tied to the flow of new knowledge and to the increasing cheapness and efficacy of numerical modelling. This continues today with the development of a user-friendly “newDEPOMOD” that incorporates detailed bathymetry and improved knowledge of resuspension. The new model promises to use verified and numerically modelled three-dimensional flow around a farm rather than single site measurements. Development of this model and its parameterizing over different sea-bed types is partly supported by SAIC and its partners involved in both industry and academia. Such innovatory decision-making regulatory science, based on cross-sectoral collaboration, will allow the Scottish Environment Protection Agency (SEPA) to improve regulation, and industry may be freed from some inevitably precautionary assumptions that arise from over-simple modelling processes.

### *4. Invest in or remove barriers to accessing test facilities and demonstration sites*

Relatedly, the ability to test new technologies in the ocean is crucial to the development and commercialisation of many ocean economy innovations. The survey reveals that important motivations for entering innovation networks are access to testing facilities and the expertise needed to prove technologies work as they should.

This suggests that the development and commercialisation of innovations could be increased through better access to testing infrastructures. Although the costs of such facilities are significant, some countries have recognised a gap and have invested in the construction of purpose built facilities. The Oceanic Platform of the Canary Islands (PLOCAN) is one such example and is able to test a broad range of technologies, including: offshore renewable energies; marine observation, monitoring and surveillance technologies; data communication technologies; and, autonomous and remotely operated vehicles. Due to the high costs of building and operating a facility such as PLOCAN, it may be more prudent for administrations to share facilities rather than investing in new ones. Where this is the case, mechanisms to encourage smooth access to facilities, either across sectors or between countries, should be considered.

Once proven inside a facility, technologies will also need to be demonstrated in the open ocean if trust in their capabilities is to be understood by the market. In the case of marine robotics and autonomous vehicles, offshore demonstration sites will necessarily be large and deep. In addition to the provision of purpose built facilities, the regulatory environment and licensing regime should allow for such offshore demonstrations to take place. The sharing of demonstration sites should also be encouraged.

### *5. Consider the role that alternative sources of finance may play in innovation networks*

While public financial support is clearly an important aspect of ocean economy innovation, it is not the only funding stream that policymakers can influence. Banks and venture capitalists also have a role to play in financing innovation and will respond to well-designed incentives created by the policy environment. Policymakers may therefore wish to explore their role in encouraging the development of collaborations between ocean economy innovators and suitable financial entities. For example, venture capitalists investing in ocean economy innovations have a stake in ensuring and maintaining connections with end-users and are likely to assist with managing an innovation’s route to market. In general, the introduction of alternative sources of finance could increase the pool from which ocean innovators are able to fund their activities, provide access to skills such as marketing that are not always common in small enterprises focused on innovation, and, ultimately, provide opportunities for innovation networks that are unavailable through traditional partners.

### *6. Provide long-term road maps to boost certainty*

Investing in research and development is inherently uncertain and risks must be taken if innovation is to be effective. For the networks surveyed, public funding helps to de-risk innovation to acceptable levels. This is likely to be true in firms of all sizes, but particularly in small, resource constrained companies. However, public finance is not limitless and, as the point above suggests, the introduction of alternative sources of finance is often necessary. A key barrier to private investment is uncertainty arising from the policy environment more generally. If policies are poorly designed, subject to regular revision and/or imply a lack of political support for particular technologies, then private decision-makers are unlikely to have the confidence necessary to invest. Key to attracting alternative sources of finance in the ocean economy is therefore a political signal that provides a degree of long-term certainty. Long-term roadmaps help to build certainty in the policy environment, which is vital for innovation networks to plan their activities and can be important for sustaining private sector investments.

## 3.5. The way forward

Ocean economy innovation networks represent a specific type of collaboration in the ocean economy. In principle, such networks have the potential to produce multiple benefits, through the organised cooperation of many innovating organisations, but their actual performance and effectiveness will need to be monitored over time.

This initial OECD exploration of ocean economy innovation networks has set the foundations for further work in the area. Most of the innovation network centres that responded to the initial OECD questionnaire were established relatively recently and changes are likely to occur rapidly as they grow. The geographical spread of the networks surveyed is also concentrated in Europe and Canada, but there are many more centres to examine, in different parts of the world, with unique set-ups and a multitude of focus areas within the ocean economy. The OECD Ocean Economy Group will therefore continue its exploration of ocean economy innovation networks, both by following developments in the networks presently surveyed and expanding the reach of case studies further afield.

## Notes

1. Offshoreenergy.dk is an innovation network for the offshore energy sector in Denmark. The centre originates in a national industry cluster organisation called Offshore Centre Denmark that was established in 2003. Since then, the centre has undertaken a number of transformations. The current incarnation occurred in 2013, when the centre merged with several knowledge institutes and was named Offshoreenergy.dk. Its status as an innovation network centre was recognised nationally by the Danish Ministry of Higher Education and Science in 2014.

2. The questionnaire responses were delivered by the network centre and, therefore, do not reflect the views and/or opinions of the partner organisations directly. This adds an element of bias to the results that should be considered. Future research could include a less detailed survey of network partners to garner their thoughts about the collaboration process.

## References


ADEUPa (2018), *Observatoire de l'économie maritime en bretagne*, Agence d'Urbanisme Bretagne, Brest, France. [30]

Allee, V. and O. Schwabe (2015), *Value Networks and the True Nature of Collaboration*, Meghan-Kiffer Press, Tampa FL, USA. [26]

Chesbrough, H. (2003), *Open Innovation: The New Imperative for Creating and Profiting from Technology*, Harvard Business School Publishing Corporation, Boston, Massachusetts. [5]

Cunningham, P. and R. Ramlogan (2016), "The impact of innovation networks", in Edler, J. et al. (eds.), *Handbook of Innovation Policy Impact*, Edward Elgar, https://doi.org/10.4337/9781784711856.00016. [23]

Daly, M. (2018), "The effect of participation in Denmark's Innovation Network program", *Economics of Innovation and New Technology*, Vol. 27/5-6, pp. 454-478, http://dx.doi.org/10.1080/10438599.2017.1374045. [28]

den Ouden, E. (2012), *Innovation Design*, Springer London, London, http://dx.doi.org/10.1007/978-1-4471-2268-5. [25]

Dhanaraj, C. and A. Parkhe (2006), "Orchestrating Innovation Networks", *Academy of Management Review*, Vol. 31/3, pp. 659-669, http://dx.doi.org/10.5465/amr.2006.21318923. [21]

Doloreux, D. and Y. Melançon (2009), "Innovation-support organizations in the marine science and technology industry: The case of Quebec's coastal region in Canada", *Marine Policy*, Vol. 33/1, pp. 90-100, http://dx.doi.org/10.1016/j.marpol.2008.04.005. [18]

EC DGMARE (2008), *The role of Maritime Clusters to enhance the strength and development of European maritime sectors: Report on results*, Directorate-General for Maritime Affairs and Fisheries, European Commission. [17]

EKOS Consultants (2016), *Business Engagement and Economic Impact Evaluation of the Innovation Centres Programme*, EKOS Economic and Social Development Consultants, Glasgow. [29]

Freeman, C. (1991), "Networks of innovators: A synthesis of research issues", *Research Policy*, Vol. 20/5, pp. 499-514, http://dx.doi.org/10.1016/0048-7333(91)90072-X. [7]

Grudinschi, D. et al. (2015), "Creating value in networks: A value network mapping method for assessing the current and potential value networks in cross-sector collaboration", *Innovation Journal*, Vol. 20/2, pp. 1-27. [27]

Karlsson, C. and P. Warda (2014), "Entrepreneurship and innovation networks", *Small Business Economics*, Vol. 43/2, pp. 393-398. [16]

Kauffeld-Monz, M. and M. Fritsch (2013), "Who Are the Knowledge Brokers in Regional Systems of Innovation? A Multi-Actor Network Analysis", *Regional Studies*, Vol. 47/5, pp. 669-685, http://dx.doi.org/10.1080/00343401003713365. [20]

Nambisan, S. and M. Sawhney (2011), "Orchestration Processes in Network-Centric Innovation: Evidence From the Field", *Academy of Management Perspectives*, Vol. 25/3, pp. 40-57, http://dx.doi.org/10.5465/amp.25.3.zol40. [3]

OECD (2017), "The links between global value chains and global innovation networks: An exploration", *OECD Science, Technology and Industry Policy Papers*, No. 37, OECD Publishing, Paris, https://dx.doi.org/10.1787/76d78fbb-en. [4]

OECD (2016), "Strategic public/private partnerships", in *OECD Science, Technology and Innovation Outlook 2016*, OECD Publishing, Paris, https://dx.doi.org/10.1787/sti_in_outlook-2016-10-en. [10]

OECD (2015), *The Innovation Imperative: Contributing to Productivity, Growth and Well-Being*, OECD Publishing, Paris, https://dx.doi.org/10.1787/9789264239814-en. [1]

OECD (2014), "Cluster policy and smart specialisation", in *OECD Science, Technology and Industry Outlook 2014*, OECD Publishing, Paris, http://dx.doi.org/10.1787/888933151884. [13]

OECD (2013), "Knowledge Networks and Markets", *OECD Science, Technology and Industry Policy Papers*, No. 7, OECD Publishing, Paris, https://dx.doi.org/10.1787/5k44wzw9q5zv-en. [9]

OECD (2012), *Knowledge Networks and Markets in the Life Sciences*, OECD Publishing, Paris, https://dx.doi.org/10.1787/9789264168596-en. [8]

OECD (2010), "Knowledge clusters", in *Measuring Innovation: A New Perspective*, OECD Publishing, Paris, http://dx.doi.org/10.1787/836148814748. [12]

OECD (2009), *Clusters, Innovation and Entrepreneurship*, Local Economic and Employment Development (LEED), OECD Publishing, Paris, https://dx.doi.org/10.1787/9789264044326-en. [11]

OECD (2008), *Open Innovation in Global Networks*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264047693-en. [15]

OECD (2008), *Public-Private Partnerships: In Pursuit of Risk Sharing and Value for Money*, OECD Publishing, Paris, https://dx.doi.org/10.1787/9789264046733-en. [2]

OECD/Eurostat (2018), *Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation (4th Edition) The Measurement of Scientific, Technological and Innovation Activities*, OECD Publishing/Eurostat, Paris/Luxembourg, http://dx.doi.org/10.1787/9789264304604-en. [14]

Perunovic´, Z., M. Christoffersen and S. Fürstenberg (2015), *Unleashing the Potential of Maritime Innovation Networks*, Technical University of Denmark, Copenhagen. [19]

Porter, M. (1998), “Clusters and the New Economics of Competition”, *Harvard Business Review*, Vol. 76/6, pp. 77-90. [24]

Porter, M. and M. Kramer (2011), “Creating Shared Value”, *Harvard Business Review*, Vol. 89/1/2, pp. 62–77. [6]

Ramboll and CORE Advokatfirma (2017), *Analysis of Regulatory Barriers to the Use of Autonomous Ships: Final Report*, Danish Maritime Authority, Korsør, Denmark. [31]

Tyrrell, P. (2007), *Sharing the idea: The emergence of global innovation networks*, Economist Intelligence Unit. [22]

UK Maritime Autonomous Systems Working Group (2017), *Being a Responsible Industry: An Industry Code of Practice for Maritime Autonomous Surface Ships up to 24m in length*, Maritime UK and the Society of Maritime Industries, London, United Kingdom. [32]

# 4. Innovative approaches to evaluate the ocean economy

*Realising the full potential of the ocean demands responsible, sustainable approaches to its economic development. And in order to better manage the ocean, decision-makers need ever more reliable data to inform their actions and evidence-based policies. This requires a good understanding of what the ocean economy represents and how its multifaceted activities may link with the large economy. This chapter four explores new approaches to measuring the ocean economy, notably by highlighting the use of satellite accounts for its twin pillars - ocean-based economic activities and marine ecosystem services - and by examining ways to better measure the benefits that sustained ocean observations provide not only to science, but also to the economy and society more generally.*

## 4.1. Measuring the ocean economy in new ways

A healthy ocean and its resources are indispensable for addressing the multiple challenges that the planet faces in the decades to come, from mitigating climate change to providing proteins to a growing world population. This calls for responsible, sustainable approaches to manage its rapid economic development. In practice, decision-makers will need ever more reliable socioeconomic data to inform their actions and evidence-based policies. This implies a good understanding of what a sustainable ocean economy represents and how its multifaceted activities – including its crucial environmental components – may link with economic statistics, such as those produced through the system of national accounts. This calls for new approaches to measure the ocean economy beyond sectoral approaches.

This chapter:

- Provides a review of current practices in measuring the ocean economy, identifying challenges and possible solutions, both on the ocean economy's economic and environmental components;
- Points to the development of satellite accounts for the ocean as a possible way forward, with lessons learned from different countries and practical advice based on OECD national accounting perspectives;
- Shares findings on how ocean observatories, as scientific infrastructure and technical operational systems, are impacting our societies and the wider economy. Beyond their crucial role in our understanding of the ocean, they will increasingly feed into more evidence-based information via socio-economic indicators, to guide policy-makers' investments and priority-setting.

## 4.2. The starting point for new measurement: finding the right balance between economic activities and the environment

This section provides an overview of the concept of the ocean economy, reviews measurement issues for ocean economy activities, and then introduces key issues related to the valuation of marine ecosystems.

### *4.2.1. The concept of the ocean economy*

There are different terminologies used around the world concerning the economic activities based on the ocean. Terms as diverse as ocean industry, marine economy, marine industry, marine activity, maritime economy, and maritime sector are all employed, and often do not encompass other ocean environmental dimensions, except for the blue economy concept, which is itself very broad (Table 4.1).

The ocean economy is defined by the OECD as the sum of the economic activities of ocean-based industries, together with the assets, goods and services provided by marine ecosystems (OECD, 2016[1]). In other words, the ocean economy encompasses ocean-based industries (such as shipping, fishing, offshore wind, marine biotechnology), but also the natural assets and ecosystem services that the ocean provides (fish, shipping lanes, CO2 absorption and the like).

The two pillars are interdependent in that much activity associated with ocean-based industry is derived from marine ecosystems, while industrial activity often impacts marine ecosystems. This concept of the ocean economy, as an interaction between two pillars with corresponding economic value, is but one motivation for ensuring that both ocean-based industry and marine ecosystems are measured in a consistent and replicable way.

Beyond ocean economy measurement comes the inspiring concept of an environmentally sustainable ocean economy, whereas not only the economic values of the two ocean economy pillars are measured over time, but their cross-over impacts are also identified and monitored. This would involve the development of further related environmental indicators feeding into the broader socio-economic assessment (e.g. tracking pressures, such as marine pollution).

**Table 4.1. Selected definitions of the ocean economy**

| Country | Main substance |
|---|---|
| USA | The economic activity, which is (a) an industry whose definition explicitly ties the activity to the ocean, or (b) which is partially related to the ocean and is located in a shore-adjacent zip code. |
| UK | Those activities which involve working on or in the sea. Also those activities that are involved in the production of goods or the provision of services that will directly contribute to activities on or in the sea. |
| Australia | Ocean–based activity ("Is the ocean resource the main input? Is access to the ocean a significant factor in the activity?"). |
| Ireland | Economic activity which directly or indirectly uses the sea as an input. |
| China | The sum of all kinds of activities associated with the development, utilization and protection of the ocean. |
| Canada | Those industries that are based in Canada's maritime zones and coastal communities adjoining these zones, or are dependent on activities in these areas for their income. |
| New Zealand | The economic activity that takes place in, or uses the marine environment, or produces goods and services necessary for those activities, or makes a direct contribution to the national economy. |
| Japan | Industry exclusively responsible for the development, use and conservation of the ocean. |
| South Korea | The economic activity that takes place in the ocean, which also includes the economic activity, which puts the goods and services into ocean activity and uses the ocean resources as an input. |
| Portugal | Economic activities that take place at sea and others that are not taking place at sea but depend on it, including marine natural capital and non-tradable services off marine ecosystems |

*Source*: Adapted from Seo Park and Kildow (2014[2]) *Rebuilding the Classification System of the Ocean Economy*. http://dx.doi.org/10.15351/2373-8456.1001 and Statistics Portugal and DGMP (2016[3]) *Satellite Account for the Sea – 2010-2013 Methodological Report*.

There are many reasons for measuring the ocean economy, be it at national, regional or global level, and wishing to put a value on ocean economic activity and marine ecosystems. At the international level, the adoption of the Sustainable Development Goal 14 on the ocean, seas and marine resources, as well as the Aichi Biodiversity Targets, provide strong incentives to make progress on qualitative and quantitative measurement (Box 4.1). Tracking the contribution of the ocean economy to the overall economy is likely to raise public awareness of the importance of the ocean, offering higher visibility to both investment opportunities in economic activities and to crucial problems that demand action at many levels (e.g. contributing to the circular economy).

Socioeconomic indicators may be used by policymakers to render more concrete policy action towards the conservation and sustainable use of marine ecosystems. Efforts to measure the ocean economy at the national level have in fact intensified in the past five years in many countries. The results of such efforts are likely to be used in decision-making across a variety of domains, raising further awareness of the ocean economy among citizens, policymakers and industry, ultimately enabling support to be targeted to areas where it is most effective (see Annex 4.B for selected national ocean economy measurement initiatives).

**Box 4.1. Global objectives for measuring the value of the ocean economy**

Of the seventeen Sustainable Development Goals (SDGs) adopted by the United Nations (UN) General Assembly on 25 September 2015, SDG 14 "*Conserve and sustainably use the oceans, seas and marine resources for sustainable development*" is the most relevant for the ocean economy. SDG 14 contains ten individual targets with an emphasis on protecting the marine environment. While SDG 14 represents an aspirational objective, measuring progress towards achieving the individual targets remains a challenge. The UN's list of suggested indicators (UNSD, 2018[4]) does not yet provide the degree of quantification required to track progress towards SDG 14 effectively (Cormier and Elliott, 2017[5]). In a study of datasets and indicators available to the OECD, SDG 14 had only one target covered by at least one indicator, the lowest proportion of all the SDGs (OECD, 2017[6]). A greater emphasis on integrated and ecosystem based management approaches is suggested as a potential policy response to the need to balance marine conservation and resource exploitation (ICSU, 2017[7]). Assessments of marine protected areas (MPAs), for example, have shown that they benefit both the ecosystems under protection *and* increase the value of fish taken from nearby fisheries (Chirico, McClanahan and Eklöf, 2017[8]). Furthermore, integrating MPAs within a fully realised marine spatial plan that manages the use of marine resources more broadly has been shown to improve the effectiveness of no-take zones (Agardy, di Sciara and Christie, 2011[9]). Connecting this with the sustainable development agenda, other marine related studies have focussed on the role of marine spatial planning as a way of enhancing the synergies between the SDGs (Ntona and Morgera, 2018[10]). A fundamental argument of all such analyses is that robust measurements of the economic, social *and* environmental elements of the SDGs are required if the core development objectives are to be achieved. And the system of national accounts has been recognised as a highly organised way of providing the required data (WAVES, 2016[11]). Beyond the SDGs, the potential for national accounting systems to provide useful data for measuring progress towards international objectives was recognised explicitly in the Convention for Biological Diversity's Aichi Biodiversity Targets for 2020. Target 2 states that "by 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems" (CBD, 2011[12]). It is clear therefore that the SDGs represent a further rationale for measuring the ocean economy.

Also on practical governance aspects, interdependency of ocean-based industry and marine ecosystems, combined with increasingly severe threats to the health of the ocean, have led to a growing recognition that management of the ocean should be based on an integrated ecosystem approach (OECD, 2016[1]). Several management strategies have been suggested to achieve this, including Integrated Coastal Zone Management (ICZM), Marine Spatial Planning (MSP) and Marine Protected Areas (MPA). Crucial to each framework is an accurate and extensive information base on ocean economic activity, the state of marine ecosystems, and the interactions between the two. At the heart of such measurements are physical units, such as ecosystem extent measured in terms of area (e.g. $km^2$) and the condition of ecosystems. This need for extensive information links well with advances in monitoring technologies and the practical applications of ocean observations, as seen in Section 4.4. A step further in refining ocean management strategies, would ideally include a regular evaluation of the effectiveness of the policy instruments used, in particular for biodiversity preservation (Karousakis, 2018[13]).

Ultimately, ocean economy data should be comparable across industries, locations and time, from international to national to local levels, and at any point. It should also be consistent theoretically and reflect up-to-date theory on the measurement of economic activity, with no double counting. Finally, it should be replicable with a clearly outlined methodology made publicly available. Such conditions apply to data on both ocean-based industry and marine ecosystems. Their respective economic measurement issues will be explored in the next two sections.

### *4.2.2. Measuring ocean economic activities*

The first stage in many ocean economy measurements is to scope relevant ocean-based industries, so that the types of economic activities conducted can be identified. A second step is to collect data on the chosen sector-specific organisations, via existing official databases and/or industry surveys, and analysing the relevant data afterwards. All these stages can be challenging when examining the ocean economy.

The sectoral scope of the ocean economy varies considerably by country. Some industries may be excluded from the ocean economy in one country but not in another. Moreover, there are significant differences among countries in the delineation of the classifications and categories used. Internationally agreed definitions and statistical terminology for ocean-based activities do not yet exist. A detailed discussion of how measurements of the ocean economy are currently undertaken at the national level is provided in Annex 4.A.

As part of its *Ocean Economy to 2030* foresight exercise, the OECD categorised established and emerging ocean-based activities, bearing in mind overlapping definitions and the existence of highly dynamic emerging activities within traditional ocean-based industries (Table 4.2).

**Table 4.2. Selected ocean-based industries**

| Established industries | Emerging industries |
|---|---|
| Capture fisheries | Marine aquaculture |
| Seafood processing | Deep- and ultra-deep water oil and gas |
| Shipping | Offshore wind energy |
| Ports | Ocean renewable energy |
| Shipbuilding and repair | Marine and seabed mining |
| Offshore oil and gas (shallow water) | Maritime safety and surveillance |
| Marine manufacturing and construction | Marine biotechnology |
| Maritime and coastal tourism | High-tech marine products and services |
| Marine business services | |
| Marine R&D and education | |
| Dredging | |

*Source*: OECD (2016[1]) *The Ocean Economy in 2030*. http://dx.doi.org/10.1787/9789264251724-en

A recent report of Scotland's Marine Economic Statistics provides a detailed illustration of the methodology generally used to measure the ocean economy (Marine Scotland, 2018[14]). The Scottish marine sector is composed of ten selected ocean-based industries, and estimates of the Gross Value Added (GVA), turnover, and employment are provided for each industry (Table 4.3). The data for the majority of the industries are sourced from surveys of Scottish businesses conducted by the UK's Office of National Statistics through the national accounting process. Data on fisheries and aquaculture are taken from detailed surveys conducted by Marine Scotland in order to meet standards for data used in support of the European Union's Common Fisheries Policy.

**Table 4.3. Measurement of the ocean economy of Scotland**

Gross value added, turnover and employment in ten Scottish ocean-based industries in 2016

| Ocean-based industry | Gross value added (GBP millions) | Turnover (GBP millions) | Employment (head count thousands) |
|---|---|---|---|
| Fishing | 296 | 571 | 4.8 |
| Aquaculture | 216 | 797 | 2.3 |
| Support for oil & gas | 1,631 | 4,483 | 19.7 |
| Seafood processing | 391 | 1,602 | 7.6 |
| Shipbuilding | 202 | 1,001 | 7 |
| Construction and water transport services | 422 | 672 | 4 |
| Passenger water transport | 63 | 168 | 1.4 |
| Freight water transport | 65 | 178 | 0.5 |
| Renting and leasing of water transport equipment | 8 | 14 | 0.1 |
| Marine Tourism | 554 | 1,031 | 27.9 |
| TOTAL | 3,849 | 10,517 | 75.3 |

*Note*: Data for most industries are sourced from the Scottish Annual Business Survey (SABS) conducted by the UK's Office of National Statistics. Data for fishing and aquaculture is sourced from Marine Scotland statistics.
*Source*: Marine Scotland (2018[14]) *Scotland's Marine Economic Statistics*.

Measurements of the ocean economy tend to focus on the direct impacts associated with ocean-based industry. However, ocean-based industries may also have broader economic impacts that could be of interest to policymakers.

Indirect impacts may be generated when ocean-based industries demand and/or supply goods and services from and/or to businesses working in related industries. Furthermore, policymakers may be interested in understanding the impact that employees of ocean-based industries have when consuming goods and services from all other areas of the economy through their normal household spending patterns (so called "induced" impacts).

The process of understanding the broader economic impacts of a sector of the economy is known as economic impact assessment. An aggregation of the direct, indirect and induced impacts reveals an estimation of the total economic contribution of ocean-based industry to the overall economy. However, estimating indirect and induced impacts is a complex endeavour and such analysis remains constrained by issues of consistency and comparability. Such difficulties are compounded by the lack of appropriate industrial codes and subsequent coverage of the ocean economy in national datasets.

Table 4.4 displays the results of a recent economic impact assessment of ocean-based industries in the UK. The estimates are derived from UK national accounts data, government and industry led surveys, and industry reports. Assessments of this sort provide an informative snapshot of the value of ocean-based industry to the overall economy. A quick glance reveals that the overall impact of the UK maritime sector in 2015 generated £ 37.4 billion in aggregate global value added and employed 957 300 people, for example. One constraint is that analysis of this sort remains largely incomparable with other national datasets.

**Table 4.4. Economic impact of the UK maritime sector in 2015**

| | Direct impact | Indirect impact | Induced impact | Aggregate impact |
|---|---|---|---|---|
| Turnover | 40,038 | 29,564 | 22,289 | 91,891 |
| Gross value-added | 14,465 | 12,438 | 10,501 | 37,404 |
| Employment* | 185.7 | 434.8 | 336.8 | 957.3 |
| Compensation of employees | 7,295 | 8,660 | 5,050 | 21,004 |

*Note*: The industries measured are shipping, ports, marine and maritime business sector, in GBP millions and thousands of FTE.
*Source*: Cebr (2017[15]) *The economic contribution of the UK maritime sector*.

### *4.2.3. Valuing marine ecosystems*

Expressing the value of marine ecosystems in monetary terms, by converting robust biophysical assessments on the marine environment to a metric that is common with other economic measures, aims to raise awareness and to support better decision-making (e.g. see WWF efforts (2015[16]) ). Valuing marine ecosystems in a transparent and evidence-based manner may contribute to put ecosystems on a more comparable level with economic data on industry.

This includes environmental impact assessments (EIAs) or ecosystem-based management approaches, as they attempt to understand the impact of particular decisions on the marine environment, and which are likely to be made more effective, if economic measurements can be added. Valuation has been indeed shown to assist with increased awareness, improved decision making, and targeted policy responses at least in certain aspects. In Europe, for example, small-scale sustainable management strategies have been achieved through applications of accounting for the environment to maritime spatial planning (Picone et al., 2017[17]) and Marine Protected Areas (Franzese et al., 2015[18]; Franzese et al., 2017[19]). Still, converting environmental data to monetary values has attracted criticism (McCauley, 2006[20]; Schröter et al., 2014[21]), not least due to the complexity associated with understanding ecosystems sufficiently enough to track their impact on human wellbeing accurately. Valuation is therefore only one of the elements contributing to analysis of the interactions between the pillars of the ocean economy in a timely manner (Vassallo et al., 2017[22]).

#### *The methodological context for valuing marine ecosystems*

Ecosystems have been studied by natural scientists since the 1940s (Lindeman, 1942[23]), but it wasn't until the late 1990s that the links between ecosystems and human wellbeing were formalised for the first time (Daily, 1997[24]; Costanza et al., 1997[25]). Several years later, the Millennium Ecosystem Assessment (MA) developed a global scale framework for assessing the avenues through which ecosystems contribute to wellbeing (MA, 2005[26]). The MA classifies ecosystems according to differences in their biological, climatic and social characteristics (Box 4.2). From the ten ecosystem types listed, two classifications are most relevant for the ocean economy: marine ecosystems (more than 50 metres below average sea level) and coastal ecosystems (between 50 metres below and 50 metres above average sea level, or estuaries 100 kilometres inland).

**Box 4.2. The conceptualisation of ecosystem service values through the Millennium Ecosystem Assessment**

The Millennium Ecosystem Assessment conceptualises ecosystem services as the benefits – either "goods" or "services", both tangible and intangible – accruing to humans from the properties of a functioning ecosystem. Ecosystem services are further classified according to whether they provide provisioning, regulating, cultural or supporting services. The first three services impact upon humans directly through, for example, the food we eat (provisioning), the air we breathe (regulating) and the seascapes we find beautiful (cultural). Supporting services impact humans indirectly and are so-called because they provide the conditions through which the other ecosystem services are produced.

The existence of a broad set of economic values associated with ecosystem services is captured through the concept of total economic value (TEV), which is disaggregated according to four key constituents:

- Direct use value: Derived from direct human uses of ecosystems, either for consumptive (reducing quantity available e.g. eating fish) or non-consumptive (no reduction in quantity e.g. enjoying a swim in the sea) purposes. The direct value of many provisioning services, such as captured fish stocks for example, is observable, because products are traded through markets and a market price is recorded. Provisioning services represent only a subset of ecosystem services leaving many regulating and cultural services unpriced through market mechanisms.
- Indirect use value: Derived from indirect human uses of ecosystems when their functions produce positive externalities or act as intermediate factors in production (e.g. naturally clean seawater in aquaculture fisheries).
- Option value: Reflects the importance humans place on retaining the option of benefiting from ecosystem services in the future, or to insure against potential future losses, despite not using them today. For example, by valuing the ocean's potential for supplying future medicines that are yet to be discovered today.
- Non-use value: Associated with knowing that ecosystems exist despite never using their services directly. Generally, three non-use values are considered; bequest value (knowing that the ecosystem will exist for future generations), altruistic value (knowing that another person will benefit), and existence value (simply knowing that it exists).

Ecosystem services valuation is a process by which these aspects are identified, quantified and valued monetarily. As only a fraction of TEV is observable through markets, a large component of ecosystem services valuation is concerned with non-market valuation methods. Non-market valuations methodologies are not detailed in this chapter, but many publications explain the types of non-market valuation methodologies available and the circumstances in which they are appropriately applied (Hanley and Barbier, 2010[27]).

The qualitative approach has not been ineffective in communicating the value of ecosystem services to policymakers; the benefits associated with healthy ocean ecosystems are increasingly recognised globally and are included in a number of international arrangements such as the United Nations Sustainable Development Goal 14, as seen earlier (UN, 2015[28]). However, recognising the value of marine ecosystem services qualitatively does not enable the interactions of both pillars of the ocean economy to be analysed using the same unit of measurement. Since the Millennium Ecosystem Assessment, much research on the valuation of marine ecosystems has been conducted, and different quantitative and qualitative methodologies are available for doing so (OECD, 2018[29]).

A database of non-market valuations for marine and coastal ecosystems is kept by the National Ocean Economic Programme (NOEP) at the Middlebury Institute of International Studies at Monterey in the USA (NOEP, 2017[30]). Torres and Hanley (2016[31]) used the database to survey valuation literature published between 2000 and 2015 (Table 4.5). The majority of the papers reviewed estimated values associated with coastal, rather than marine, ecosystem services. The authors also note a focus on valuing cultural services with a particular emphasis on recreation. This is perhaps due to greater "familiarity" among valuation researchers of coastal ecosystems and the recreational opportunities associated with them.

Despite the growing body of work attempting to value ecosystem services robustly, there is some evidence to suggest that doubts surrounding the validity of ecosystem service valuations in general have resulted in relatively limited uptake in policymaking (Rivero and Villasante, 2016[32]). This observation appears to be true also of marine and coastal policy (Torres and Hanley, 2017[33]), where, despite recent advances in methods to quantify marine ecosystem services, considerable additional research is required before data is available on the full extent of their value (Pendleton et al., 2016[34]). In light of such uncertainties, several attempts have been made to assess ecosystem services and calculate their value in a policy setting and at the national level. Some of these efforts are reviewed below.

**Table 4.5. Number of papers on marine and coastal ecosystem service valuation published in peer-reviewed journals (2000-2015)**

| Ecosystem type | Number of papers |
|---|---|
| **Coastal ecosystems** | **100** |
| Wetlands | 30 |
| Beaches | 40 |
| Coastal areas | 8 |
| Inland and transitional waters | 22 |
| **Marine ecosystems** | **86** |
| Coastal waters | 37 |
| Coral reefs | 11 |
| Deep sea | 2 |
| Marine protected areas | 36 |
| **Both coastal and marine ecosystems** | **10** |
| **Total** | **196** |

*Source*: Torres and Hanley (2017[33]) *Communicating research on the economic valuation of coastal and marine ecosystem services*. http://dx.doi.org/10.1016/J.MARPOL.2016.10.017

### *National level marine ecosystem assessments*

Since the Millennium Ecosystem Assessment (MA) provided a basic framework for assessing ecosystem services and their value, several additional approaches have become available. These include The Economics of Ecosystems and Biodiversity (TEEB) (TEEB, 2010[35]) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Díaz et al., 2015[36]). Although each initiative has a slightly different focus, all provide conceptual frameworks for understanding ecosystems and their contribution to human wellbeing, including through the valuation of ecosystem services.

Relying on such approaches and inspired by global assessments such as the MA, several countries have begun the process of understanding their ecosystem services better through national ecosystem assessments. In Europe, for example, knowledge of ecosystems and their services in Europe has benefited from the *European Union Biodiversity Strategy 2020*. Target 2 Action 5 of the strategy states that "Member States, with the assistance of the Commission, will map and assess the state of ecosystems and their services in their national territory by 2014, assess the economic value of such services, and promote the integration of these values into accounting and reporting systems at EU and national level by 2020".

The latest national level assessment in response was completed in 2018 by France. The large study entitled "évaluation française des écosystèmes et des services écosystémiques" (EFESE) provides assessments of six ecosystem types, including marine and coastal ecosystems (Government of France, 2018[37]).

**Table 4.6. National ecosystem assessments conducted by EU Member States before 2016 and objectives related to the valuation of ecosystem services**

| Country | Year | Name | Objective | |
|---|---|---|---|---|
| | | | Valuation | Valuation methods |
| Portugal | 2009 | Ecosystems and Human Well-Being: Portuguese Assessment of the Millennium Ecosystem Assessment | | |
| United Kingdom | 2011 | UK National Ecosystem Assessment | X | |
| Spain | 2012<br>2014 | Ecosystems and Biodiversity for Human Well-Being: Spanish National Ecosystem Assessment | X | |
| Norway | 2013 | Nature's Benefits: On the Values of Ecosystem Services | | X |
| Flanders | 2014 | Nature Report: State and Trend of Ecosystems and Ecosystem Services in Flanders | X | |
| Netherlands | 2014 | Indicator's for nature's services | | X |
| Finland | 2015 | Towards a Sustainable and Genuinely Green Economy: The Value and Social Significance of Ecosystem Services in Finland (TEEB for Finland) | X | X |
| Germany | 2015 | Recommendation for the development of a national set of indicators for ecosystem services | | X |

*Source*: Adapted from Schröter et al. (2016[38]) *National Ecosystem Assessments in Europe: A Review*. http://dx.doi.org/10.1093/biosci/biw101.

National ecosystem assessments are complex exercises, with each assessment requiring substantial resources and tens, if not hundreds, of authors. The methodology adopted depends on the specific objectives and, often, a range of frameworks will be used (Table 4.6). Valuing ecosystem services monetarily is not always a priority. Of the eight national ecosystem assessments carried out by EU Member States before 2016, four included the "social and economic valuation of ecosystem services" among their primary objectives and another four aimed to "explore and generate adapted concepts, methods and indicators to value ecosystem services" (Schröter et al., 2016[38]). However, national ecosystem assessments play an important role in communicating the benefits of ecosystem services and valuation can be a useful component of this. There is some evidence to suggest that valuations conducted through assessments have influenced policymaking at local, national, regional and international levels (Wilson et al., 2014[39]). However, the focus of many assessments carried out so far, with the exception of those such as the French EFESE, is skewed towards terrestrial rather than marine ecosystems (Brouwer et al., 2013[40]). This suggests a gap in national level knowledge of marine ecosystem services and their value that in certain cases has been filled through alternative structures.

An example of national level estimates of ecosystem services in a context other than a national ecosystem assessment is provided by Norton, Hynes and Boyd (2018[41]). Table 4.7 details the results of an assessment of Irish marine ecosystem service values carried out on behalf of the Irish Environmental Protection Agency. In order to produce national level estimates with the time and resources available, the authors have used mainly secondary sources to arrive at their estimations. Both market and non-market valuation methodologies have been used. The list of ecosystem services does not exhaust those that flow from the marine environment in Ireland, however, with many cultural values having been excluded.

**Table 4.7. Values of Irish coastal and marine ecosystem service benefits**

| Ecosystem Service (ES) | Value of ES per annum (EUR) |
|---|---|
| Offshore capture fisheries | 472 542 000 |
| Inshore capture fisheries | 42 113 000 |
| Aquaculture | 148 769 000 |
| Algae/ Seaweed harvesting | 3 914 000 |
| Waste services | 316 767 000 |
| Coastal defence | 11 500 000 |
| Climate regulation | 818 700 000 |
| Recreational services | 1 683 590 000 |
| Scientific and educational services | 11 500 000 |
| Aesthetic services | 68 000 000 |

*Source*: Norton, Hynes and Boyd (2018[41]) *Valuing Ireland's Coastal, Marine and Estuarine Ecosystem Services*.

### *4.2.4. Summarising the challenges*

Although recent progress has occurred, some important challenges remain in producing robust measurements of the ocean economy. Many countries report difficulties in identifying relevant industries, leading to problems in disaggregating data from broader sources. A lack of specific ocean-based industry classifications has left interested parties with little choice but to estimate values using sub-optimal methods. This has resulted in approximations that are unlikely to be incomparable internationally. What's more, ad-hoc surveys conducted to fill the gaps have led to issues with time and other data inconsistencies. Perhaps on of the most important challenge in achieving robust measurements is a willingness to fund long term data collection, particularly through a central statistical authority. Despite these challenges:

- Measuring ocean-based industries consistently is far from insurmountable given decades of experience of valuing other forms of economic activity (including those that take place in the ocean economy).
- Measuring the ecosystem aspect of the ocean-economy, on the other hand, runs in parallel with efforts to fundamentally change the way nations measure their economies through programmes concerned with natural capital accounting. Despite the best efforts of those involved in valuing ecosystem services, it remains a niche subject with relatively little exposure to policymakers – particularly in the marine environment. This could explain why there are still relatively few examples of national ecosystem valuation studies for marine and

coastal areas. Even less attention has been paid to the valuation of ecosystem services in the deep sea. If ocean economy satellite accounts that measure both industry and the environment are to be realized, then long term funding of marine ecosystem assessments must also be achieved.

- Beyond national ecosystem assessments, the valuation of marine ecosystem services has tended to focus on assessing the welfare impacts associated with changing ecosystems. This has been driven by legislation that requires the assessment of the environmental costs associated with development and/or by academic exploration. While it is often possible to assess at least some of the marine ecosystem services within a country's exclusive economic zone (EEZ), their complexity makes developing a comprehensive assessment difficult and resource intensive. For this and many other reasons explored in this chapter, assessments tend to restrict their scope either geographically and/or by the number and types of ecosystem service studied. Frequently a small number of marine ecosystem services are selected from a specific part of a country's waters.

## 4.3. Linking the ocean economy with the system of national accounts

There is a demand, from the public and private sectors alike, for a structured and internationally comparable approach to measuring the ocean economy. Building on lessons learned in other domains of economic activities, where links to the national accounts framework have contributed to ensure the emergence of improved socioeconomic data that are comparable, consistent and replicable over time, some steps can be taken for better ocean economy measurement. Examples include dedicated satellite accounts set up for special purposes such as monitoring healthcare expenditure, the state of the environment or even the development of tourism, that have been set up in many countries of the world.

The next sections introduce the system of national accounts and present arguments in favour of collecting data on the ocean economy, through satellite accounts, linking with other past and ongoing efforts in academia and national administrations (for example, Colgan (2007[42]), Kildow and McIlgorm (2010[43]) and Mcilgorm (2016[44])).

### *4.3.1. What are national accounts?*

National accounts collect data on the economic activity of a country in a systematic manner, and are the primary means by which economies are described. The core national accounts contain economic statistics generally compiled by institutions appointed by national governments such as national statistical offices and central banks

There are two frameworks setting international standards for the compilation of national accounts. The 2008 System of National Accounts (2008 SNA) is a globally recognised reference manual, published jointly by the United Nations, the European Commission, the International Monetary Fund, the OECD and the World Bank. The 2008 SNA guides national statistical offices towards the creation of a national accounting database and provides a framework for reporting economic statistics. In Europe, European Union member countries are legally obligated to implement the European System of National Accounts (ESA 2010), which is, with a few minor exceptions, fully compatible with the global version.

When compiled for successive time periods, the national accounts provide a flow of information indicating the behaviour of economic agents. Ideally, the data used to compile the national accounts are collected regularly (at least annually). The more regular the data are collected, the more able the national accounts are to provide up-to-date time-series of observations of economic performance. Such time-series are used in economic policy analysis and form the basis for economic forecasting. The data collected can also contribute to estimates of causal relationships through econometric modelling; a practise that is used to inform policymaking in both public and private organisations, and at all levels of government (see Box 4.3 for examples). Finally, national accounts provide a data resource for comparing economic performance across countries using a common standard (supposing compared countries meet the 2008 SNA framework).

**Box 4.3. A glance at Supply and Use Tables (SUTs) and Input-Output (I-O) tables in the ocean economy**

In order to examine at a glance the production and use of goods and services in a given country or region, by industry branches and product groups, two linked statistical tables are used in national accounting: the Supply and Use Tables (SUTs) and the derived Input-Output (I-O) tables.

Supply and Use Tables are fundamental to ensuring that data collected from a wide range of sources are coherent, so that accurate measurements of Gross domestic product (GDP) can be achieved (OECD, 2017[45]). The Supply Table contains, for each product, the total supplied calculated by recording domestic output by industry plus imports. The Use Table collects, for each product, total demand or use by recording intermediate consumption (products used as inputs in the production of other goods and services) by industry, final consumption (by households and government), gross fixed capital formation or investments (including changes in inventories) and exports. In both the Supply and the Use Table, the columns are ordered by industries as classified through ISIC and the rows by products, labelled according to digit codes through systems such as the UN's Central Product Classification (CPC).

The interconnections between industries are then made explicit by the Input-Output (I-O) tables. IO tables are created using SUTs, so if an industry doesn't appear in the SUTs, as most ocean-based industries do not, then it won't appear in the IO tables. Furthermore, IO tables are not always produced by national statistical offices. Often then, analysts have to create their own, leading to problems of incomparability and inconsistency. Still these tables have already been used as the basis of measurements of the indirect and induced impacts of ocean-based industry by many countries. There are several ways to do this, including through the estimation of I-O "multipliers" and other, more complex econometric modelling techniques.

As recent illustrations for the ocean economy, Grealis et al. (2017[46]) estimate the direct and indirect economic impacts of meeting targets set for aquaculture expansion in Ireland using IO analysis. Lee and Yoo (2014[47]) explore the interdependency between capture fisheries and aquaculture through IO analysis and find some interesting results, such as aquaculture having a larger impact on employment per dollar invested than capture fisheries.

The 2008 SNA is designed for, amongst others, the measurement of economic activity as defined by key indicators such as GDP, value added and employment. As a contribution to such measures, the flow of income resulting from harvesting an environmental asset is included. This means that the standard SNA framework counts environmental commodities such as captured fish stocks or extracted energy resources. But these commodities are only two examples of the goods and services that flow from the marine environment. In aggregate, environmental flows represent an important proportion of many ocean economies. What's more, the income generated through the exploitation of an environmental resource does not account for the depletion or degradation of environmental resources that are required to "produce" them. In order to account for environmental stocks and flows more broadly, the basic structure of the SNA must be augmented to include wider effects such as the impact of economic activity on environmental assets and the value of ecosystem services.

In this context, a feature of national accounting systems is that they can be altered or extended to include specific themes that are of particular interest to a country. Accounts created in this manner are known as satellite accounts. Satellite accounts offer a robust framework for monitoring and analysing aspects of a country's economy not shown in detail in the core national accounts. In order to maintain coherency, the formation of a satellite account would typically adopt the basic concepts and accounting rules of the core national accounting system.

**Box 4.4. OECD Workshop: New Approaches to Evaluating the Ocean Economy**

As part of its *Innovation and the Ocean Economy work programme*, the OECD STI Ocean Economy Group, in conjunction with the Centre for the Blue Economy (CBE) at the Middlebury Institute of International Studies in Monterey, USA, organised a workshop entitled "New Approaches to Evaluating the Ocean Economy". Held on 22 and 23 November 2017 at the OECD Headquarters in Paris, the objective of the workshop was to share national and international perspectives on progress made in measuring the ocean economy. Some 60 representatives from government, industry, academia and international organisations attended the event. The meeting represented the third in a series of colloquia on the oceans in national accounts organised by the CBE. The first took place in California, USA, in October 2015 and the second in Tianjin, China, in November 2016. The methodologies presented and constraints discussed are briefly presented in Annex 4.A below.

Satellite accounts can conceivably be compiled for any sector in which there is sufficient interest. Common examples of satellite accounts within the OECD are related to health, tourism and environmental issues. Wider examples of satellite accounts abound. France, for example, compiles satellite accounts for housing, health, social welfare, national defence, education, research and the environment (OECD, 2014[48]). Each account is compiled by a relevant agency in contact with the national statistical system. The health accounts are the responsibility of the statistical service of the Health Ministry, while the French Institute for the Environment compiles the environmental-economic accounts. The creation of a satellite account for the ocean economy could be managed along these lines, with an agency relevant to the ocean working alongside the statistical authority.

Broadly, there are two types of satellite accounts.

- "*Key sector account"*. In the 2008 SNA, industries are presented according to the order they appear in their respective classifications. However, alternative aggregations are possible for a group of industries operating within a sector of particular interest. One could be interested in understanding the economic performance of the high-tech manufacturing sector, for example, and aggregate data only for a range of industries in which high-tech manufacturing is used. Normally this exercise would only be carried out for sectors of particular importance to an individual economy. This type of satellite account is therefore termed a "key sector account". The data for the key sector can then be evaluated in the context of the broader national accounts which contain the aggregated data for all other industries. An ocean economy key sector account would be possible were it not for the fact that many ocean-based activities are not recognised in current industrial classifications. An ocean key sector account built upon the present classifications would therefore miss the economic contribution of a number of important activities, hence the present need to adopt a more flexible type of satellite account such as the one presented below.

- "*Broader account including benefits that do not appear in the SNA*": the international statistical community has developed further guidelines for accounting for impacts, goods and services that would not normally be counted through the core national accounts. This type of satellite account allows for greater flexibility than the "key-sector account" to include important data that would otherwise be missing from measurements of the total economy – such as data collected outside of the usual surveys used for the national accounts and environmental information. For accounts measuring environmental stocks and flows, both in physical and monetary terms, the System of Environmental-Economic Accounting 2012 - Central Framework (SEEA Central Framework) is the internationally accepted standard. The System of Environmental-Economic Accounting – Experimental Ecosystem Accounting is a framework for accounting for the concept of ecosystem services, not yet accepted as an international standard due to its experimental status.

### *4.3.2. A focus on the accounting approach for measuring the marine environment*

The System of Environmental-Economic Accounting (SEEA) Central Framework was adopted as an international standard through the United Nations Statistical Commission in March 2012 and outlines the key accounting requirements for official environmental-economic accounts.

Whereas flows from environmental stocks appear in the core 2008 System of National Accounts as income generated through the production process (e.g. when fish is captured and sold), the SEEA Central Framework extends the accounting framework to include environmental issues that are biophysical in nature (Table 4.8). The SEEA Central Framework provides guidelines for developing such accounts, while adhering to the principles outlined in the 2008 System of National Accounts and thus maintaining compatibility. There are still few examples of accounts that attempt to capture the full range of stocks and flows associated with the marine environment. However, an example of an environmental-economic account for fish stocks present in New Zealand fishing grounds is outlined below (Box 4.5).

**Table 4.8. Accounts and environmental assets detailed in the SEEA Central Framework**

| Account type | Unit of measurement | Tables |
|---|---|---|
| Physical flows of natural inputs, products and residuals) | Physical only | Energy |
| | | Materials |
| | | Freshwater |
| | | Air emissions |
| | | Waste water |
| | | Solid waste |
| Stock of environmental assets (living and non-living) | Physical and monetary | Mineral and energy resources |
| | | Soil resources |
| | | Timber resources |
| | | Freshwater resources |
| | | Land |
| Economic activity associated with the environment | Monetary only | Environmental protection expenditure |
| | | Resource management expenditure |
| | | Production of environmental goods and services |
| | | Environmental taxes and subsidies |

*Source*: UN SEEA (2012[49]) *System of Environmental-Economic Accounting 2012: Central Framework*.

The focus of the SEEA Central Framework is on the stock of individual environmental assets and the material that flows from them (as inputs) and towards them (as residuals) in economic activity. As such, it treats each individual environmental asset as if it were separate to the others. In reality, environmental assets within similar spatial areas interact through ecosystems. Ecosystem services, which only exist if individual environmental assets function in combination, provide many benefits to humans. Much like individual environmental assets, ecosystems can be degraded by economic activity, restricting their ability to produce ecosystem services.

In order to account for the contribution of ecosystems to human wellbeing, an extension to the SEEA Central Framework has been developed – SEEA Experimental Ecosystem Accounting (SEEA-EEA). The SEEA-EEA framework details how ecosystem assets and their provisioning, regulating and cultural services can be accounted for in both physical and monetary terms. As many of their services are not exchanged through markets, observable values tend not to exist. Information in physical terms is therefore required to estimate the value of either in monetary terms. A marine area may provide provisioning services through aquaculture while being used for recreational services at the same time, for example (Box 4.5).

**Box 4.5. Example of System of Environmental-Economic Accounts for the marine environment: New Zealand's accounts for fish and the marine economy**

The national statistical office of New Zealand, Stats NZ, released in 2018 a series of environmental-economic accounts containing data to 2016 (Stats NZ, 2018[50]). Accounts detailed in the release include physical stocks of land cover, timber and water, physical flows of greenhouse gas emissions, and environmental taxes and protection expenditure. The release also includes accounts detailing the monetary value of New Zealand's fish stocks and estimates of the marine economy in GDP and employment terms.

The marine economy is defined by New Zealand as the sum of the economic activities that take place in or use the marine environment, or produce goods and services necessary for those activities, and make a direct contribution to the national economy. The "environmental activity" account measuring the marine economy details the GDP and employment generated by nine ocean-based industries: offshore minerals, fisheries and aquaculture, shipping, government and defence, marine tourism and recreation, marine services, research and education, manufacturing, and marine construction. The data developed through the marine economy account suggest a number of policy-relevant insights such as "New Zealand's marine economy contributed NZD 3.6 billion (1.4 percent) to the national economy as measured by GDP ($255 billion). While this value represents an increase of nearly 33 percent in GDP over the period 2007 16, the proportion of GDP remained steady at about 2 percent, with a small decrease in recent years".

The accompanying outline of *Sources and methods* published by Stats NZ describes many of the same challenges outlined in this chapter (Stats NZ, 2018[51]). The fish account, on the other hand, uses the System of Environmental-Economic Accounts (SEEA) Central Framework as its guiding reference. The fish account shows trends in the total asset value of New Zealand's commercial, non-aquaculture produced, fish resources broken down by individual species. The monetary estimations are based on economic data recorded through the fishing quota system. The fish account reveals that the total value of New Zealand's commercial fish resources was NZD 7.2 billion in 2016 with the top 20 species contributing 91 percent of this value.

Several classification systems have been developed to identify, label and differentiate between the ranges of ecosystem services generated by an ecosystem asset. Some of these have been already mentioned in the previous section, and include: the Millennium Ecosystem Assessment (MA, 2005[26]), The Economics of Ecosystems and Biobiversity (TEEB) (TEEB, 2010[52]) and the Common International Classification for Ecosystem Services (CICES) (Haines-Young and Potschin, 2018[53]). The CICES system was developed particularly to provide ecosystem classifications for the SEEA Experimental Ecosystem Accounting guidelines and is the most appropriate classification system for accounting purposes. It has also been applied more broadly to areas not necessarily concerned with ecosystem accounting (Haines-Young, Potschin-Young and Czúcz, 2018[54]). That said, the classification of ecosystem services is particularly complicated and is likely to require further study before double-counting is eliminated (La Notte et al., 2017[55]). Finally, CICES will likely require further refinement before it is entirely suitable for the classification of marine ecosystem services (Haines-Young, Potschin-Young and Czúcz, 2018[54]; Liquete et al., 2013[56]), particularly in the deep-sea (Armstrong et al., 2012[57]).

More broadly, the existing accounts detailed in the SEEA Central Framework and Experimental Ecosystem Accounting (EEA) are suitable for many terrestrial ecosystems and some freshwater bodies, but do not cover marine ecosystems particularly well. A key issue in this regard is how to treat the spatial boundaries of marine ecosystems in order to identify the particular ecosystem services flowing from them. The focus of the current SEEA guidelines is, however, on the measurement of terrestrial ecosystems, where non-living organisms tend not to move and the majority of living organisms do not move very far (with the exception of migrating birds). Yet the interconnectedness of the ocean allows seawater and its contents to move considerably large distances. Furthermore, the ocean is much larger than the land, contains diverse ecosystems in every part of the water column – unlike the land where only a few living creatures are capable of flying beyond the surface – and is not very well mapped, within and beyond EEZs. Marine ecosystems therefore do not have rigid spatial boundaries in the same way as terrestrial ecosystems.

**Box 4.6. Example of Experimental-Ecosystem Accounting for the marine environment: Australia's experimental ecosystem account for the Great Barrier Reef**

Alongside the production of statistics for economic activity and other related subjects, the Australian Bureau of Statistics (ABS) has produced environmental-economic accounts of various types for at least twenty years. One area of focus for these efforts is the Great Barrier Reef, the largest coral reef ecosystem on Earth and, perhaps, the most famous of the world's marine ecosystems. Recently, the ABS has begun to connect a growing body of scientific work undertaken in the Great Barrier Reef Marine Park to environmental and macroeconomic indicators. The result is an experimental ecosystem account for the Great Barrier Reef consistent with the System of Environmental-Economic Accounts – Experimental Ecosystem Accounting (SEEA-EEA) (ABS, 2015[58]; ABS, 2017[59]).

The ABS uses the SEEA to produce accounts that measureme environmental assets, net wealth, income and resource depletion; the environmental intensity of resource use; and, production, employment and expenditure relating to environmental activities. To date, two versions of the experimental ecosystem account have been produced. In April 2015, the ABS published an "Information Paper: An Experimental Ecosystem Account for the Great Barrier Reef Region". A second publication in 2017 extends the scope of the 2015 paper to inform a wider range of environmental-economic issues. These issues were selected to increase the public value of statistics; to demonstrably improve policy-makers' ability to detect economic problems emerging from changes to environmental assets; and, to demonstrate the ongoing ability of SEEA-compliant environmental-economic (including ecosystem) accounts to inform policy programmes. The key benefit in this regard being that the SEEA framework ensures consistency with the core national accounts detailing economic activity in accordance with the UN's System of National Accounts (2008 SNA).

Despite such difficulties, progress is being made. The global ocean is being mapped according to distinct ecosystem units for the first time, showing, for example, that is possible to separate ocean space according to physical and chemical properties at large scales (Sayre et al., 2017[60]). Furthermore, efforts on multiple fronts have begun to reduce the gap between coverage of terrestrial and marine ecosystems in accounting circles. The current revision process for the SEEA EEA is in part focussed on delivering guidance for the description and classification of marine ecosystems (UN SEEA, 2018[61]). At a regional level, the United Nations Economic and Social Commission of Asia and the Pacific (ESCAP) has contributed towards encouraging the international statistical community to progress on the statistical standards necessary for marine ecosystem accounting (UN SEEA, 2018[62]). These initiatives will contribute significantly towards the development of accounts measuring marine ecosystems.

### *4.3.3. Moving forward with ocean economy satellite accounts*

Satellite accounts provide an organising framework for monitoring and presenting economic data that are consistent with the broader macroeconomic framework, between sectors in an economy, and over time (van de Ven, 2017[63]). Satellite accounts also enable a wide range of informative analyses for understanding the impact and contributions of a sector on all others.

The adoption of satellite accounts for the ocean economy that adhere to the appropriate accounting guidelines would provide an organised method to tackle the challenges mentioned above. Furthermore, the existence of international guidelines such as the 2008 System of National Accounts and the System of Environmental-Economic Accounting – Central Framework and extensions imply that internationally comparable measurements of the value of the ocean economy are achievable. Should a critical mass of countries develop ocean economy satellite accounts then international governance of the ocean is likely to be enhanced.

There are already good examples of national level efforts to develop ocean economy satellite accounts to be learned from. The Portuguese Satellite Account for the Seas represents an initial attempt at developing an ocean-based industry account; meeting international guidelines for national accounts more broadly and with responsibility shared between ocean experts and the national statistical office (Box 4.7). Of use to the international community, the issues met during the development of the account have been published in a methodological report (Portugal and DGMP, 2016[3]). The New Zealand marine economy “environmental activity” account and accompanying methodological note are helpful examples (Stats NZ, 2018[50]; Stats NZ, 2018[51]). So too is the Economics: National Ocean Watch database from the United States of America, which is publicly available and simple to use for a wide audience (NOAA, 2018[64]).

**Box 4.7. Example of a satellite account for the ocean economy: Portugal's Satellite Account for the Sea**

Perhaps the most comprehensive attempt at producing a satellite account for ocean-based industry was completed by the Portuguese Government in May 2016 (Portugal and DGMP, 2016[31]). The pilot-project for a "Satellite Account for the Sea (SAS)" required collaboration between the national statistics office, Statistics Portugal (INE), and the Directorate-General for Maritime Policy (DGMP). The collaboration allowed for the statistical competences of Statistics Portugal to be aligned with DGMP's knowledge of the ocean economy. The SAS represents the first attempt to measure the ocean economy through the national accounts of Portugal, and is the only example of a formal satellite account for the ocean economy currently available.

The creation of an SAS was considered the most appropriate instrument to estimate the contribution of the ocean economy to the whole economy. The SAS was compiled using the same accounting principles as adopted in the core national accounts (activities, classifications, criterion of residence and accounting rules), which meet the standards set by the European System of Accounts (ESA 2010) and is therefore compatible with the 2008 SNA. The objective of the SAS is to collect economic data that will:

- Support decision making regarding the coordination of public policies for the ocean;
- Monitor the National Ocean Strategy 2013-2020 (NOS 2013-2020) in its economic component; and,
- Provide reliable information for the Integrated Maritime Policy (IMP) and other processes where data for the Ocean Economy is required.

After a value-chain analysis of the Portuguese ocean economy, nine groups of activities were defined: fisheries, aquaculture, processing, wholesale and retail of products; non-living resources; ports, transport and logistics; recreations, sports, culture and tourism; shipbuilding, maintenance and repair; maritime equipment; infrastructures and maritime works; maritime services; and, new uses and resources of the ocean. A Supply-Use table was then built for the years 2010-2013, producing a number of variables including output, GVA, compensation of employees and employment.

The SAS results suggest the Portuguese ocean economy consists of around 60,000 establishments. On average between 2010 and 2013, their activity represented 3.1% of GVA and 3.6% of employment in the total economy. The average compensation of employees exceeded the national average by roughly 3%. While the national economy recorded a cumulative reduction in GVA of 5.4% and employment by 10%, the SAS registered increases of GVA of 2.1% for ocean-based industries, while employment decreased by only 3.4%. This suggests the ocean economy outperformed the economy as a whole between 2010 and 2013.

The information produced under the SAS is being used in a variety of policy contexts, including in marine spatial planning. The data has also been used to assess Portugal's status with regards to meeting European Union regulations aimed at safeguarding the marine environment. Several indictors have been developed including those designed to measure Portugal's progress with meeting its targets under the Sustainable Development Goals Agenda 2030. At present, work is continuing to improve the regional disaggregation of the SAS so that the statistics can be used to support decision making at multiple levels.

A framework is necessary for countries wishing to move towards satellite accounting for the ocean economy. The National Accounts Division of the OECD's Statistics and Data Directorate has developed guidance for sectoral experts wishing to pursue satellite accounts. The ten steps outlined in Box 4.8 provide an approach to the work that should be carried out when setting up a satellite account of any type. Cross referencing the steps outlined below with the limitations described above suggest the international community is still some way from formalising satellite accounts for the ocean economy, but progress can be made.

**Box 4.8. The ten main steps to compiling satellite accounts**

1. Define and compile data for the desired breakdown of economic activities (industries)
2. Define and compile data for the desired breakdown of products
3. Further breakdown of taxes less subsidies on products
4. Define and compile data for the desired breakdown of value added components
5. Extend the production boundary with services produced within the enterprise (e.g. in-house transport)
6. Extend the production boundary with services produced by households for own private use (if relevant)
7. Define and compile data for more details on employment
8. Define and compile data for more details on investments and capital stocks, and – if relevant – extending the asset boundary (e.g. fish stocks, ecosystems)
9. Complement the supply and use tables with physical performance and/or outcome indicators
10. Complement the supply and use tables with other physical indicators considered relevant

Source: van de Ven (2017[63]) *Presentation at New Approaches to Measuring the Ocean Economy Workshop*.

While the development of international statistical guidelines for ocean economy satellite accounts is likely to be the ultimate aim for all involved in measuring the ocean economy, before this can be realised the OECD will continue to assist countries as they aim to define and measure their ocean economies in a robust and internationally comparable way. In the meantime, those looking to measure the ocean economy through the national accounting system might wish to consider the following four recommendations:

11. Many countries have begun collecting data on the ocean economy either directly or via industry-led surveys. Such studies represent a good first step in the development of future accounting measures. The first recommendation is therefore to continue to support these efforts and to ensure that the results and methodologies used are distributed openly. Accumulating as much data as possible on the scope of the ocean economy within a country will provide a valuable baseline from which a more formal ocean satellite account can be built.

12. For the ocean-based industries missing from current accounting systems, arriving at data consistent with accounting values will require a range of adjustments for definition, exhaustiveness and time consistency (van de Ven, 2017[63]). This is almost certainly a process that requires expertise in the ocean economy – for knowledge on what data are available and where it can be retrieved - and expertise in national accounts –to ensure the data meets the standards set by international guidelines. Therefore, the secondary recommendation in this regard is that some resources are committed for ocean industries' specialists to work alongside national accountants to lay the foundations for experimental satellite accounts in interested countries.

13. In parallel, countries could continue to work internationally on common basic ocean economy definitions - as in the framework of OECD workshops for

example - to bridge the gap between current estimations and values suitable for future inclusion in the national accounts. Despite the shortcomings of current classification systems, there are additional steps that could be taken at the international level to assist in this area. Fundamentally, industrial classifications are required that capture all ocean-based activities and differentiate between land-based and ocean-based industries. This could be considered in the next round of revisions for ISIC at the United Nations level, should enough countries support the initiative.

14. While this chapter suggest that much progress is required before marine ecosystem accounts could be added to an ocean economy satellite account, it's important not to lose sight of the experimental nature of ecosystem accounting at present. The Australian Great Barrier Reef example provides a good testing ground for future efforts and the information provided publicly should be studied by any organisation looking to begin accounting for marine ecosystem services in-line with the SEEA. Internationally, more efforts to experiment – and, most importantly, to share the experiences of doing so with as wide an audience as possible – would benefit the process of refining both the international accounting guidelines and ecosystem service classifications. In the meantime, not all ecosystem services valuation methodologies are compatible with national accounting frameworks. Valuations based on exchange values should therefore be considered a priority by policymakers wishing to make the transition to ocean accounts that include marine ecosystem services. Finally, emphasis should be placed on conducting baseline estimations of ecosystem coverage for physical ecosystem accounts as such studies are likely to represent the first step in developing a representative ocean economy satellite account for marine ecosystems.

## 4.4. Quantifying the contribution of sustained ocean observation to the ocean economy

The need to better understand the ocean, its dynamics, and its role in the global earth and climate system has led to the development of complex ocean observing systems at local, regional, national and international levels. Ocean observations encompass many types of physical, chemical, biogeochemical and biological data, most of them categorised as Essential Ocean Variables (GOOS, 2018[65]). These observations are crucial for many different scientific communities and for a wide range of public and commercial users who are active in the ocean economy (OECD, 2016[1]). But developing and sustaining ocean observations requires significant public support. As with all public investments, a thorough assessment of the associated costs and benefits of sustained ocean observations is useful to understanding their value to society.

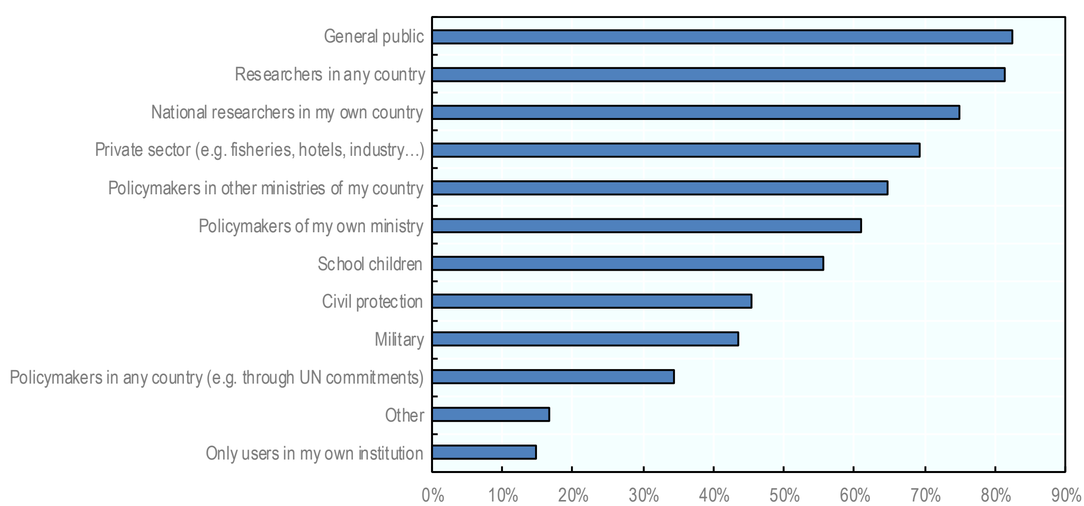
The OECD has built upon its experience of valuing the ocean economy to study the economics of sustained ocean observations, in cooperation with the international research community and many stakeholders. At the core of this research is an extensive review of over 90 papers written on the valuation of ocean observations. The results reveal the extent of current knowledge on the economics of ocean observations, with a focus on publicly funded observations, and provide a path forward for future research in this area. More details on this research can be found in a forthcoming *OECD Policy Paper* (OECD, 2019[66]).

### *4.4.1. The crucial role of science for ocean observations*

Science remains a crucial driver for most ocean observations and contributes to advancing fundamental knowledge on the ocean, weather and the climate, directly and via the critical data time series they provide which are used to drive, calibrate and verify ocean, atmospheric and climate models. Ocean observations also help describe and forecast developments of sea state, marine weather, climate and marine ecosystems in order to support scientific research, operational ocean services and political decision making at local, regional, national, multinational and global levels. The observing systems comprise fixed platforms, autonomous and drifting systems, submersible platforms, ships at sea, and remote observing systems such as satellites and aircraft, using increasingly efficient technologies and instruments to gather, store, transfer and process large volumes of ocean observation data.

Scientific communities represent one of the most important end users (around 80%) of data centres that provide ocean observation data, products and services, according to the Intergovernmental Oceanographic Commission (Figure 4.1). National co-ordinators for data management, marine information management, and associate data unit contact points were surveyed in 2016 in the framework of the International Oceanographic Data and Information Exchange (IODE) Programme. The general public represents also a top user category. However, there are no detailed data sets at national or regional levels to capture the evolution of users of ocean observation data; in terms of their numbers, their disciplines, the frequency of their observation data usage and the activities they conduct (e.g. for researchers, ad hoc studies or long-term assessments relying on continuous data time series) (IOC, 2017[67]).

**Figure 4.1. Users of ocean observations data, products or services, as provided by oceanographic data centres**




*Source:* IOC (2017[67]), *Global Ocean Science Report: The Current Status of Ocean Science Around the World*, UNESCO /IOC, Paris.

Many of the benefits associated with improved science are not readily associated with economic value, partly because they do not flow through markets and do not generate economic benefits in and of themselves. For this reason, the literature has often considered ocean observations data to be a public good, the benefits of which are difficult to identify and value. Despite the relative complexity of valuing social benefits, a number of recent studies have used a range of methodologies to do so. Further valuation of social benefits is of particular importance to undertaking a thorough assessment of the value of ocean observing systems and is of crucial importance to any future overall economic assessment.

### *4.4.2. Mapping the applications and types of users of ocean observations*

Ocean observations data, and their derived products and services, have a very large range of applications, beyond their contribution to science, serving very diverse public missions, and commercial undertaking in a wide range of sectors.

Many current ocean observing initiatives aim to serve all these diverse applications and end-users' communities. For example, the focus of the AtlantOS (a European Union H2020 Research and Innovation project that began in April 2015 with more than 60 partners across the Atlantic) is to design a multiplatform, multidisciplinary Atlantic-wide system, so that data collected by the observing platforms can be used for many different observing objectives (AtlantOS, 2018[68]).

When examining different ocean economy sectors, ocean observations find their way indeed in very different domains (Table 4.9). The maritime shipping sector relies for example traditionally on sea state forecasts. In offshore oil and gas exploration and production, different activities such as exploration, platform's location choice, engineering design and set-up, production and decommissioning require different products and services including wind, wave, current and bathymetric information. In some cases, past experiences can be transferred from one industry to another. The offshore aquaculture sector benefits from lessons learnt in the offshore oil and gas industry with respect to engineering design and marine construction (Rayner, 2018[69]). In contrast, some emerging industries like marine renewable energy production need new types of products and services on salinity gradients, resource and temperature, in addition to information on wave, wind and currents (Gruet, 2018[70]).

**Table 4.9. Selected domains of applications of ocean observations**

| Area | Applications |
|---|---|
| Transport (excluding military) | Shipping operations, hovercraft operations, hydrofoil operations, submersible or submarine operations, remotely operated vehicles, tunnel subsea operations, barrage roads, causeway, bridges, sea channels, navigational safety, lights, electronic charts, safety services, rescue, life preserving, fire, port operations |
| Energy production | Oil and gas production, oil and gas exploration and prospecting and drilling services, ocean thermal energy conversion, wave energy, tidal energy, wind energy, offshore installations |
| Environmental protection and preservation | Clean beaches, oil pollution control, non-oil pollution control, estuarine pollution, health hazards, marine reserves, species protection, environmental forecasts, flood protection, safe waste disposal, amenity evaluation, environmental quality control, environmental data services |
| Mineral extraction | Aggregate, sand, gravel, deep ocean, manganese nodules, hydrothermal muds, crusts, placer minerals, diamonds, tin, salt extraction, magnesia, bromine, desalination, phosphate, coal, subsea |
| Food from the sea | Fisheries, catching, fish farming, shellfisheries, shellfish and crustaceans farming, fishing gear |
| Defence | Military vessels, surface and submarine, anti-submarine warfare, oceanographic applications, underwater weapons, navigation, position fixing, defence sales equipment, components, operations and efficiency, logistics, controls, computing |
| Building, | Coastal defences, port construction, dredging, land reclamation, dam construction, |

| | |
|---|---|
| construction and engineering | tunnel construction, outfalls/intakes, consulting engineering, components, hydraulics, motors, pumps, batteries, cables, manufacture and operations, laying, corrosion prevention, paint, antifouling, heavy lifting, cranes, winches, marine propulsion, efficient ship, automatic ships, props, offshore construction, platforms, pipe-laying, trenching, burial, ship-building (non-defence, all kinds) |
| Services | Certification, climate forecasting, data consultancy, data services, data transmission, telecommunications, diving including suppliers, inspection, maintenance, repair, insurance, meteorology and oceanography surveys, mapping, hydrographic surveys, project management, non-defence, consultancy, remote sensing, salvage, towing, ship routing, weather forecasting |
| Equipment sales | Marine electronics, instruments, radar, optoelectronics, sonar, buoys, etc. |
| Tourism and recreation | Fishing, boating, beaching |
| Basic and strategic research | Acoustics, electronics, civil engineering, climate change, climate forecasting, coastal modelling, data centre, environmental sciences, estuarine modelling, fisheries, marine biology, marine weather forecasting, ocean modelling, oceanography, polar research, remote sensing, shelf seas modelling, shipping and naval architecture |
| Hinterland | Agriculture, land-use planning or zoning, urban management, local government, wetlands management, public health |

*Source*: Adapted from Flemming (2001[71]), "Dividends from investing in ocean observations: a European perspective", *Observing the Oceans in the 21st Century*, GODAE Project Office/Bureau of Meteorology, Melbourne, Australia.

Ocean observations and many related products and services tend to be made available via open online data platforms that are free and easy to access, often without registration. Examples of open data platforms for ocean observations include the Australian Open Data Network (AODN), the European Union Copernicus Marine Environment Monitoring Service (CMEMS), the European Marine Data Observation Network (EMODnet), the US Integrated Ocean Observing System (IOOS), the Pan-European Infrastructure for Ocean and Marine Data Management (SeaDataNet) and the UNESCO-IOC Ocean Biogeographic Information System (OBIS). The IOC International Oceanographic Data and Information Exchange program (IODE) integrates at international levels archives and assesses the quality of millions of ocean observations in over 80 oceanographic data centres.

Effortless access to data reduces the frictional costs associated with downloading and using the data, potentially increasing use and maximising the associated benefits. However, it is not without consequence. One such issue is that, while the volume of data downloaded is known, the type of user and the final use of the data are, in most cases, unknown. This is a substantial barrier to the identification of the benefits associated with the data and may impede efforts to ensure sustainable funding streams. Few open data platforms track or plan to track downloads of data sets from their portals, with very limited registration hurdles. But when they do measure downloads, it brings valuable information on the types of users groups and the activities they conduct with different kinds of ocean observations (Box 4.10).

**Box 4.9. Two examples of ocean observations data platforms measuring the frequency of their user groups' access to their portals: EMODnet and CMEMS**

The European Marine Observation and Data Network (EMODnet) is a long-term marine data initiative of the European Union, started in 2009. Over 150 organisations co-operate to assemble and provide marine data, metadata, and products and services to the data network. EMODnet has seven thematic data portals providing access to bathymetric, biological, chemical, geological, human activities, physical and seabed habitat data. The data of each portal are freely and publicly available. EMODnet has been measuring access to each of its data portals since 2015, and has seen increases in downloads, particularly on its physics portal (+140%) and human activities portal (+60%). EMODnet documents cases where data are used for specific applications or projects. These use cases indicate the demand for ocean observations as well as the variety of uses. In May 2018, a first user survey was launched to collect information on users and their downloads in more detail. Results of this survey are forthcoming.

The Copernicus Marine Environment Monitoring Service (CMEMS) is the operational Marine Service of the European Union delivered in the frame of the European Union programme COPERNICUS. It is operated by the non-profit company Mercator Ocean International since 2015, a multinational ocean analysis and forecasting centre providing expert service that covers all of the world's oceans. The CMEMS provides regular and systematic core reference information on the physical and biogeochemical state of the ocean, with 150 oceanographic products and services (observations and models) based on in-situ and satellite data as well as expert information, (e.g. *The Ocean State Reports*). CMEMS has a strong focus on intermediate users who produce their own downstream products and services for the end-user market. Intermediate users can be found in universities, business and private companies, public services, associations and foundations. As part of providing better services to its user groups, CMES has a registration process where users are asked to indicate their organisation's type, the main objective for using the CMEMS products and services, and the area of benefits to which their work contributes. Data collected through the registration procedure allows conclusions to be drawn on the distribution of user groups and their demand for and use of CMEMS products and services. As of March 2018, the CMEMS had 12 700 subscribers with roughly 8 400 active subscribers over the rolling year, i.e. subscribers that downloaded data at least once in the year. The number of subscribers more than doubled in a year, up from 6 000 subscribers in 2015. Around 200 to 300 new subscribers register on line on the CMEMS website per month on average.

Source: Original aggregated information on users of ocean observations kindly provided by Mercator Ocean International and by the European Marine Observation and Data Network (EMODnet).

The potential match between providers of ocean observations data, products and services and user groups is also crucial issue. Operational users often prefer products and services tailored to their specific needs. Publicly available data do not necessarily match these requirements, due, for example, to different spatial or temporal resolutions. In addition, often end users do not have the capacity or skills to convert the raw data into the products they need. Thus, even if data are publicly available, they might not be used to their full potential.

In the United States, major customers of products and services from the ocean measurement, observation and forecasting sector include scientific researchers, marine industries such as offshore oil and gas production, ports, commercial shipping, and fisheries and aquaculture. This is a finding of a survey conducted for the US Integrated Ocean Observing System (IOOS) managed by the National Oceanic and Atmospheric Administration (NOAA) (US IOOS and NOAA, 2016[72]). The purpose of this study was to identify the companies and estimate the revenue generated by these companies in the

US ocean measurement, observation and forecasting sector, which serve as either providers of observing system technology or intermediaries delivering value added data products to end-users. The study did not attempt to measure the benefits derived by end-users, although it sought to identify the ocean observations used by intermediary firms to enhance or create a product or service (Rayner, Gouldman and Willis, 2018[73]). In that context, around 59% of the surveyed US intermediary firms use marine in-situ data, with the most often used type including physical oceanographic data (48%), followed by bathymetric data (34%) and geophysical data (26%). Around 41% of surveyed US intermediary firms use also remotely sensed data. The most often used remotely sensed data types were shore observations (33%) and satellite observations (33%), followed by aircraft observations (19%).

### *4.4.3. Economic and societal benefits from ocean observations*

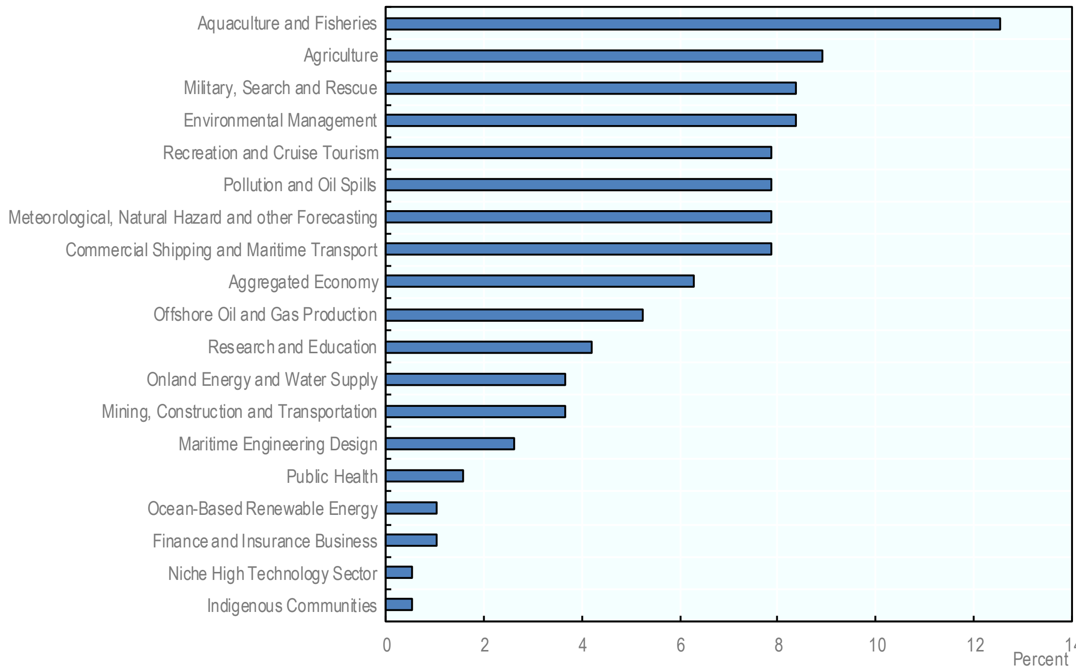
Economic and societal benefits underpinned by ocean observations, measurements and forecasts are thought to be large. However, they are difficult to quantify. There have been no comprehensive global attempts to describe and quantify these benefits, although numerous case studies have sought to understand and quantify socioeconomic benefits associated with use of ocean data in support of specific ocean uses or regulatory measures. In aggregate, the cost of obtaining and using ocean observations is almost certainly only a small percentage of the value of the benefits derived.

There are a wide diversity of operational products and services based on sustained ocean observations. Based on the OECD literature review of ocean observations' valuation studies, weather forecasts (36%), sea state forecasts (21%), and climate forecasts (7%) are the products and services most taken up for operational use. Some of the traditional operational user groups include navies and coastguards, offshore oil and gas industry, commercial shipping fisheries and aquaculture. User domains benefiting from ocean observations and covered the most by the literature do not paradoxically mirror the distribution of these traditional user groups, some of which identified with some details in Table 4.9. This is because much of the work on quantifying these areas exists only in the 'grey' literature rather than as peer-reviewed material.

The socio-economic assessments conducted so far and providing some valuation of the uses of ocean observations, consider primarily aquaculture and fisheries (13%); agriculture (9%); environmental management (8%); tourism and cruises (8%); pollution and oil spills (8%); military, search and rescue (8%); and commercial shipping and maritime transport (8%).

**Figure 4.2. Selected operational user domains benefiting from sustained ocean observations**

As a percentage of occurrences in the reviewed literature




Source: OECD (2019[66]), *Valuing Sustained Ocean Observations,* OECD Science, Technology and Industry Policy Papers (forthcoming).

These benefits can be divided in three main categories:

- Direct economic benefits are the revenues associated with the sale of information products derived, in whole or in part, from ocean observations. For example, the sale of sea surface temperature products used by the commercial and sport fishing industries to aid in the location of target fish species. Many of these commercial products are based in part on free data made available by publicly funded open data platforms. This direct economic benefits category is relatively straightforward, but the statistics needed to conduct the assessment are generally quite scarce. Commercial revenues from selling products or services based directly on ocean observations are not often taken into account in impact assessment;
- A second category comprises indirect economic benefits. These are accrued when an end-user derives an indirect benefit from purchase of an information product or service resulting in whole or in part from ocean observations (e.g. better ship routes as a result of accurate weather forecasts, valued, for example, by reduced fuel costs as a result of avoiding bad weather). The indirect economic benefits follow gains in efficiency or productivity from using improved ocean observations. This category is the most represented in the literature with cost savings (30%), cost avoidance (15%) and increased revenues (14%) as the three most frequent types of benefits cited in the studies.
- Finally, societal benefits are received by society in general in ways that are often easier to identify than to quantify (e.g. improved ocean governance,

environmental management or better understanding of the impacts of climate change valued, for example, by estimation of the avoided costs associated with mitigation). The most frequent types of societal benefits are improved environmental management (10%), lives saved (7%) and improved forecasting (6%).

These different types of benefits can be assessed with qualitative or quantitative measures. In the literature reviewed, two-thirds of benefits are assessed quantitatively.

### *4.4.4. The next steps in valuing sustained ocean observations*

A thorough assessment of the value of ocean observations requires further effort in identifying and understanding the different communities of intermediate and end-users, their use of ocean observations and the associated benefits, based on common standards for the evaluation process. While ongoing efforts are to be commended and recent progress has been made on mapping operational user communities, this research reveals that (as for scientific users), data on intermediate and end-users are usually not collected. This lack of basic data collection is sometimes motivated by different interpretations of open data policies. A more thorough and detailed analysis of dedicated value chains could contribute to more robust valuation of socio-economic benefits.

Quantifying socio-economic benefits will bring a stronger argument, in addition to the scientific benefits – for the sustainability and improvement of ocean observations. The following steps could contribute to this undertaking:

- Tracking the users and mapping value chains: Increased efforts among providers of ocean observations to track user groups, their downloads and use of the data would help identify associated marketable and social values. This would involve improved identification and mapping of end-users, whether they are scientific or operational. Dedicated surveys of end-users of ocean observations could be a useful tool to gather characterisations of users, the products and services they require, and the benefits they realise by using ocean observation. These surveys could be conducted in co-operation with open data platforms, such as the Australian Open Data Network, CMEMS, EMODnet or NOAA IOOS, with their user base as the target group. A more thorough and detailed analysis of dedicated value chains for some of the main products and services derived from ocean observations could also contribute to a more robust valuation of socio-economic benefits. There are very useful efforts underway at national and international levels (e.g. National Oceanic and Atmospheric Administration, Global Ocean Observing System), but there are still some overlooked sectors as revealed in this literature review. Convening an expert meeting specifically on lessons learnt from mapping user groups at different levels of value chains would be very useful for the ocean observing community.

- Advancing methodologies: The studies differ considerably in spatial and temporal scope, methodology used, and user domain considered. The ocean observation community would benefit from international standards or guidelines for the Valuation of ocean observations. This would simplify the comparison of different studies and allow the aggregation of results. There are several general challenges when assessing the benefits of ocean observations, e.g. the public good character of many ocean observations, complex value chains and taking stock of a variety of stakeholders. Comparing the results of individual studies can be complicated by varying temporal, sectoral and spatial scales applied in the assessments.

Improvements in methodologies are, however, possible. The weather and the environment policy communities have both tested and paved the way for useful and proven value of information techniques that may be applicable to ocean observations. A holistic socio-economic valuation of ocean observations needs to account for marine environment, ecosystems and their associated services. Valuing the environment is still challenging even though some tools and methodologies exist which could contribute to the discussions (OECD, 2018[74]).

- Expanding the international knowledge base: This exercise on ocean observations is a starting point for sharing the international knowledge base with the community. Expanding the known literature and making it ever more inclusive would constitute a natural next step, since based on discussions with different stakeholders, more substance could be included. This would involve an even more international coverage (e.g. considering recent studies from Asia and Latin America) and the inclusion of further work on the valuation of social benefits, based in part on existing OECD streams of activities on the links between sustained scientific investments and economic growth. There is a real potential to improve the knowledge base on the value of ocean observations, with the objective to provide robust evidence-based information to decision makers and funding bodies.

## References


Abildgaard, C. (2017), "Measuring the Ocean Economy: A Norwegian Perspective", *presentation at OECD Workshop: New Approaches to Evaluating the Ocean Economy, 22 & 23 November 2017*, OECD, Paris. [103]

ABS (2017), *4680.0 - Experimental Environmental-Economic Accounts for the Great Barrier Reef*, Australian Bureau of Statistics, Canberra, Australia. [59]

ABS (2015), *4680.0.55.001 - Information Paper: An Experimental Ecosystem Account for the Great Barrier Reef Region*, Australian Bureau of Statistics, Canberra, Australia. [58]

ADEUPa (2018), *Observatoire de l'économie maritime en bretagne*, Agence d'Urbanisme Bretagne, Brest, France. [91]

Agardy, T., G. di Sciara and P. Christie (2011), "Mind the gap: Addressing the shortcomings of marine protected areas through large scale marine spatial planning", *Marine Policy*, Vol. 35/2, pp. 226-232, http://dx.doi.org/10.1016/J.MARPOL.2010.10.006. [9]

Ali, Z. (2017), "Canada's Experience Measuring the Ocean Economy", *presentation at OECD Workshop: New Approaches to Evaluating the Ocean Economy, 22 & 23 November 2017*, OECD, Paris. [79]

Armstrong, C. et al. (2012), "Services from the deep: Steps towards valuation of deep sea goods and services", *Ecosystem Services*, Vol. 2, pp. 2-13, http://dx.doi.org/10.1016/J.ECOSER.2012.07.001. [57]

AtlantOS (2018), *AtlantOS Legacy: Optimizing and Enhancing the Integrated Atlantic Ocean Observing Systems*, GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany, April 2018. [68]

Borra, M. (2017), "Measuring the Ocean Economy: An Italian Perspective", *presentation at OECD Workshop: New Approaches to Evaluating the Ocean Economy, 22 & 23 November 2017*, OECD, Paris. [96]

Brouwer, R. et al. (2013), *A synthesis of approaches to assess and value ecosystem services in the EU in the context of TEEB*, Institute for Environmental Studies, VU University Amsterdam, Amsterdam, Netherlands. [40]

CBD (2011), *Quick guide to the Aichi Biodiversity Target 2: Biodiversity values integrated*, Convention on Biological Diversity, Rio de Janeiro, Brazil. [12]

Cebr (2017), *The economic contribution of the UK maritime sector*, Maritime UK, London, United Kingdom. [15]

Chang, J. (2017), "Measuring Ocean Economy in Korea", *presentation at OECD Workshop: New Approaches to Evaluating the Ocean Economy, 22 & 23 November 2017*, OECD, Paris. [97]

Chirico, A., T. McClanahan and J. Eklöf (2017), "Community- and government-managed marine protected areas increase fish size, biomass and potential value", *PLOS ONE*, Vol. 12/8, p. e0182342, http://dx.doi.org/10.1371/journal.pone.0182342. [8]

Colgan, C. (2013), "The ocean economy of the United States: Measurement, distribution, and trends", *Ocean & Coastal Management*, Vol. 71, pp. 334–343, http://dx.doi.org/10.1016/j.ocecoaman.2012.08.018. [76]

Colgan, C. (2007), *A Guide to the Measurement of the Market Data for the Ocean and Coastal Economy in the National Ocean Economics Program*, National Ocean Economics Program, University of Maine, Maine, USA. [42]

Cormier, R. and M. Elliott (2017), "SMART marine goals, targets and management – Is SDG 14 operational or aspirational, is 'Life Below Water' sinking or swimming?", *Marine Pollution Bulletin*, Vol. 123/1-2, pp. 28-33, http://dx.doi.org/10.1016/j.marpolbul.2017.07.060. [5]

Costanza, R. et al. (1997), "The value of the world's ecosystem services and natural capital", *Nature*, Vol. 387/6630, pp. 253-260, http://dx.doi.org/10.1038/387253a0. [25]

Daily, G. (1997), *Nature's services: societal dependence on natural ecosystems*, Island Press, Washington D.C., USA. [24]

DFO (2009), "Economic Impact of Marine Related Activities in Canada", *Statistical and Economic Analysis Series, Fisheries and Oceans Canada, Government of Canada*, Vol. 1/1. [78]

Díaz, S. et al. (2015), "The IPBES Conceptual Framework — connecting nature and people", *Current Opinion in Environmental Sustainability*, Vol. 14, pp. 1-16, http://dx.doi.org/10.1016/J.COSUST.2014.11.002. [36]

Didier, A. (2017), "Measuring the Ocean Economy - A French Perspective", *presentation at OECD Workshop: New Approaches to Evaluating the Ocean Economy, 22 & 23 November 2017*, OECD, Paris. [89]

ECLM (2017), *Employment and Production in Blue Denmark 2017*, Danish Maritime Authority, Korsør, Denmark. [84]

ECLM (2016), *Employment and Production in Blue Denmark 2016*, Danish Maritime Authority, Korsør, Denmark. [87]

ECLM (2015), *Employment and Production in Blue Denmark 2015*, Danish Maritime Authority, Korsør, Denmark. [86]

European Commission (2018), *The 2018 Annual Economic Report on EU Blue Economy*, Directorate-General for Maritime Affairs and Fisheries, European Union (EU), http://dx.doi.org/10.2771/305342. [88]

Flemming, N. (2001), "Dividends from investing in ocean observations: a European perspective", in *Observing the Oceans in the 21st Century*, GODAE Project Office/Bureau of Meteorology, Melbourne, Australia. [71]

Franzese, P. et al. (2017), "Natural capital accounting in marine protected areas: The case of the Islands of Ventotene and S. Stefano (Central Italy)", *Ecological Modelling*, Vol. 360, pp. 290-299, http://dx.doi.org/10.1016/j.ecolmodel.2017.07.015. [19]

Franzese, P. et al. (2015), "Environmental Accounting in Marine Protected Areas: the EAMPA Project", *Journal of Environmental Accounting and Management*, Vol. 3/4, pp. 323-331, http://dx.doi.org/10.5890/JEAM.2015.11.002. [18]

Girard, S. and R. Kalaydjian (2014), *French Marine Economic Data 2013*, Marine Economics Unit, IFREMER, Issy-les-Moulineaux, France, http://dx.doi.org/10.13155/36455. [90]

GOOS (2018), *Global Ocean Observing System - Essential Ocean Variables*, Global Ocean Observing System (GOOS), UNESCO, Paris. [65]

Government of France (2018), *L'évaluation française des écosystèmes et des services écosystémiques*, Ministry of Solidarity and Ecological Transition, Government of the French Republic, Paris. [37]

Government of Ireland (2012), *Harnessing Our Ocean Wealth – An Integrated Marine Plan for Ireland*, Dublin, Ireland, Government of Ireland. [94]

Government of Norway (2017), *New Growth, Proud History*, Ministry of Trade, Industry and Fisheries, Oslo, Norway. [101]

Grealis, E. et al. (2017), "The economic impact of aquaculture expansion: An input-output approach", *Marine Policy*, Vol. 81, pp. 29-36, http://dx.doi.org/10.1016/J.MARPOL.2017.03.014. [46]

Gruet, R. (2018), "Marine renewable energies: Overview of industry and ocean information needs"*, presentation at the GEO Blue Planet Symposium, Toulouse, France, 4-6 July 2018*. [70]

Haines-Young, R. and M. Potschin (2018), *Common International Classification of Ecosystem Services (CICES) V5.1 Guidance on the Application of the Revised Structure*, Fabis Consulting Ltd., Nottingham, UK. [53]

Haines-Young, R., M. Potschin-Young and B. Czúcz (2018), *Report on the use of CICES to identify and characterise the biophysical, social and monetary dimensions of ES assessments*, Deliverable D4.2, EU Horizon 2020 ESMERALDA Project, Grant agreement No. 642007. [54]

Hanley, N. and E. Barbier (2010), *Pricing Nature, Cost-Benefit Analysis and Environmental Policy*, Edward Elgar, Cheltenham, UK. [27]

Hynes, S. (2017), "Progress in Measuring the Ocean Economy: An Irish Perspective"*, presentation at OECD Workshop: New Approaches to Evaluating the Ocean Economy, 22 & 23 November 2017*, OECD, Paris. [93]

ICSU (2017), *A Guide to SDG Interactions: From Science to Implementation*, International Council for Science (ICSU), Paris. [7]

IOC (2017), *Global Ocean Science Report : The Current Status of Ocean Science Around the World*, Intergovernmental Oceanographic Commission, UNESCO Publishing, Paris. [67]

Karousakis, K. (2018), "Evaluating the effectiveness of policy instruments for biodiversity: Impact evaluation, cost-effectiveness analysis and other approaches", *OECD Environment Working Papers*, No. 141, OECD Publishing, Paris, https://dx.doi.org/10.1787/ff87fd8d-en. [13]

Kildow, J. and A. McIlgorm (2010), "The importance of estimating the contribution of the oceans to national economies", *Marine Policy*, Vol. 34/3, pp. 367-374, http://dx.doi.org/10.1016/j.marpol.2009.08.006. [43]

Kim, J., D. Jung and S. Yoo (2016), "Analyzing the Market Size and the Economic Effects of the Oceans and Fisheries Industry", *Ocean and Polar Research*, Vol. 38/1, pp. 59-70, http://dx.doi.org/10.4217/OPR.2016.38.1.059. [99]

KMI (2019), *Korea's Ocean Economy*, forthcoming Korea Maritime Institute (KMI), Busan, South Korea. [100]

Kwak, S., S. Yoo and J. Chang (2005), "The role of the maritime industry in the Korean national economy: an input–output analysis", *Marine Policy*, Vol. 29, pp. 371-383, http://dx.doi.org/10.1016/j.marpol.2004.06.004. [98]

La Notte, A. et al. (2017), "Ecosystem services classification: A systems ecology perspective of the cascade framework.", *Ecological indicators*, Vol. 74, pp. 392-402, http://dx.doi.org/10.1016/j.ecolind.2016.11.030. [55]

Lee, M. and S. Yoo (2014), "The role of the capture fisheries and aquaculture sectors in the Korean national economy: An input–output analysis", *Marine Policy*, Vol. 44, pp. 448-456, http://dx.doi.org/10.1016/J.MARPOL.2013.10.014. [47]

Lindeman, R. (1942), "The Trophic-Dynamic Aspect of Ecology", *Ecology*, Vol. 23/4, pp. 399-417, http://dx.doi.org/10.2307/1930126. [23]

Liquete, C. et al. (2013), "Current Status and Future Prospects for the Assessment of Marine and Coastal Ecosystem Services: A Systematic Review", *PLoS ONE*, Vol. 8/7, p. e67737, http://dx.doi.org/10.1371/journal.pone.0067737. [56]

MA (2005), *Ecosystems and human well-being: biodiversity synthesis*, Millenium Ecosystem Assessment Series, World Resources Institute, Island Press, Washington, D.C., USA. [26]

Marine Scotland (2018), *Scotland's Marine Economic Statistics*, Scottish Government, Edinburgh, Scotland. [14]

McCauley, D. (2006), "Selling out on nature", *Nature*, Vol. 443/7107, pp. 27-28, http://dx.doi.org/10.1038/443027a. [20]

Mcilgorm, A. (2016), "Ocean Economy Valuation Studies in the Asia-Pacific Region: Lessons for the Future International Use of National Accounts in the Blue Economy", *Journal of Ocean and Coastal Economics*, Vol. 2/2, http://dx.doi.org/10.15351/2373-8456.1046. [44]

Menon Economics (2018), *Maritim Verdiskapingsbok 2018*, Menon Economics, Oslo, Norway. [102]

NOAA (2018), *Economics: National Ocean Watch (ENOW) Data*, Office for Coastal Management, National Oceanic and Atmospheric Administration (NOAA), USA. [64]

NOEP (2017), *Environmental and Recreational (Non-Market) Values - Valuation Studies Search*, National Ocean Economics Program, Center for the Blue Economy, Middlebury Institute for International Studies at Monterey, USA. [30]

Norton, D., S. Hynes and J. Boyd (2018), *Valuing Ireland's Coastal, Marine and Estuarine Ecosystem Services*, Research Report 239, Environmental Protection Agency of Ireland, Co. Wexford, Ireland. [41]

Ntona, M. and E. Morgera (2018), "Connecting SDG 14 with the other Sustainable Development Goals through marine spatial planning", *Marine Policy*, Vol. 93, pp. 214-222, http://dx.doi.org/10.1016/J.MARPOL.2017.06.020. [10]

OECD (2019), "Valuing Sustained Ocean Observations", *OECD Science, Technology and Industry Policy Papers (forthcoming)* OECD Publishing, Paris. [66]

OECD (2018), *Cost-Benefit Analysis and the Environment: Further Developments and Policy Use*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264085169-en. [29]

OECD (2018), *Cost-Benefit Analysis and the Environment: Further Developments and Policy Use*, OECD Publishing, Paris, https://dx.doi.org/10.1787/9789264085169-en. [74]

OECD (2017), *Measuring Distance to the SDG Targets 2017*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264308183-en. [6]

OECD (2017), *Statistical Insights: What role for supply-use tables?*, OECD Insights Blog, OECD, Paris. [45]

OECD (2016), *The Ocean Economy in 2030*, OECD Publishing, Paris, https://dx.doi.org/10.1787/9789264251724-en. [1]

OECD (2014), *Understanding National Accounts: Second Edition*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264214637-en. [48]

OECD; European Union; United Nations; World Tourism Organization (2010), *Tourism Satellite Account: Recommended Methodological Framework 2008*, United Nations, New York, USA, https://doi.org/10.1787/9789264274105-en. [77]

Pendleton, L. et al. (2016), "Has the value of global marine and coastal ecosystem services changed?", *Marine Policy*, Vol. 64, pp. 156-158, http://dx.doi.org/10.1016/J.MARPOL.2015.11.018. [34]

Picone, F. et al. (2017), "Integrating natural capital assessment and marine spatial planning: A case study in the Mediterranean sea", *Ecological Modelling*, Vol. 361, pp. 1-13, http://dx.doi.org/10.1016/J.ECOLMODEL.2017.07.029. [17]

Portugal, S. and DGMP (2016), *Satellite Account for the Sea – 2010-2013 Methodological Report*, Statistics Portugal and Directorate-General for Maritime Policy, Government of Portugal, Lisbon, Portugal. [3]

Rayner, R. (2018), "Aquaculture development: An overview", *presentation at GEO Blue Planet Symposium, Toulouse, France, 4-6 July 2018*. [69]

Rayner, R., C. Gouldman and Z. Willis (2018), "The Ocean Enterprise – understanding and quantifying business activity in support of observing, measuring and forecasting the ocean", *Journal of Operational Oceanography*, pp. 1-14, http://dx.doi.org/10.1080/1755876X.2018.1543982. [73]

Rivero, S. and S. Villasante (2016), "What are the research priorities for marine ecosystem services?", *Marine Policy*, Vol. 66, pp. 104-113, http://dx.doi.org/10.1016/J.MARPOL.2016.01.020. [32]

Sawney, S. (2017), "Blue Grenada: A commitment to blue growth, sustainability and innovation", *presentation at OECD Workshop: New Approaches to Evaluating the Ocean Economy, 22 & 23 November 2017*, OECD, Paris. [92]

Sayre, R. et al. (2017), "A New Map of Global Ecological Marine Units - An Environmental Stratification Approach", *A Special Publication of the American Association of Geographers, Washington, D.C., USA*. [60]

Schrøder Bech, M. (2017), "New Approaches to Evaluating the Ocean Economy: The Danish Government Perspective", *presentation at OECD Workshop: New Approaches to Evaluating the Ocean Economy, 22 & 23 November 2017*, OECD, Paris. [83]

Schröter, M. et al. (2016), "National Ecosystem Assessments in Europe: A Review", *BioScience*, Vol. 66/10, pp. 813-828, http://dx.doi.org/10.1093/biosci/biw101. [38]

Schröter, M. et al. (2014), "Ecosystem Services as a Contested Concept: A Synthesis of Critique and Counter-Arguments", *Conservation Letters*, Vol. 7/6, pp. 514-523, http://dx.doi.org/10.1111/conl.12091. [21]

Seo Park, K. and J. Kildow (2014), "Rebuilding the Classification System of the Ocean Economy", *Journal of Ocean and Coastal Economics*, Vol. 2014/1, http://dx.doi.org/10.15351/2373-8456.1001. [2]

Song, W., G. He and A. McIlgorm (2013), "From behind the great wall: The development of statistics on the marine economy in china", *Marine Policy*, Vol. 39, pp. 120-127, http://dx.doi.org/10.1016/j.marpol.2012.09.006. [80]

Sornn-Friese, H. (2003), *Navigating Blue Denmark: Danish Maritime Cluster Employment and Production*, Søfartsstyrelsen, København, Denmark. [85]

Stats NZ (2018), *Environmental-economic accounts: 2018 (corrected)*, Retrieved from www.stats.govt.nz, Stats NZ Tatauranga Aotearoa, Wellington, New Zealand. [50]

Stats NZ (2018), *Environmental-economic accounts: Sources and methods*, Retrieved from www.stats.govt.nz, Stats NZ Tatauranga Aotearoa, Wellington, New Zealand. [51]

TEEB (2010), *Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB*, The Economics of Ecosystems and Biodiversity (TEEB), Geneva, Switzerland. [35]

TEEB (2010), *The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations*, The Economics of Ecosystems and Biodiversity (TEEB), Geneva, Switzerland. [52]

Torres Figuerola, C. and N. Hanley (2016), "Economic valuation of marine and coastal ecosystem services in the 21st Century: an overview from a management perspective", *Working Paper*, No. 2016-01, Discussion Papers in Environment and Development Economics, University of St. Andrews, School of Geography and Sustainable Development. [31]

Torres, C. and N. Hanley (2017), "Communicating research on the economic valuation of coastal and marine ecosystem services", *Marine Policy*, Vol. 75, pp. 99-107, http://dx.doi.org/10.1016/J.MARPOL.2016.10.017. [33]

UN (2015), *Transforming Our World: The 2030 Agenda For Sustainable Development A/RES/70/1*, United Nations General Assembly, New York, USA. [28]

UN SEEA (2018), *Ocean Accounts Partnership Holds First Meeting*, United Nations System of Environmental Economic Accounting website: https://seea.un.org. [62]

UN SEEA (2018), *SEEA Experimental Ecosystem Accounting Revision 2020: Revision Issues Note*, United Nations System of Environmental Economic Accounting website: https://seea.un.org. [61]

UN SEEA (2012), *System of Environmental-Economic Accounting 2012: Central Framework*, United Nations, New York, USA. [49]

UNSD (2018), *Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development*, United Nations Statistics Division (UNSD), New York, USA. [4]

UNSD (2008), *International Standard Industrial Classification of All Economic Activities (ISIC), Rev.4*, Statistical Papers (Series M), United Nations Statistics Division (UNSD), New York, USA, https://doi.org/10.18356/18b0ecdc-en. [75]

US IOOS and NOAA (2016), *The ocean enterprise: A study of US business activity in ocean measurement, observation and forecasting*, US Integrated Ocean Observing System (IOOS), National Oceanic and Atmospheric Administration (NOAA), ERISS Corporation and The Maritime Alliance, USA. [72]

van de Ven, P. (2017), "Satellite accounts and SEEA implementation in national accounts: some best practices", *presentation at OECD Workshop: New Approaches to Evaluating the Ocean Economy, 22 & 23 November 2017*, OECD, Paris. [63]

Vassallo, P. et al. (2017), "Assessing the value of natural capital in marine protected areas: A biophysical and trophodynamic environmental accounting model", *Ecological Modelling*, Vol. 355, pp. 12-17, http://dx.doi.org/10.1016/J.ECOLMODEL.2017.03.013. [22]

Vega, A. and S. Hynes (2017), *Ireland's Ocean Economy*, Socio-Economic Marine Research Unit (SEMRU), Whitaker Institute of Innovation and Societal Change, National University of Ireland, Galway, Ireland. [95]

Wang, X. (2017), "Blue Economy in China"*, presentation at OECD Workshop: New Approaches to Evaluating the Ocean Economy, 22 & 23 November 2017*, OECD, Paris. [82]

WAVES (2016), *Policy Briefing: Natural capital accounting and the Sustainable Development Goals*, Wealth Accounting and Valuation of Ecosystem Services (WAVES), World Bank. [11]

Wilson, L. et al. (2014), "The Role of National Ecosystem Assessments in Influencing Policy Making"*, OECD Environment Working Papers*, No. 60, OECD Publishing, Paris, http://dx.doi.org/10.1787/5jxvl3zsbhkk-en. [39]

WWF (2015), *Reviving the Ocean Economy: the case for action*, WWF International, Gland, Geneva, Switzerland. [16]

Zhao, R., S. Hynes and G. Shun He (2014), "Defining and quantifying China's ocean economy", *Marine Policy*, Vol. 43/C, pp. 164-173, http://dx.doi.org/10.1016/j.marpol.2013.05.008. [81]

# Annex 4.A. Ocean economic activities and international classifications

### *Basics about classifications and ocean-based industries*

National statistical offices collect data on economic activities according to systematic digit codes. The codes enable economic data to be labelled by the sector of the economy in which the activity takes place, the fishing industry or the oil and gas sector, for example. The internationally accepted reference for industries is the International Standard Industrial Classification of all Economic Activities (ISIC).

The latest version, ISIC Revision Four (Rev. 4), was released by the United Nations Statistics Commission in 2008, and is the reference classification for industries in the 2008 System of National Account (SNA). Countries providing data according to ISIC ensure the data are comparable with other countries who use ISIC, or whose classification is derived from or related to ISIC. The General Industrial Classification of Economic Activities within the European Communities (NACE) Revision 2, for example, is derived from ISIC Rev. 4 but contains additional activities important in the European context. Similarly, the Australian and New Zealand Standard Industrial Classification (ANZSIC) is aligned with ISIC Rev. 4. The North American Industry Classification System (NAICS), while different in structure, is related to ISIC Rev. 4 and maintains comparability at broad levels of aggregation.

All of the national level methodologies for measuring the ocean economy begin by looking to data collected through the existing national statistical system (see Annex 4.B for more information on national level methodologies). At the core of national accounts compiled according to the 2008 SNA are observations of economic activity based on combining source data collected through official surveys, administrative data, censuses, etc. Data compiled in national accounts frameworks following the 2008 SNA guidelines meet the desirable properties of ocean economy data outlined in this chapter: comparability, consistency and replicability.

Although it would be impossible to create a code for every possible activity taking place within an economy, all industry classifications used by national statistical offices have a particular structure that splits the economy into increasingly detailed groupings. The total economy according to ISIC Rev. 4 categorisation consists of 21 Sections which are labelled using a letter from A to U (see Annex Table 4.A.1). Each level beyond the 21 Sections disaggregates the previous, with each Section being further detailed into a number of Divisions which are represented by a two-digit code. There are 99 Divisions in total. Divisions are split into Groups (three-digit code), of which there are 238. Groups are split finally into 419 Classes (four-digit code). The Sections therefore represent the *highest* level aggregation after the total economy, while Classes – commonly referred to as a “four-digit ISIC code” – are the most *detailed* level aggregation. All categories at each level are mutually exclusive of each other to avoid double counting.

**Annex Table 4.A.1. Broad categories of industries classified in ISIC Rev. 4**

| Section | Description |
|---|---|
| A | Agriculture, forestry and fishing |
| B | Mining and quarrying |
| C | Manufacturing |
| D | Electricity, gas, steam and air conditioning supply |
| E | Water supply; sewerage, waste management and remediation |
| F | Construction |
| G | Wholesale and retail trade; repair of motor vehicles and motorcycles |
| H | Transportation and storage |
| I | Accommodation and food service activities |
| J | Information and communication |
| K | Financial and insurance activities |
| L | Real estate activities |
| M | Professional, scientific and technical activities |
| N | Administrative and support service activities |
| O | Public administration and defence; compulsory social security |
| P | Education |
| Q | Human health and social work activities |
| R | Arts, entertainment and recreation |
| S | Other service activities |
| T | Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use |
| U | Activities of extraterritorial organizations and bodies |

*Source*: UNSD (2008[75]) *International Standard Industrial Classification of All Economic Activities (ISIC): Revision 4*.

## *Using current industrial classifications*

The first stage in many of the ocean economy measurements is to decide upon the scope of ocean-based industries involved so that the types of economic activities conducted can be identified and the relevant industrial classification referred to for appropriate codes.

The existence of codes matching ocean-based industries should in theory enable economic data to be sourced from official tables produced by the requisite statistical office. Such data would provide a robust measurement of direct value that, assuming the statistical office adheres to the guidelines of the 2008 SNA, would be accepted as internationally comparable. For illustrative purposes, Annex Table 4.A.2 gives the OECD classifications of ocean-based industries from *Ocean Economy in 2030*. An analyst would therefore check for the existence of industrial codes that match these industries.

**Annex Table 4.A.2. Selected ocean-based industries**

| Established industries | Emerging industries |
|---|---|
| Capture fisheries | Marine aquaculture |
| Seafood processing | Deep- and ultra-deep water oil and gas |
| Shipping | Offshore wind energy |
| Ports | Ocean renewable energy |
| Shipbuilding and repair | Marine and seabed mining |
| Offshore oil and gas (shallow water) | Maritime safety and surveillance |
| Marine manufacturing and construction | Marine biotechnology |
| Maritime and coastal tourism | High-tech marine products and services |
| Marine business services | |
| Marine R&D and education | |
| Dredging | |

*Source*: OECD (2016[1]) *The Ocean Economy in 2030* http://dx.doi.org/10.1787/9789264251724-en

*Ocean-based industries with fully concordant ISIC Rev. 4 codes*

Mapping the OECD ocean-based industries onto industrial activities defined in ISIC Rev. 4 reveals a number of limitations to using national accounts data. The obvious problem with using data labelled by such codes is that they are only fully concordant with three of the OECD ocean-based industries given in Annex Table 4.A.2.

Annex Table 4.A.3 gives the full ISIC classifications for industries for which ISIC codes exist. The remaining industries are unrepresented at any level of detail. A further consideration is that, even among the three industries listed below, the level of detail required to separate ocean-based industries from land-based equivalents only occurs at the four-digit level (i.e. the most detailed aggregation).

For example, capture fisheries could be measured using the fully concordant four-digit code "0311: Marine fishing". The Class "Marine fishing" belongs to the Group (three-digit code) "031: Fishing", which also includes the four-digit code "0312: Freshwater fishing". The Group "Fishing" belongs in turn to the Division (two-digit code) "03: Fishing and aquaculture", which also includes Group "032: Aquaculture" containing both "0321: Marine aquaculture" and "0322: Freshwater aquaculture". Finally, the Division "Fishing and aquaculture" sits within Section "A: Agriculture, forestry and fishing". The Section "Agriculture, forestry and fishing" contains two additional Divisions, eleven additional Groups and 34 additional Classes, all of which are directly unrelated to ocean-based industry.

The example above illustrates a key problem for measuring even fully concordant ocean-based industries; national statistics offices must present data at a level of aggregation detailed enough so that ocean-based industries are split from their land-based alternatives. Using three-digit codes to measure capture fisheries would result in the inclusion of data on freshwater fishing. At the two-digit level, it would include marine and freshwater aquaculture. And at the Section level, it would include a vast array of industries in the agriculture and forestry sectors. Clearly only the four digit code presents an appropriate metric for directly measuring the value associated with the ocean-based industry in question.

Unfortunately, many countries do not present accounts for the most detailed levels of classifications on a regular basis. Instead, summary accounts based usually at the Section level, two-digit and occasionally three-digit level, are derived annually. The United

States, for example, collects annual data aggregated to a level that includes only 71 defined industries. The most detailed level of aggregation, which includes 389 industries (the "benchmark" census), was last compiled in 2007. The same is true when countries provide data from their national accounts for international databases. The OECD receives national accounts data from most-OECD countries for 56 industry aggregations (van de Ven, 2017[63]). The OECD's Database for Structural Analysis (OECD STAN), for example, presents data mainly at ISIC Rev. 4 two-digit level with only some detail provided to three digit-level.

**Annex Table 4.A.3. Ocean-based industries with fully concordant ISIC Rev. 4 codes**

| OECD Industry | Section | Division | Group | Class |
|---|---|---|---|---|
| **Capture fisheries** | A | 03 | 031 | 0311 |
| | Agriculture, forestry and fishing | Fishing and aquaculture | Fishing | Marine fishing |
| | | | | |
| **Marine aquaculture** | A | 03 | 032 | 0321 |
| | Agriculture, forestry and fishing | Fishing and aquaculture | Aquaculture | Marine aquaculture |
| | | | | |
| **Shipping** | H | 50 | 501 | 5011 |
| | Transportation and storage | Water transport | Sea and coastal water transport | Sea and coastal passenger water transport |
| | H | 50 | 501 | 5012 |
| | Transportation and storage | Water transport | Sea and coastal water transport | Sea and coastal freight water transport |

*Source*: UNSD (2008[75]) *International Standard Industrial Classification of All Economic Activities (ISIC) Revision 4*.

### *Ocean-based industries with partially concordant ISIC Rev. 4 codes*

Of the 19 OECD ocean-based industries listed in Annex Table 4.A.2, only four have fully concordant four-digit codes.

For the remaining 15 industries, the four-digit ISIC code either excludes data that could be an important contributor to an ocean-based industry; contains data from areas other than the ocean; and/or, gives no indication as to whether the classified activity is ocean- or land-based. Consider the classification for the OECD industry "Seafood processing". The most appropriate ISIC Rev. 4 code is "1020: Processing and preserving of fish, crustaceans and molluscs". However, no distinction between freshwater fish and marine fish is made. The value of seafood processing could therefore be overestimated using this code unless some additional calculations are made.

Where the aggregates presented by national statistical offices do not provide enough detail to isolate ocean-based industries, analysts may choose to return to the original micro-data used to build those aggregates. Combining business-level data with information in business registers may allow for certain indicators of size to be built by statistical offices. Such methodologies are, however, resource intensive and require access to data that are not always publicly available. The US, for instance, does not include firm-level data where they are likely to give away information about, and damage the competitiveness of, individual firms (Colgan, 2013[76]).

**Annex Table 4.A.4. ISIC Rev. 4 codes related to seafood processing**

| OECD Industry | Section | Division | Group | Class |
|---|---|---|---|---|
| **Seafood processing** | | | | |
| | C | 10 | 101 | 1020 |
| | Manufacturing | Manufacture of food products | Processing and preserving of fish, crustaceans and molluscs | Processing and preserving of fish, crustaceans and molluscs |
| | C | 10 | 104 | 1040 |
| | Manufacturing | Manufacture of food products | Manufacture of vegetable and animal oils and fats | Manufacture of vegetable and animal oils and fats |
| | C | 10 | 107 | 1075 |
| | Manufacturing | Manufacture of food products | Manufacture of other food products | Manufacture of prepared meals and dishes |
| | C | 10 | 107 | 1075 |
| | Manufacturing | Manufacture of food products | Manufacture of other food products | Manufacture of other food products n.e.c. |

*Source*: UNSD (2008[75]) *International Standard Industrial Classification of All Economic Activities (ISIC): Revision 4*.

Given the resource requirements and legal barriers to re-estimating national accounts aggregates, analysts most often estimate GVA and employment using data sourced from elsewhere. The contributions of these industries' can be modelled through proxies and/or econometric techniques. Or data from industry publications can be used to project the relative share of the industry that is ocean-based, for example. Remaining with the "Seafood processing" industry, if data are available on the number of firms processing seafood as opposed to freshwater fish, then the proportion of seafood to freshwater establishments could be applied to the value given under code 1020.

Box 4.A.1 explains how measurements for some industries not suitably covered by industrial codes were estimated using proxies in the OECD's Ocean Economy Database. Alternatively, ad-hoc surveys designed specifically for the purpose of supplementing official data could be commissioned. The national-level measurements outlined in Annex 4.B apply similar methodologies to these.

**Annex Box 4.A.1. The OECD Ocean Economy Database**

To build the ocean economy database, a review of relevant industries for which datasets exist was conducted. As a baseline, ISIC Rev. 3 was used as it included at the time a larger number of countries and industry datasets than ISIC Rev. 4, at the start of the project in 2013 (since then, more countries have adopted ISIC Rev. 4 and have aimed to reclassify datasets). Using ISIC codes has two main limitations: 1) ISIC codes often include non-ocean-based activities (e.g. fisheries captures both land- and sea-based activities), and 2) ISIC codes do not exist for every ocean-based industry. Given these limitations, the OECD Ocean Economy Database contains data on the Gross Value-Added (GVA) and employment in ocean-based industries split into three groups according to broad definitions of data availability. The selected industries fall into three groups, based on data availability.

**Group One: Ocean-based industries included in ISIC Rev. 3 for which official data is readily available**

Group One includes industrial fish processing, fisheries, shipbuilding and repair, and maritime transport. Data for this set of industry ISIC codes is available in many official databases with two main advantages. First, the data are comparable and relatively consistent across countries. Second, data sources contain values for a sufficient number of countries in order to obtain a realistic approximation of the global value, especially when supplemented by data from other official sources.

**Group Two: Ocean-based industries included in ISIC Rev. 3 for which official data is limited**

Group Two of the ocean-based industries includes industries defined in ISIC Rev. 3 but where publicly available data does not meet consistency criteria. These are maritime and coastal tourism, port activities, education and research, and offshore oil and gas. Estimations of GVA and employment are therefore less straightforward than in Group One and require the use of proxy values. With regards to marine and coastal tourism, the measurement of the tourism industry has benefited significantly from international efforts to develop an appropriate statistical system. These efforts include the publication of a recommended methodological framework for tourism satellite accounts (OECD; European Union; United Nations; World Tourism Organization, 2010[77]). The OECD's *Ocean Economy Database* suggests that, in 2010, marine and coastal tourism was the second largest ocean-based industry after the oil and gas sector in terms of GVA and the second largest after capture fisheries in terms of employment. The codes suggested for use in the tourism satellite account are presented in the aforementioned report. Aggregating the data collected under these codes provides a robust measurement of the overall tourism economy, but gives little indication of the contribution of marine and coastal tourism to the total. In order to isolate their contribution, countries have tended to rely on arbitrary ratios to split marine and coastal from all other tourism and/or geographical limits that assume all tourism taking place in coastal zones can be attributed to the ocean economy. This poses the same challenges to consistency and comparability.

**Group Three: Ocean-based industries not defined by ISIC Rev. 3 and without any available data**

The third group includes the industries listed that are not defined by ISIC Rev. 3 and for which primary official data at global level are not available. Estimates are conducted using a variety of reports from national governments, international organisations and industry associations. Proxies are necessarily constructed for this group, which includes maritime equipment, industrial marine aquaculture, and offshore wind energy.

# Annex 4.B. Selected national and regional-level ocean economy measurements

The following sections summarise selected national and regional-level measurements of the ocean economy, including recent estimates, methodologies used and in some cases ongoing efforts to measure ocean-based industry and marine ecosystems. In addition to extensive desk-based research and consultations conducted by the OECD Secretariat, a dedicated workshop was held at the OECD in Paris in November 2017 (see Box 4.4 for more information on the workshop).

### *Canada*

The Statistics Department of Canada's Department of Fisheries and Oceans estimates the value of Canadian ocean-based industries annually using a methodology outlined in a 2009 publication (DFO, 2009[78]). The data are sourced from the Canadian national accounts and, where data gaps exist, are supplemented with government and industry led surveys. The results are presented in terms of contribution to GDP, household income and employment, at national and regional level. In addition, an input-output model has been used to estimate the broader impacts of ocean-based activity in multiple private industries and of spending by public bodies concerned with the oceans. The results of this analysis are presented in Annex Table 4.B.1.

A key constraint for the measurement of the Canadian ocean economy is the lack of a suitable methodology for the subsistence economy in Arctic regions, which is based on both cash and non-cash transactions (Ali, 2017[79]). Non-cash items, such as hunted seals, are shared among the community, rather than sold, leaving them unpriced and particularly difficult to measure using typical national statistical methodologies, although they have strong importance to the livelihoods and wellbeing of the population.

**Annex Table 4.B.1. GDP and employment in Canada's "ocean economic activities" (2009-2012), in CAD and FTE**

| | 2009 | | 2010 | | 2011 | | 2012 | |
|---|---|---|---|---|---|---|---|---|
| | GDP | Employment | GDP | Employment | GDP | Employment | GDP | Employment |
| Private Sector | | | | | | | | |
| Seafood | 5,601 | 84,381 | 6,012 | 84,614 | 6,573 | 92,388 | 6,829 | 95,954 |
| Offshore oil & gas | 7,548 | 15,737 | 8,930 | 14,858 | 11,291 | 17,964 | 8,461 | 13,189 |
| Transportation | 6,735 | 66,997 | 7,138 | 71,717 | 7,600 | 76,617 | 8,411 | 85,102 |
| Tourism & recreation | 4,272 | 67,249 | 4,295 | 63,601 | 4,264 | 63,098 | 4,376 | 64,795 |
| Manufacturing & construction | 1,706 | 24,141 | 1,679 | 19,657 | 1,695 | 19,935 | 1,658 | 19,831 |
| Sub-total private sector | 25,861 | 258,502 | 28,053 | 254,446 | 31,423 | 270,001 | 29,735 | 278,871 |
| Public sector | | | | | | | | |
| National Defence | 3,703 | 41,230 | 3,836 | 42,002 | 3,821 | 41,837 | 3,776 | 41,339 |
| Stewardship | 2,698 | 28,023 | 2,885 | 29,562 | 2,749 | 28,247 | 2,551 | 26,336 |
| Sub-total public sector | 6,401 | 69,253 | 6,722 | 71,562 | 6,571 | 70,085 | 6,327 | 67,675 |
| **Total Marine Economy** | **32,262** | **327,755** | **34,776** | **326,008** | **37,993** | **340,085** | **36,062** | **346,547** |

*Source*: Ali (2017[79]) *Canada's Experience Measuring the Ocean Economy*, presentation at OECD Workshop: New Approaches to Evaluating the Ocean Economy, 22 & 23 November 2017.

### *China*

China began developing a statistical system for measuring the ocean economy in the late 1980s (Song, He and McIlgorm, 2013[80]). By 2006, the Ocean Economy Accounting System (OEAS) of China was established in order to provide an agreed methodology for estimating China's Gross Ocean Product (GOP) – essentially direct GVA of ocean-based industries. The OEAS contains several accounts including a Principle Account for measurements of ocean-based industry that are used to calculate GOP. Three other accounts include those suitable for producing input-output tables and measures of natural capital (Zhao, Hynes and Shun He, 2014[81]). The National Marine Data and Information Service of China has overseen the development of the OEAS and is responsible for producing the data required for a number of ocean economy publications including the annual China Marine Economic Statistical Bulletin. The latest statistical bulletin, from 2016, estimates that China's national GOP was USD 1,061.5 billion in 2015. This is equal to 9.5% of 2015 total economy GDP and represents a 6.8% increase from 2014 (Wang, 2017[82]).

China's ocean-based industries are classified by a statistical standard released by the State Oceanic Administration in 2006. The *Industrial Classification for Ocean Industries and Their Related Activities* is aligned with the internationally recognised ISIC Rev.4 (Song, He and McIlgorm, 2013[80]). However, the ocean-based industry classifications do not necessarily align with the classifications used by the National Bureau of Statistics of China (Zhao, Hynes and Shun He, 2014[81]). Additional surveys must therefore be relied upon in order to collect data for the missing industries so that the entire ocean economy is measurable. Annex Table 4.B.2 gives the breakdown of 2010 GOP by ocean-based industry using this approach (Zhao, Hynes and Shun He, 2014[81]).

**Annex Table 4.B.2. Gross value added and employment in China's "ocean economy" in 2010**

| Ocean sectors | Gross value added (USD billions) | Employment (10,000 persons) |
|---|---|---|
| Marine fishery | 42.12 | 553.2 |
| Offshore oil and gas | 19.23 | 19.7 |
| Ocean mining | 0.67 | 1.6 |
| Marine salt | 0.97 | 23.8 |
| Shipbuilding | 17.95 | 32.7 |
| Marine chemicals | 9.07 | 25.6 |
| Marine biomedicine | 1.24 | 1.0 |
| Marine engineering and building | 12.91 | 61.5 |
| Marine electric power | 0.56 | 1.1 |
| Seawater utilization | 0.13 | - |
| Marine communications and transport | 55.92 | 80.7 |
| Coastal tourism | 78.33 | 124.4 |
| **Total** | **239.09** | **925.3** |

*Source*: Zhao, Hynes and Shun H (2014[81]) *Defining and quantifying China's ocean economy*. http://dx.doi.org/10.1016/j.marpol.2013.05.008

## *Denmark*

The Danish Maritime Authority publishes annually a range of statistics for the Danish ocean economy, known as Blue Denmark (Schrøder Bech, 2017[83]). The analysis considers employment, production, productivity, education level and place of domicile of the labour force among others, for both direct and indirect economic activity. The latest publication reveals that 59 692 people were directly employed (94 600 if indirect employment is counted) and DKK 83 billion in gross-value added (GVA) was produced in 2016 (ECLM, 2017[84]). This corresponds to 2.2% and 4.6% of the respective direct figures for the total economy. The collection of such statistics over time enables trends to be highlighted. For example, direct employment decreased by 12 446 between 2006 and 2016, while indirect employment increased by 3 000.

Many of the difficulties associated with measuring the economic activity of the Danish ocean economy are outlined in a 2003 paper (Sornn-Friese, 2003[85]). One difficulty highlighted is that data are only available through Statistics Denmark, the national statistical office, for a proportion of ocean-based industries. Where official data is missing, proxy values are estimated. To better understand the performance of the offshore sector, Statistics Denmark recently conducted a "calibration" survey that delimited offshore activities from land-based activities in the oil, gas and renewable energy sectors (Schrøder Bech, 2017[83]). The calibration revealed substantial differences with the data estimated through the existing statistical framework, with the official sources underestimating the value of the Danish ocean economy both in terms of value-added and employment, and direct and indirect impacts. In addition, innovation in the ocean economy is reported to be exceeding that in the total economy as measured by the number of companies applying for patents. However, the survey was a one-time occurrence and no annual figures are being produced (Schrøder Bech, 2017[83]).

**Annex Table 4.B.3. Employment and production in "Blue Denmark" (2014-2016)**

| | 2014 | 2015 | 2016 |
|---|---|---|---|
| Employment | | | |
| Direct only | 60,255 | 60,443 | 59,692 |
| Direct + indirect | 102,000 | 100,000 | 94,600 |
| Production (DKK billions) | | | |
| Total | 335 | 330 | 315 |
| GVA | 91.7 | 98.9 | 83 |

*Source*: ECLM (2015[86]) *Employment and production in Blue Denmark 2015*, ECLM (2016[87]) *Employment and production in Blue Denmark 2016* and ECLM (2017[84]) *Employment and production in Blue Denmark 2017*.

### *European Commission*

The Joint Research Centre of the European Commission publishes economic data on a number of ocean-industry related fields such as fishing fleets, aquaculture and fish processing on its website. In addition to these data series, a recent report estimated the size of the ocean economy in the 28 European Union (EU) Member States (European Commission, 2018[88]). The sectors measured include those that are well established in EU countries: Living resources, marine extraction of oil and gas, ports, warehousing and water projects, maritime transport, shipbuilding and repair, and coastal tourism. Economic data are taken from national accounts compiled by Eurostat, the statistical office of the EU. Where ocean-based industries are not well represented by industry codes, several assumptions on their contribution are made (in most cases it is assumed that 100% of the value associated with an industry can be attributed to the ocean). In addition, several emerging industries are considered and recent trends in their performance discussed qualitatively. These include: Marine renewable energy, the bio-economy, desalination, deep-seabed mining, and coastal and environmental protection.

Annex Table 4.B.4 details direct global value added (GVA) of the established EU ocean economy industries between 2012 and 2016. In 2016, the established ocean-based industries are estimated to directly contribute roughly EUR 174 billion to the overall EU economy. Other metrics published include employment (3.48 million), average annual salary (EUR 28 300) and contribution to total EU GDP (1.3%).

**Annex Table 4.B.4. Gross value added in the EU's "blue economy" (2012-2016)**

| | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|
| Living resources | 16,777 | 16,330 | 17,521 | 18,082 | 18,563 |
| Marine extraction of oil and gas | 30,876 | 29,341 | 26,444 | 26,398 | 26,398 |
| Ports, warehousing and water projects | 17,009 | 17,722 | 17,850 | 19,547 | 19,546 |
| Maritime transport | 21,744 | 23,103 | 23,282 | 27,430 | 27,428 |
| Shipbuilding and repair | 11,463 | 10,955 | 11,934 | 11,917 | 11,878 |
| Coastal tourism | 64,524 | 67,569 | 67,137 | 67,472 | 70,410 |
| **Total** | **162,393** | **165,020** | **164,168** | **170,846** | **174,223** |

*Note*: In EUR millions (2016)
*Source*: European Commission (2018[88]), *The 2018 Annual Economic Report on EU Blue Economy* https://10.2771/305342.

### *France*

France manages the second largest exclusive economic zone (EEZ) in the world and the French Government increasingly supports efforts to recognise the impacts of its ocean economy (Didier, 2017[89]). The Maritime Economy Research Unit of the French Research Institute for Exploitation of the Sea (IFREMER) has produced a number of reports on the size and state of the French ocean economy. The first French Marine Economy Data (FMED) report was produced in 2001 and the most recent in 2014 (Girard and Kalaydjian, 2014[90]). Ocean-based industries are split according to whether they are in the private sector or the "non-market public sector". The data is taken from the national accounts and in several cases – transport, tourism and environment – satellite accounts have been relied upon. A number of international comparisons are also made, mainly at the European Union level and using data from Eurostat and industry sources. Annex Table 4.B.5 details GVA and employment estimates for the French ocean economy.

**Annex Table 4.B.5. Gross value added and employment in France's "maritime economy" in 2013**

| | Gross value added (EUR millions) | Employment |
|---|---|---|
| Private sector | 32,679 | 412,642 |
| Coastal tourism | 17,700 | 254,000 |
| Seafood industry | 2,338 | 39,445 |
| Shipbuilding and repair | 2,883 | 42,329 |
| Sea and river transport | 2,989 | 32,051 |
| Sea salt | 90 | 828 |
| Extraction of marine aggregates | 23 | 650 |
| Electricity production | - | 9,828 |
| Marine and river civil engineering | 535 | 3,976 |
| Submarine cables | 111 | 1,363 |
| Offshore oil and gas services and equipment | 6,100 | 29,000 |
| Non-market public sector | 2,940 | 47,911 |
| French navy | 2,471 | 39,696 |
| Public intervention | 182 | 3,745 |
| Coastal and marine environment protection | - | 900 |
| Marine research | 287 | 3,570 |
| **Total** | **35,619** | **460,553** |

*Source*: Girard and Kalaydjian (2014[90]), *French Marine Economic Data 2013* https://10.13155/36455.

An alternative measurement of the French ocean economy but from a regional perspective was conducted by the urban planning agency of Brest, Brittany (ADEUPa, 2018[91]). The analysis considers employment and the number of establishments associated with 17 industries in the Brittany maritime economy. The results suggest that, in 2016, 65 650 people were employed across 7 160 establishments. This is roughly equal to 5% of total employment in the region. Over half of the number of jobs are split between activities related to national defence (31%) and the seafood industry (25%). Tourism is not taken into account due to the difficulty of disaggregating marine and coastal tourism from the total in the region. The data is broken down further according to commune, indicating that the largest number of maritime jobs and establishments are found in Brest, the capital of the region. The analysis relies on a number of assumptions including that at least 25% of an establishments activity be maritime related in order to be counted.

### *Grenada*

The Government of Grenada, an island state in the southeast Caribbean, does not yet measure its ocean economy but is actively encouraging investment in potential growth areas. The Blue Innovation Institute has been created in order to encourage investment in nine strategically selected ocean-based industries; marine services, boutique tourism, marine research, eco-tourism, fisheries and aquaculture, global tourism, science and technology, coastal residential, and, finally, shipping and industry (Sawney, 2017[92]). Grenada has set an ambitious objective "to optimise the coastal, marine, and ocean resources, to become a world leader and an international prototype for creating economic blue growth and sustainability". Key to achieving this aim will be that the value of economic activity in these industries, and the environmental impacts associated with it, are measured correctly.

### *Ireland*

The Irish Government has funded the collection of ocean economy statistics, including the publishing of five reports on *Ireland's Ocean Economy*, since 2004 (Hynes, 2017[93]). The reports, annual updates of ocean economy statistics and analysis of trends and changing dynamics are produced by the Socio-Economic Marine Resource Unit (SEMRU) at the University of Galway. In general, there is a high-level of awareness and use of ocean economy statistics produced by SEMRU and the data is used to inform policy at all levels of government (Hynes, 2017[93]).

At the national level, the Irish Government's Integrated Marine Plan aims to double the ocean economy's share in the total economy from 1.2% in 2010 to 2.4% in 2030 (Government of Ireland, 2012[94]). Annex Table 4.B.6 provides data on Ireland's ocean-based industries from the most recent version of *Ireland's Ocean Economy* which provides data for 2016. The same publication estimates Irish ocean economy GVA to be around 1.7% of the total economy, suggesting a gradual movement towards the objectives outlined in the plan. At regional, local and rural levels, the data is used in planning and development decision-making (Hynes, 2017[93]).

As in all countries, the lack of appropriate industry classifications for the ocean economy poses a challenge for collecting Irish ocean economy data. This is particularly true for emerging industries, which are unrepresented by industry codes despite their high-growth potential. The SEMRU data is collected at industry level, but there is a need for better micro-level data (Hynes, 2017[93]). This would be particularly important for sub-national levels of policymaking.

**Annex Table 4.B.6. Direct turnover, gross value-added and employment in Ireland's "ocean economy" in 2016**

| Industry | Turnover (€ Millions) | GVA (€ Millions) | Employment (FTE) |
|---|---|---|---|
| Shipping & Maritime Transport | 2,123.27 | 533.15 | 4,666 |
| Marine Commerce | 140.73 | 41.76 | 342 |
| Tourism in Marine and Coastal Areas | 1,304.29 | 489.65 | 14,891 |
| International Cruise | 25.94 | 9.76 | … |
| Sea Fisheries | 279.80 | 187.00 | 2,536 |
| Marine Aquaculture | 167.17 | 71.53 | 1,030 |
| Seafood Processing | 537.11 | 140.46 | 3,029 |
| Marine Advanced Technology | 139.68 | 60.63 | 695 |
| Marine Biotechnology and Bio-products | 43.61 | 16.99 | 453 |
| Oil and Gas Exploration and Production | 597.28 | 71.67 | 265 |
| Manufacturing, Construction and Engineering | 132.23 | 70.99 | 1,023 |
| Marine Retail Services | 162.38 | 63.89 | 790 |
| Marine Renewable Energy | 59.00 | 38.10 | 454 |

*Source*: Vega and Hynes (2017[95]) *Ireland's Ocean Economy*.

## *Italy*

Italy has highlighted a number of sectors important for the ocean economy including fisheries, transport, tourism and environmental protection and management. Where official classifications are available, economic data on these activities has been assessed (Borra, 2017[96]). This exercise reveals that Italian ocean-based industry currently measurable through official statistics was equal to EUR 42.6 billion in GVA, or around 3% of the total economy, in 2015. Employment figures for 2015 were 835,000 or 3.5% of employment in the total economy. Of all ocean-based industry GVA, marine tourism has the largest share (57%) followed by fisheries (18.2%). The results also suggest that the Italian ocean economy is more resilient to downturns than the total economy. Between 2011 and 2015 GVA/employment decreased by 0.4%/1.0% in the ocean economy compared to 2.5%/3.6% in the total economy.

## *Korea*

For the Korea Maritime Institute, the concept of the ocean economy has evolved over the past 30 years. Originally limited to the conventional industries (fisheries, shipbuilding, shipping and ports), it now includes emerging high value-added sectors and additional environmental sectors such as water purification and coastal restoration (Chang, 2017[97]). The Korea Maritime Institute (KMI) recently analysed the ocean-based industries using Korean Input-Output tables. The results of this analysis are presented in Annex Table 4.B.7. The linkages between the industries and the rest of the economy have been explored through input-output analysis (Kwak, Yoo and Chang, 2005[98]; Kim, Jung and Yoo, 2016[99]). To enhance the accuracy and detail of such statistics, the Korea Maritime Institute (KMI) is currently working to ensure data is consistent across industries and is developing subsector surveys for important emerging industries such as marine biotechnology (Chang, 2017[97]).

**Annex Table 4.B.7. Output, value-added and employment in Korea's "ocean economy" in 2014**

| | Output (USD millions) | Value-added (USD millions) | Employment |
|---|---|---|---|
| Fisheries & aquaculture | 7,211.2 | 2,946.5 | 44,990 |
| Seafood processing | 8,966.1 | 1,248.8 | 40,655 |
| Seafood wholesale and retail | 4,454.5 | 2,195.4 | 65,827 |
| Marine leisure & tourism | 264.8 | 136.1 | 3,752 |
| Marine resource development and construction | 2,458.0 | 1,153.4 | 13,739 |
| Shipping | 29,429.2 | 4,388.2 | 70,791 |
| Port | 4,724.5 | 1,883.9 | 27,494 |
| Shipbuilding and offshore plant | 61,478.0 | 11,548.3 | 132,476 |
| Marine machine & equipment | 5,274.4 | 1,401.5 | 18,623 |
| Marine services (mapping, surveying, consulting, education, R&D) | 13,883.7 | 8,062.4 | 133,156 |

*Note*: USD 1 = KRW 1,053.26 in 2014
*Source*: KMI (2019[100]) *Korea's Ocean Economy*.

### *Norway*

The Government of Norway's recent ocean strategy document outlines the government's role in promoting sustainable growth of the ocean economy and gives economic data on Norwegian ocean-based industries (Government of Norway, 2017[101]). The estimates were conducted by a consulting firm which produces an annual report on several Norwegian ocean-based industries, the latest was released in 2018 and contains data for 2016 (Menon Economics, 2018[102]). The ocean strategy details the Norwegian Government's intention to adopt a holistic, cross-sectoral approach to ocean policymaking. The economic data on ocean-based industry improve the knowledge base and are used in a variety of policy settings (Abildgaard, 2017[103]). Annex Table 4.B.8 displays the data for value creation and employment published in the ocean strategy.

Beyond the ocean strategy, Norway has a long tradition of collecting statistics related to the ocean economy. Data on wild fish catches were first published in 1868, the aquaculture industry in 1971 and the oil and gas industry in 1984. Typical metrics collected include economic data on fish sales, numbers of workers and acquisitions and sales of fixed assets. This rich statistical resource suggests that Norway could make a good case for the development of a satellite account for ocean-based industry.

**Annex Table 4.B.8. Value creation and employment in Norway's "ocean economy" in 2014**

| Industry | Value creation (NOK billions) | Employees |
|---|---|---|
| Petroleum | 537 | 117,200 |
| Maritime/petroleum | 130 | 75,600 |
| Maritime | 51 | 33,000 |
| Maritime/seafood | 1.8 | 1,100 |
| Seafood | 40 | 29,000 |
| Seafood/petroleum | 0.07 | 100 |
| **Total** | **760** | **256,000** |

*Note*: Value creation in an industry is the sum of value creation in each business (calculated as wage costs plus earnings before interest, taxes, depreciation and amortization (EBITDA)). The public sector is not included.
*Source*: Government of Norway (2017[101]) *New Growth, Proud History*.

### *Portugal*

See Box 4.7 for a short summary of Portugal's pioneering "Satellite Account for the Sea".

### *United States of America*

The Office for Coastal Management of the National Ocean and Atmosphere Administration (NOAA) collects data on the ocean economy through the Economics: National Ocean Watch (ENOW) programme. The ENOW database provides data on the number of establishments, employment, wages and contribution to GDP across six sectors dependent on the ocean and Great Lakes. ENOW data is freely accessible and easily explored through the ENOW Explorer interface (NOAA, 2018[64]). The dataset has been updated annually since 2005 and can be disaggregated according to industry, region, state and county. Annex Table 4.B.9 gives employment and contribution to GDP data for the ocean economy across the six sectors available through the ENOW database. Colgan (2013)[16] details a methodology used to estimate the value of the ocean economy in the USA. Several important limitations and difficulties associated with the data are also presented.

**Annex Table 4.B.9. Employment and GDP in the USA's "ocean economy" (2010-2015)**

| | 2012 | | 2013 | | 2014 | | 2015 | |
|---|---|---|---|---|---|---|---|---|
| | Employment | GDP | Employment | GDP | Employment | GDP | Employment | GDP |
| Marine Construction | 43.1 | 5.6 | 44.2 | 5.7 | 43.0 | 5.7 | 44.6 | 6.2 |
| Living Resources | 61.6 | 7.4 | 61.8 | 7.8 | 61.6 | 7.5 | 62.2 | 7.6 |
| Offshore Mineral Extraction | 160.1 | 150.7 | 170.5 | 169.1 | 170.5 | 168.2 | 157.0 | 106.8 |
| Ship and Boat Building | 150.6 | 15.4 | 153.5 | 16.2 | 156.6 | 16.7 | 160.6 | 17.9 |
| Tourism and Recreation | 2077.2 | 97.9 | 2149.9 | 103.3 | 2216.3 | 107.5 | 2295.0 | 115.7 |
| Marine Transportation | 421.7 | 58.1 | 421.6 | 61.9 | 428.2 | 62.4 | 454.1 | 65.9 |
| **All Ocean Sectors** | **2914.3** | **335.2** | **3001.4** | **363.9** | **3076.0** | **368.2** | **3173.4** | **320.1** |

*Note*: Employment figures are by 1000s of persons employed by business establishments, including part-time and seasonal workers; but not including self-employed workers. GDP is in billions of 2015 USD billions.
*Source*: NOAA (2018[64]) *Economics: National Ocean Watch (ENOW) Data* https://coast.noaa.gov/digitalcoast/tools/enow.html.

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