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Bridging Knowledge Gaps towards 2030: The Use of Foresight for the Strategic Management of a Sustainable Blue Economy

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Abstract: There is need to better understand the trends and future challenges influencing the marine and coastal environments and identify the opportunities to develop innovative sustainability-oriented solutions to address these. Alongside mainstream decision support tools used in environmental management and conservation sciences, foresight techniques provide comprehensive and well-rounded information and knowledge about likely developments in the long-term future. This study uses a horizon scanning exercise to explore emerging signals and trends of future developments and innovation for the sustainable development of the blue economy looking towards 2030. It derives a series of global developments, challenges and opportunities relating to the blue economy from a review of high-level international reports and studies. Through a workshop conducted with 29 scientists and researchers based in maritime universities in six countries in Europe, the study identifies and prioritizes emerging signals and trends considered of high impact for a sustainability transition. The outputs include a synthesis of 11 global developments in the blue economy and 7 cross-cutting trends and trend projections. These may be valuable to marine scientists as a source of inspiration for a future research agenda or can be used as evidence for decision- and policymakers to deal with future uncertainties about the growth of the blue economy.

Keywords: foresight; blue economy; horizon scanning; trends; science and innovation; sustainable development

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1. Introduction

Alongside predictive models and other decision-support tools, novel forward-looking approaches are needed to support decisions on complex issues such as those related to sustainable development, climate change and environmental management and planning that are characterized by high uncertainties about the choices and solutions to adopt, and the impacts these choices may have on different components of socio-ecological systems [1–4]. A challenge is developing forward-looking tools to guide marine scientists, decisionmakers and policymakers in harnessing the opportunities derived from marine and coastal resources and ocean-based activities whilst safeguarding the resilience of marine ecosystems, in line with the requirements of SDG14. In a European policy context, 'sustainable development' of the blue economy rests on creating opportunities to develop innovative approaches that uphold the principles of biodiversity and coastal ecosystems preservation, circularity, and pollution reduction [5]. This also bears on the objective of the Green Deal for Europe to achieve climate neutrality by 2050 [6]. The European Commission's Blue Economy Strategy emphasizes the importance of mainstreaming sustainability in decision-making in priority areas including aquaculture and fisheries, clean energy, sustainable maritime transport, and green shipping. Innovation lies at the heart of the EU's sustainable blue economy strategy, playing a central role in harnessing the untapped potential of marine and coastal

resources and in creating new business opportunities based on "clean, climate-proof and sustainable activities" [5] (p. 2). This policy context sets the stage for science and research to develop innovative ocean-based solutions, business models and services that promote the preservation of coastal and marine resources and solutions that lead to the decarbonisation of industry [7].

This study contributes to a growing corpus of knowledge on the use of foresight tools and approaches for the strategic management of natural resources and marine and coastal activities linked to the blue economy [2,8]. Foresight is not a predictive tool. It considers the impacts of present-day decisions on a range of alternative futures and helps design research agendas and policies that are resilient to different future options [2,9]. A tool used in foresight is horizon scanning (HS) that aims to identify near- and long-term signals and trends of issues and challenges linked to a particular domain or topic. This study combines an analytical and participatory approach to implement a HS exercise of future developments that could potentially catalyse a sustainability transformation in the blue economy looking towards 2030 [10]. It derives trends about emerging topics, challenges and opportunities relating to the blue economy from a review of high-level international reports and studies. A workshop conducted with 29 scientists and researchers based in maritime universities in six countries in Europe served to brainstorm and prioritize future opportunities to advance science and research for a sustainable blue economy. This study forms part of a foresight exercise implemented in three phases—these are scanning, scenario, and strategy phases—whose aim was to explore future research and innovation directions for a sustainable blue economy (see [8]). The present research expands on the scanning phase implemented as part of the foresight exercise, to explore the approach used in identifying global developments linked to the blue economy and to investigate the role of expert participation in identifying and prioritizing future trends in the blue economy.

The outputs include 11 future trends cards delineating global developments in the blue economy and 7 integrated or cross-cutting trends and trend projections looking towards 2030. These outputs may be valuable to scientists as a source of inspiration for a future agenda for resource management and planning and could inspire new research and innovation directions to develop innovative sustainable ocean solutions. They can be used as evidence for decision- and policymakers to deal with future uncertainties about the blue economy, complementing quantitative forecasting exercises aimed at developing future scenarios of the oceans and related economic activities.

The remainder of the paper is organised as follows. Section 2 provides a brief overview of trends in the blue economy and outlines the salient characteristics of foresight and its use as a decision support tool in environmental management to then focus on horizon scanning as a tool for trends diagnosis. Next, Section 3 describes the methodology and the analytical and participatory phases of the study. The results are presented in Section 4. These consist of global developments derived from a literature search (presented as 'future trends cards' in Appendix A) and the themes mapped and prioritized by the experts in the participatory workshop. Section 5 includes a discussion to conclude in Section 6 with suggested areas for further research.

2. Theoretical Background

2.1. Future Trends for Innovation in the Blue Economy—A Preliminary Outlook

Realizing a sustainable blue economy requires knowledge, research, development and innovation as its main cornerstones. The UN Decade of Ocean Science highlights the potential for innovation of "finding solutions to climate change but also to enhance and preserve the biodiversity of the ocean, sustainably feed the population, end poverty and inequality, and stimulate a thriving and sustainable ocean economy." [11] (p. 3). Likewise, the Ocean Panel's vision for a sustainable blue economy emphasizes the role of innovation in scaling up the "ocean's tapped opportunities to deliver medicines, animal feed, fuel, new materials and carbon-storage solutions, the need for which has been further evidenced and strengthened by the COVID-19 pandemic and its repercussions" [12] (p. 9). New

technology developments in artificial intelligence, big data and robotics, could go a long way to support sustainable development and modernisation of traditional industries such as shipping, fisheries and tourism. Likewise, emerging sectors such as offshore renewable energy and blue biotechnology rely on innovative business models and on establishing cross-sectoral collaborations and partnerships to sustain their activities [5,7].

Advancements in global ocean monitoring and surveillance systems have started to reveal the impacts of climate change on ocean dynamics and coastal activities [13]. These changes call for innovative solutions and applications that are scalable across diverse marine and maritime sectors [14]. The needed innovation capacity can be achieved in part by establishing partnerships between academia, industry and government and by aligning priorities for research, technology development and commercialisation in the blue economy [15–17]. The importance of exploring new markets and establishing industrial service platforms to connect technologies and markets and link maritime industries with adequate financing for technology development are key elements for a successful blue economy ([18]. At present, the solutions to achieve a sustainable blue economy in an integrated way remain somewhat open in terms of opportunities that lie at the frontier of science and research. For this purpose, foresight can help identify knowledge gaps and opportunities in the blue economy [14]. This information can be valuable to build resilience and the capabilities needed to adapt to different future developments in the blue economy [8].

2.2. Foresight and Its Applications in Strategic Environmental and Resource Management

Foresight is a systematic forward-looking process that anticipates future threats and opportunities influencing complex systems in the long-term and contributes to developing adaptive strategies to guide decisions about the future [2,4,9,19,20]. It draws attention to the systemic and complex nature of an issue by analysing this through multiple and often competing worldviews and by drawing attention to the factors in the external environment—these relate to political, economic, social, technological, legal and ecological factors—that influence the direction and speed of change [21,22]. It has a practical application, in enabling decision-makers and scientists to consider the impacts of policy options and to prioritize decisions and research directions under different future scenarios [8,9].

Unlike forecasting that is associated with predictions based on past and present data [23], foresight generates a range of possible and plausible futures, and attempts to understand the challenges as well as possible solutions associated with achieving sustainability futures for the natural environment [2,3]. The literature addressing foresight and sustainable development underscores the importance of exploring multiple futures that integrate across disciplines, sectors, and spatial scales [1,8,21,22,24]. Foresight claims both a creative and participatory mission, aimed at exploring a wide range of perspectives on the uncertainties and potential impacts of future developments and in so doing spurs stakeholders to take action to shape future outcomes [25].

A foresight exercise involves the systematic use of different tools and techniques to explore alternative futures. Typically, these tools are deployed in key stages of the foresight exercise that consist in setting the scope of the exercise and collecting inputs; analysing trends and signals and interpreting information; prospection and scenario-building, and implementing the outcomes [9,26]. In this study, we report on a horizon scanning (HS) that is typically implemented in the initial stage of a foresight exercise because it helps frame the search process by defining the focal issues and defining the boundary of a system. The themes emerging from a scan provide input into scenario building and into developing alternative possibilities of how the future might unfold.

2.3. Scanning the Horizon for Emerging Signals and Trends

Horizon scanning (HS) is part of a futures toolkit [27] used as an early-warning tool to scope themes—potential threats and opportunities—that often lie at the margins of current thinking and that may forewarn of signals of change that alert scientists and deci-

sionmakers about emerging issues of importance in the medium to long-term future [28]. A HS exercise is often used to provide background information on the domain or topic such as generating information about trends. It also serves as an early warning system of emerging developments that can be used to help environmental planners, managers and decision-makers to prioritise research and develop resilient policies for environmental monitoring and conservation [29]. The aim of HS is to elicit a structured search, collecting and organizing information about current trends and emerging issues. HS creates awareness about potential opportunities and threats in the medium to long-term future, enabling organisations and firms to prepare for change by enacting timely responses in the way of new policy development or identifying research questions that need to be answered [19,29,30]. Thus, the aim of a scanning exercise is that of "monitoring existing problems, highlighting emerging threats, and identifying promising new opportunities" [9] (p. 531).

There are different types of 'issues' that emerge from a HS exercise: these could include continuing or emerging trends, weak signals, wild cards, and seeds of change that could become important in the medium to long-term future [9,28,30]. A trend typically represents a factor that is fairly well-understood. It is usually already widespread and active in society and typically describes how past and present developments are likely to develop in the future. Several global trends have a high impact on the oceans and coasts: e.g., climate change, population growth, depletion of fish stocks, human pressures on coastal areas. These are well-established trends that are likely to influence the medium to long-term future of the blue economy [31]. A trend is defined by the degree of predictability of the change it describes and how it moves in a specific direction over time [32]. However, arguably a trend can also describe what is new—an innovation or deviation from normality—referring to novel discontinuities that arise when unexpected connections between trends merge and come together, such as when concepts or themes are transferred between different contexts [33,34].

Weak or emerging signals are defined as the first symptom of change taking place—this could refer to an upcoming phenomenon or an emerging opportunity—that has a relevant and significant impact on an organisation or sector or country [27]. A weak signal may develop into a trend but at a given point in time, it is not mainstream and there are only indications of how this may evolve in the future and whether this is likely to increase or decrease in influence or relevance over time. Weak signals either serve to reinforce the emerging issue or identify modifications and developments. They refer to discontinuities that represent early warning signals of change to which organisations need to be alerted and prepared [28]. Wild cards are potentially shifting paradigms [1]; and seeds of change refer to how marginal ideas and innovations might evolve and become established as mainstream in a future [35]. Common for weak signals, wild cards and seeds of change is the high degree of uncertainty compared to trends.

HS provides strategic information about changes in the business environment, alerting organisations to new opportunities e.g., on the development of new markets or to possible threats on the horizon [19]. Cuhls stated that expert judgment is required following the information gathering in HS "for filtering, sense-making, and synthesizing or combining material from different angles and perspectives" [30] (p. 20). Thus, the sense-making phase often engages experts in exploring the inter-relations between different trends and drivers of change, their uncertainties and plausible impacts, allowing for a comprehensive exploration of possibilities around desirable and undesirable futures which can serve as input for building future scenarios to inspire innovation [36,37].

There is a paucity of research on the use of forward-looking tools for the management of marine and coastal resources. With the rapid growth of the blue economy and the heightened interest in its potential to fulfil climate change targets, by promoting concepts of 'sustainability', 'innovation' and 'resilience', there is need to explore how to channel investments in science and innovation to support these ambitious policy goals and match these goals with appropriate science-based evidence. To this end, this study implements

a HS exercise to gather futures intelligence about emerging signals and trends and their likely development towards a sustainable blue economy.

3. Materials and Methods

3.1. Overview

The study explored emerging signals and trends that are likely to grow in importance and have a significant impact on the future of a sustainable blue economy. For this purpose, the HS was implemented in two phases, first through a review of the literature mapping global developments and emerging trends related to the blue economy, and second through a participatory expert workshop involving scientists and researchers from the University of Brest (France), University of Cádiz (Spain), University of Gdánsk (Poland), University of Kiel (Germany), University of Malta (Malta) and University of Split (Croatia). These are maritime universities that formed part of the 'Universities of the Seas' (SEA-EU) alliance, a flagship initiative of the European Commission. The HS process is summarized in Figure 1 and discussed in more detail below.

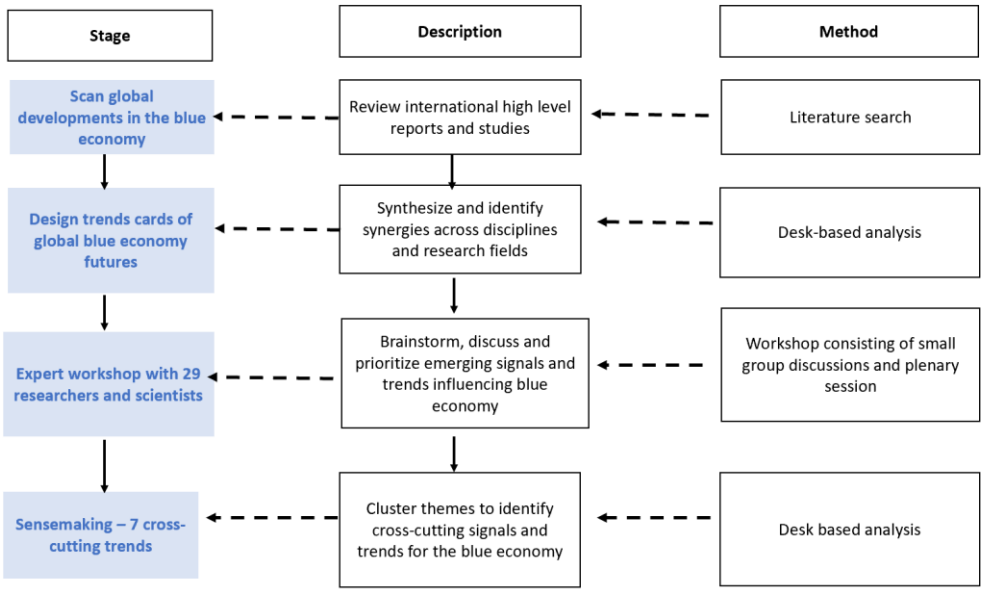

Figure 1. The horizon scanning process.

3.2. Scanning Global Developments in the Blue Economy

A literature search was performed to identify global trends that could represent potential threats or opportunities towards achieving a sustainable blue economy until 2030. An analysis of high-level international reports and studies addressing the future of the oceans and coasts [7,31,38–49] was conducted between September 2020 and March 2021. This was complemented by an analysis of the proceedings from online public stakeholder consultations and dialogues that discussed the future of the blue economy [50–52]. When scanning for global trends, the authors scanned broadly to identify current trends as well as signals of change influencing the future of marine and maritime activities. The objective was to obtain a bird's eye view on future developments in different areas of economic activity, value chains, technological advancements and innovation linked to the oceans and coasts.

A review of abstracts and report summaries was conducted to assess the relevance of the publications to the subject of 'future', 'ocean', 'marine', 'trend' 'new development', 'future potential' and 'blue economy' using Scopus and Google Scholar as the principal search engines. The main inclusion criteria were that the publications addressed global topics pertaining to the oceans and coasts and related economic activities, and secondly that they had a future-orientation seeking to address future developments in the marine environment. The analysis involved identifying the major trends and drivers of change in

political, economic and societal factors, technological developments and regulatory and environmental issues (these are PESTLE-type factors) that were mapped across diverse marine and coastal activities. For this purpose, the EU's classification of the sectoral activities that encompass the blue economy was used as a reference of the principle economic areas related to the oceans and coasts [7]. These include well-established sectors (fisheries, aquaculture, tourism, maritime transport and port activities) and emerging sectors such as blue biotechnology, ocean energy and maritime defence. The search outcomes were organised in a data sheet with a short description of the PESTLE factors and trends influencing each of the sectors. The search continued until no new developments or trends were identified.

3.3. Designing Trends 'Cards' of Global Blue Economy Futures

In the next stage, the global trends were clustered into themes by looking horizontally across sectors of economic activity and vertically along different PESTLE factors. The clustering of themes involved thinking beyond traditional disciplines and grouping themes or topics at the intersection of different fields and that cross sectoral boundaries. The aim was to identify developments and opportunities for technological advancements, new services, business models, cross-sectoral partnerships etc.

A series of 11 'trend cards' were designed that consist of (1) the trend description; (2) trend projection up to 2030 and (3) opportunities and challenges of the trend being realized. These are presented in Appendix A. The 'trends cards' proved to be an effective way to summarize the key issues pertaining to the future of the blue economy. They were distributed to the participants of an expert workshop several weeks prior to the event and served as a starting point for the experts to explore emerging signals and trends that could potentially impact a transition to a sustainable blue economy.

3.4. Expert Workshop

In June 2021, a full day online workshop was organised with scientists and early-stage researchers with expertise in a broad range of disciplines relating to the marine and coastal sciences. The format of the workshop was adapted from the methodology developed by [10] for horizon scanning exercises involving the participation of experts. The experts were organised into small groups of 5–6 individuals for the brainstorming and evaluation phases of the process; and then met in a plenary to rank and prioritize signals and trends emerging from the small groups. The groups were mixed to include both experienced scientists as well as junior researchers.

In the first phase of the workshop, the participants were asked to brainstorm about emerging signals and trends that are likely to impact the sustainable development of the blue economy by 2030. This allowed for a stage of divergent thinking where the participants could explore trends and emerging opportunities in the blue economy and map these across different sectors and disciplines, without focussing on a specific region or territorial boundary.

Then the participants were asked to rank the emerging signals and trends based on two criteria commonly used in horizon scans addressing ecological conservation and management [53,54]. These are: the degree of uncertainty and whether a future event will likely develop into an opportunity to think about in the future; and secondly whether the issue is likely to have a significant impact on the sustainable development of blue economy activities in the future. A qualitative scale was used to score each issue based on a scale of "high", "medium" and "low" to evaluate both criteria.

Finally, in a plenary session the participants were asked to score through a voting process the high importance and high impact issues to obtain a manageable list of trends and emerging opportunities relevant for strategic research activity and that could potentially lead to new solutions that support the sustainable growth of the blue economy towards 2030. A summation of votes (3 votes per participant) produced a ranked list of priority issues to take forward.

3.5. Sensemaking

In the post-workshop phase, the authors organized and sorted the issues prioritized and ranked by the experts by filtering issues that were not considered emerging or novel and by clustering similar or overlapping issues together [10]. In the process, not all relevant themes were retained, but only those considered to be directly pertinent to the goal of the HS exercise of identifying opportunities to advance science and innovation for a sustainable blue economy.

4. Results

4.1. Global-, European- and Regional-Level Themes and Trends

43 themes were initially mapped by the workshop participants, after data cleaning and eliminating duplicates and themes that refer to broad trends e.g., those on the state of oil contamination and disruptions caused by climate change—see Table 1. The participants were encouraged to identify trends and emerging signals at global, European, and regional levels. However, these geographical demarcations were considered artificial since the participants agreed that most of the issues discussed were of global importance and consequence.

Table 1. Trends mapped by participants in the brainstorming phase of the expert workshop.

	Emerging Signals and Trends		
Category *	**Global Level**	**European Level**	**Regional Level**
Ecosystem services	Sustainable fishing and aquaculture and fishing effort characterisation particularly in restricted areas. Industrial marine aquaculture and capture fisheries are expected to experience an annual growth in gross value added of 5.69% and 4.10% respectively between 2010 and 2030 [44] Sustainable tourism e.g., eco-friendly cruise ships, fast growth in nautical tourism. Ocean-based industries contributed roughly 2.5% to global gross value added in 2010 [44]	Zero-waste, circular economy. Diversified products from aquaculture. By 2030, it is estimated that circular economy initiatives could reduce EU carbon emissions by 43% [9] Increased demand for seafood products. EU citizens consume more than three times the amount of seafood produced within the EU and demand is anticipated to grow [9] Blue tourism: towards more sustainable coastal tourism in Europe. Seaweed for feed and food and high-value products.	New industries based on the use of subproducts or waste streams from related industries (e.g., fisheries, aquaculture).
Financing	Recognition of blue carbon markets, especially seagrass, and other emerging elements like fish carbon, whale carbon. SDG14 was the least funded SDG in 2019 and only 1.7% of national research budgets is allocated to ocean science [11] so that de-risking financing and developing innovative financing solutions is needed to mobilize public and private investments to sustain the ocean economy [49]	EU fishing agreements with small island developing states (SIDS) incorporated in conservation funds. Standardized definitions and rules for issuing green and blue bonds at EU level. Green bonds are expected to raise 30% of funds in the European Commission's 'NextGenerationEU' instrument for green investments [9]	

Table 1. *Cont.*

	Emerging Signals and Trends		
Category *	**Global Level**	**European Level**	**Regional Level**
Technology	Technology advancements replace fish protein and lipids. Biomaterials. Advance of underwater drones and other related technologies. Maritime transport—autonomous ships—cyber security. Alternatives to produce "clean water" at source. Smart restoration of degraded habitats. Smart bioplastics.	Autonomous technological systems as biomarkers of animal health, plant health. Innovative biotechnologies in the treatment of waste e.g., bioplastic materials derived from microalgae. A priority action defined by the Ocean Panel is that of developing viable and sustainable plastic alternatives to eliminate microplastics in the ocean [12]	Innovative fishing gear designs to reduce the number of overfishes and by-catches.
Monitoring and observations	Marine surveillance technology/human capital development for better management and monitoring of marine spatial plans. Integration of observations and model outputs to evaluate the effects of climate change on the state of health of ocean.	Centralised monitoring and data surveillance systems. An open data repository/database for sharing of resources/data to gain insights and for cross-sectoral collaboration. The trend toward digitalization of the ocean and useability of data supports the 'DestinationEarth' flagship initiative of the European Union to develop a digital model of earth [7]	
Governance	Multi-level cooperation among stakeholders in the blue economy.	Multi-level cooperation among stakeholders in the blue economy.	Stakeholder engagement in the sustainable socio-economic development of the territory. Synergies across different sectors, integrating supply chains and value systems. Transdisciplinary knowledge creation.
Policy and planning	Toward a universal definition for blue economy. Offshore renewable energy strategies. The compound annual growth rate for gross value added of offshore wind between 2010 and 2030 is 24.52% [44] Growth in marine genetic resources interest, research and services spurred by the Biodiversity Beyond National Jurisdiction (BBNJ) negotiations.	Politics related to sustainable food. Marine spatial planning towards achieving an equilibrium between economic development and marine biodiversity conservation. A growing trend to integrate an ecosystem-based approach to maritime spatial planning and to cross-border cooperation [7]	Increased conservation efforts around blue carbon ecosystems in regional Marine Spatial Plans. New job opportunities and gender inclusion in blue sectors. Streamlined use of marine and coastal resources across regions and nations. Improved coherence across sectoral policies and streamlined legislative processes.

Table 1. *Cont.*

	Emerging Signals and Trends		
Category *	**Global Level**	**European Level**	**Regional Level**
People	Mainstreaming ocean literacy. Improving livelihoods by creating blue jobs and blue innovation ecosystems. Establish citizen-researchers' relationships. Improved dialogue between academia and policymakers.	Urban expansion of coastal areas for improved quality life and remote working.	Exponential demand for sustainability products sourced from the marine environment. Citizen awareness and education to eliminate plastic pollution. Environmental education on the sustainability of marine resources and the impacts of climate change.

* The broad categories were assigned by the authors to group the themes mapped by the participants in the workshop. (Source: expert workshop)

As per Table 1, several themes refer to the continuation of present-day trends whereas others represent signals of innovative opportunities such as those linked to the development of global integrated ocean observation models or to the large-scale commercialisation of innovative bioplastics from microalgae. The participants were asked to consider issues that represent novel developments in the blue economy; but the search was circumscribed to the participants' own areas of expertise. Some of the themes identified focus on specific sectors and the ecosystem services these support (e.g., tourism, renewable energy, aquaculture) whereas others constitute cross-cutting themes (e.g., those related to governance and to the co-production and co-dissemination of knowledge and stakeholder collaboration).

4.2. Prioritized and Ranked Trends

Out of the 43 trends mapped, 16 themes were prioritized by the participants based on their degree of impact on achieving a sustainability transition in the blue economy and the level of uncertainty of future developments—see Figure 2 that illustrates the matrix of themes prioritized. For this stage, the participants claimed that most of the themes were equally important and impactful since they considered an investigation about the future of a sustainable blue economy to be well-rounded when based on all relevant sectors and related maritime activities. This made it difficult to differentiate the relative impact of different themes and as a result, most were categorized as "high impact" e.g., sustainable fisheries and aquaculture, tourism, and the role of marine spatial planning in resource conservation and management as seen in Figure 2. Most themes were ranked as being of "medium" to "low" uncertainty; whereas only five themes were flagged as highly uncertain in terms of the direction they are likely to develop in the future. Examples relate to the development of marine surveillance for resource monitoring and management and technology advances for the development of novel proteins and lipids.

Once the participants voted to rank the trends, it was observed that the votes were broadly distributed among the 16 prioritized themes as seen in the matrix in Figure 2. The top-ranked theme ('blue tourism') received 11% of total votes cast; the second-ranked themes (sustainable fisheries and aquaculture, zero-waste circular economy and innovative biotechnologies) together received 27% of total votes; whereas the third-ranked themes relating to education and to the development of high-value added products received 18% of the total votes. Several themes are very broad e.g., blue tourism, circular economy and sustainable fisheries; whereas others appear to be topic- or field-specific and possibly reflect the experts' areas of expertise e.g., marine surveillance and spatial planning.

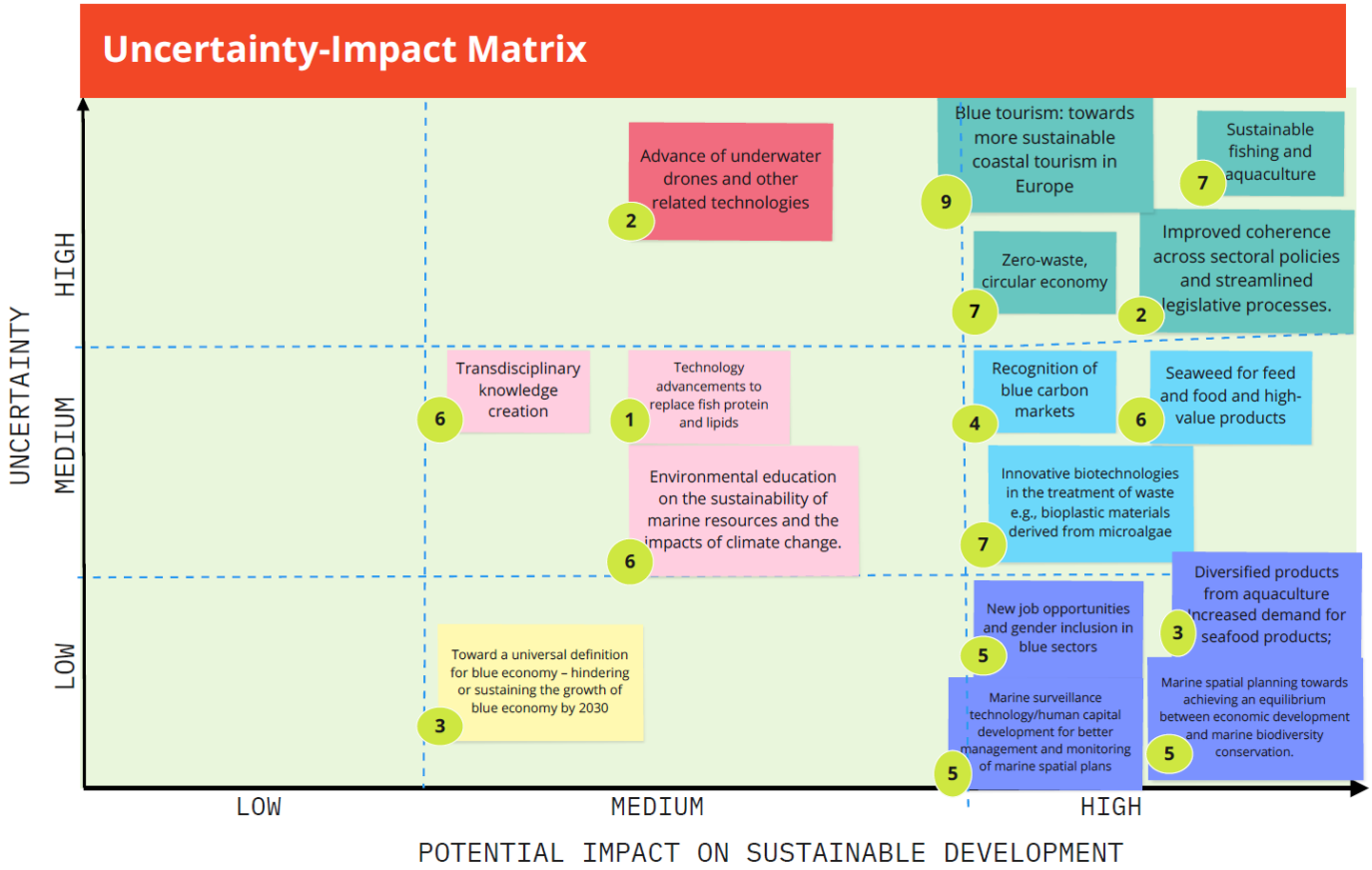

Figure 2. Matrix of 16 themes prioritized by the experts and results from the voting session (Source outputs from experts' deliberations).

4.3. Cross-Cutting Trends

The sensemaking exercise clustered the themes prioritized in the matrix in Figure 2 to produce seven cross-cutting trends [8]. Looking towards 2030, we elaborate on each of the seven trends and trend projections below:

4.3.1. Integrated Food Production Systems

Technology advancements enhance energy efficiency in the production of food and feed, reducing waste and enhancing the quality and diversity of the fish produce. In Europe, seaweed and algae production for higher-value food and feed products is an emerging topic. Mass cultivation of algae and the use of algae as a source of protein for food could realise their potential to replace fish protein and lipids. There are opportunities to reconsider the quality of our diets and the type of species consumed for food. The sustainability of food production systems is enhanced in terms of the benefits and trade-offs and synergies across the production, provisioning, and consumption of food whether sourced from fisheries or aquaculture and seaweed production. Innovative methods and approaches to produce food become established such as using genetic technologies to enhance the nutritional profile of algal biomass.

4.3.2. Co-Designing a Marine Science Agenda

The marine and maritime sciences increasingly rely on interdisciplinary and transdisciplinary research and on integrating knowledge from different fields of science. A dialogue amongst natural, social and political scientists and the arts is established based on a shared understanding of the blue economy and on the value of marine resources. The

co-production of knowledge about the state of the ocean is a priority as open ocean governance systems engaging broad societal actors (citizens, civil society organisations, hobbyists, nature groups, clubs etc.) are recognized as being central to decision- and policymaking.

4.3.3. Advanced Marine Surveillance and Monitoring for Integrated Management of the State of the Ocean

Centralised and integrated data platforms enable the harmonisation of data about marine and coastal processes and activities. Innovative marine surveillance and monitoring technologies enable scientists to develop a better understanding of the state of the ocean also thanks to advances in ocean robotics, digitalisation and artificial intelligence. Likewise advances in modelling and data analytics produce near real-time data on the state of the ocean. These data provide an evidence-base for valuing ocean and coastal resources and the ecosystem services they support, contributing to the growth of blue capital and blue carbon markets. A data revolution allows ocean data to be shared openly and transparently for better monitoring and management of marine resources and processes and to support decisions about maritime spatial planning. A persistent challenge is that of developing models that integrate bio-geophysical and socio-ecological data that is actionable and that can be used to support decisions about ocean resources.

4.3.4. Optimized Marine Resource Use for a Circular, No-Waste Blue Economy

A shift to a circular economy is accelerated through advancements in harvesting technologies and the improved coordination of existing infrastructures (e.g., co-use of fishing vessels and production facilities) and identifying innovative solutions to valorise different uses of waste (such as through biomimicry). Establishing new or circular supply chains is based on the effective management and integration of activities in key sectors and on establishing synergies between actors in different supply chains including aquaculture, fisheries, and tourism.

4.3.5. Advanced Biotechnologies for Water Purification & Wastewater Treatment

Water purification is crucial as pollution and contamination by oil and waste, and microplastics spiral. Although water treatment technology has been around for decades, there are interesting and innovative developments to make water purification sustainable. Innovative biotech solutions utilize enzyme technology, specialized microbes and bio-based filters to remove contaminants such as micro-pollutants. Nonetheless, the potentially unknown side-effects of releasing genetically engineered microorganisms in nature are a constraining factor as also the risks of releasing toxic biproducts from microbial plastic degradation.

4.3.6. Diversified Economic Activities to Sustain Multi-Use Coastal Spaces

Spatial and territorial conflicts sharpen as the coastal zone becomes a melting pot of blue economy activity. Coastal tourism expands as coastal locations continue to attract visitors for holidays, cruise and medical tourism. Achieving an equilibrium between tourism, ports and maritime transport and marine biodiversity conservation relies on diversifying economic activities in the coastal zone and establishing synergies with emerging sectors, sharing best practices in innovation, and developing sustainability strategies. Examples of these opportunities are linked to the development of renewable energy tourism, aquaculture linked to healthy food for tourism, and the implementation of 'no-take' marine protected areas for sustenance of traditional fishing communities.

4.3.7. Novel High Value Non-Food Marine Products

Commercial interest in novel non-food marine products grows, especially among blue start-up tech clusters, and leads to the production of a variety of innovative bio-based compounds including pharmaceuticals, nutraceuticals, enzymes, cosmetics, and other products such as synthetic substitutes for chemicals derived from fossil-based materials. Knowledge about marine genetic diversity remains one of the principal constraining factors influencing the potential development of industrial applications and innovations.

These cross-cutting trends transcend sectors and areas of industrial activity to explore future developments and the inter-relations between different topics and drivers. Thus, the HS exercise produced a limited but relevant number of future trends and developments likely to inform a science and research agenda towards a sustainable blue economy. The trends refer mainly to technological advancements and economic and environmental factors likely to influence future developments in the blue economy. Social factors are comparatively under-represented. However, the experts participating in the workshop reflected on the importance of social factors related to such themes as social innovation, community engagement, and ocean literacy and the impact of economic activities on the wellbeing of local communities as being central to a discourse on the sustainable growth of blue economy activities.

5. Discussion

5.1. Scanning the Horizon for Future Trends and Developments—Implications from the HS Data

One of the observations from the HS exercise outputs concerns the rapid technological advancements particularly in the use of artificial intelligence and robotics in marine and coastal activities. The reason for this is the growth of technology applications for use in ocean monitoring and for genetic diagnostics and preservation of biodiversity and applications in health [7,12,44,54]. The growth of scientific knowledge in the marine and maritime sectors creates new challenges and demands different approaches to synthesize, store and interpret data. In this regard, big data analytics offer an opportunity to develop global systemic data monitoring systems with a wide variety of applications in the marine and maritime industries such as providing support for the optimization of maritime operations and port activities [7,31]. There are opportunities for technological advancements in several other areas e.g., novel non-food marine products and the development of integrated zero-waste food systems. However, at present there may be gaps between research and commercial applications and an evaluation of whether the science system can support the development of these applications would be useful [3,5,8].

Some topics such as ocean monitoring and surveillance received more attention in the mapped trends (Table 1). This may in part be due to the background of the participants, but it may also reflect a greater awareness on the importance of developing systemic approaches for data collection and management and for the conservation of marine ecosystems and the resources that support ecosystem services. The significance of establishing multilevel governance and cooperation mechanisms for sustainable blue growth was raised in the trends mapped and this became an underlying theme throughout the HS exercise as it underscored the role of interdisciplinary cooperation in working towards a sustainability agenda.

The scan results emphasize the importance of developing synergies between scientific domains and sectors to develop innovative ocean-based solutions for the long term, as seen by the cross-cutting trends resulting from the HS outputs (Section 4.3). In practical terms, opportunities for collaborative engagement may arise through cross-sectoral synergies established between traditional industries such as ports, transport and tourism and emerging areas linked to renewable energy and blue biotechnologies [8,15,17]. These activities could contribute to establishing blue value chains either directly through core activities within the sector or indirectly by providing the necessary supporting services.

Investments in a science and research agenda require a broad view of the signals lying at the frontier of science and technology. Indeed, a HS exercise creates a greater awareness about future developments and possibilities related to new applications and

solutions to current problems. The outputs from the HS scan and the list of trends that emerged could be potentially useful for research and industry as well as for policymakers to determine whether sufficient attention is being given to specific areas of intervention. In this exercise, the data also point to a present gap which is that of better integrating the social and the natural sciences to understand the implications of current and future socio-economic, environmental, and geo-political developments and drivers to achieve a sustainability transition in the blue economy.

5.2. Reflections on Expert Participation in the HS Exercise

Foresight and horizon scanning addressing topics relating to environmental and resource management and to sustainability, typically involve experts because these are assumed to be attuned to developments in their respective fields. A survey undertaken after the workshop revealed that 80% (n = 29) of the participants claimed to have limited the search for emerging signals and trends to themes related to their areas of professional expertise and academic background. This confirms previous claims [19,28] that when scanning, experts drawn mainly from events and themes that lie close to their domain of knowledge and that experts may not necessarily be sensitive to searching beyond the margins of the known environment. Thus, a different group of experts participating in a HS may have selected and prioritized other issues to those emerging from this exercise.

The aim of engaging experts from different disciplinary backgrounds of the marine sciences was that of building a 'collective' intelligence of signals and trends that could potentially develop into innovative solutions and opportunities for a sustainability transformation in the blue economy [10,30]. 80% of the workshop participants claimed that the exchanges occurring in the breakout groups helped generate ideas about new developments and trends that were not within their radar and possibly would have gone unnoticed. Thus, expert engagement in the HS favoured the 'cocreation' of ideas about future developments from across disciplines and domains of the blue economy rather than having the experts think in silos by area of economic activity. The workshop initially aimed to elicit divergent thinking amongst participants through a process of brainstorming signals and trends on the horizon to then converge and prioritize those signals and trends with potential to leverage innovation for a sustainability transformation.

The HS outputs resulted in broad issues being evaluated as high-impact and high-uncertainty that potentially contribute to global developments in the blue economy. When prioritizing trends, most participants considered the impact these were likely to have on environmental preservation of ocean and coastal resources and on societal challenges. When asked to identify the factors that are likely to influence the trends developing in the future, 95% of the participants stated that the impacts of climate change are likely to drive the further development of the trends; 90% considered technology advances and innovative applications as well as governance of the oceans and its resources as influential factors; and 86% considered policy and regulatory regimes to play a role.

The participants needed some time to familiarise with the online platform used and the virtual setting of the workshop was not always conducive to establish a space for participants to engage informally and exchange research ideas and explore areas of mutual research interest.

5.3. Recommendations for the Use of the HS Data

The implementation and integration of the HS data into decisions about a research and innovation agenda for a sustainable blue economy were not part of this study. However, the outputs from the HS could inspire future research directions and thematic areas that are currently not well-addressed or are unexplored and represent an opportunity for further investigation [2,8]. The aim of the HS data is to support decision- and policymakers in better understanding the near-future trends and challenges impacting the marine and coastal environments and identify innovative solutions to address these [28,30]. The HS method could be easily learnt and implemented within policy units to identify knowledge gaps and

develop strategic policy. The data could also be useful for scientists, environmental managers and planners involved in interdisciplinary research to obtain information on global developments influencing the marine and coastal environments that could help address complex issues such as those relating to climate change and sustainable development.

The study offers insights for practitioners conducting foresight and forecasting exercises on trends in industrial and socio-economic activities as well as developments in science and innovation. For example, the trends 'cards' in Appendix A can be readily deployed as an icebreaker in a foresight exercise to engage stakeholders in exploring current and emerging topics in marine and maritime sectors and related industrial activities. The integrated cross-cutting trends that emerged from the expert workshop could serve as input for scenario building and complement quantitative forecasting techniques investigating the future of the blue economy. In this study, the trends inspired the experts involved in the foresight exercise to develop a series of 6 qualitative future scenarios to inspire research for a sustainable blue economy published in [8].

6. Conclusions and Areas for Future Research

The horizon scanning (HS) exercise in this study identified emerging signals and trends that if addressed, could have a significant impact on a science and research agenda for the future of a sustainable blue economy. The HS data were developed through consultation with a group of scientists and researchers from six maritime universities in Europe. The data provide insights on the opportunities and challenges for the future of the blue economy, looking towards 2030, that could inspire the development of innovative technologies, services, products and business models within diverse economic and industrial sectors linked to marine and maritime activities and the blue economy.

As stated in Section 5.2, the output from the HS scan is limited by the diversity of the participants' professional background and disciplines and reflects the perspective of researchers based in Europe. A future HS exercise could include experts with diverse academic, professional and cultural backgrounds to add different perspectives when identifying and prioritizing trends and emerging issues. The workshop was restricted to the participation of scientists. Other experts from government agencies and the private sector as well as stakeholders from not-for-profit organisations could be involved to offer their insights for a horizon scanning exercise. As stated by [9], participants bring different knowledge, worldviews, and experience that influence their creative contribution to the process and to making sense of different streams of information by identifying likely connections between different pieces of information. Additionally, the HS exercise identified emerging issues based on the "perceptions, interests and needs of those people who are involved in the process" [28] (p. 219). These factors, together with the issues selected for discussion by the participants, limit the applicability of the data for decision-making. Indeed, more research is needed to understand how the diversity of the participants (from different disciplines and professional and cultural backgrounds) influence the outcome of strategic foresight and HS exercises [9].

Despite these limitations, horizon scanning can be used as an additional source of evidence alongside decision support systems and quantitative forecasting models for environmental management and planning [2,4]. HS needs to be implemented as a sustained effort rather than as a one-off exercise. Organizations need to build a collective intelligence to monitor developments in the long term for these to have a significant impact on decision making and planning. Horizon scanning is typically undertaken by specialized units within both public and private organizations. This requires an effort in capacity building and training in the use of foresight tools and in embedding foresight in the organization's culture and decision-making processes [32].

Although scans may target a wide variety of users (including decision-makers, researchers, enterprises etc.) these users are not always directly involved in identifying and selecting the issues or themes for a HS exercise and need support to integrate HS outputs into strategy-building. In practice, many organizations lack institutionally embedded scanning activities and require external support, such as from foresight practitioners and specialized agencies to implement a horizon scanning exercise and to integrate the outputs from global and national-level scans into the organization's decision-making and research planning agenda. Future research could investigate how to effectively communicate the outputs of HS exercises to different audiences including politicians, policymakers, environmental planners, and decision-makers and develop tools and approaches tailored to their different needs and expectations. By using the appropriate search and sensemaking tools, HS outputs can be made more relevant to the foresight process by addressing specific challenges and contextual factors—including societal, cultural and political factors—within which a foresight exercise is implemented.

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Appendix A

In this appendix, we include the trends 'cards' and trend projections towards 2030 derived from an analysis of high-level international reports and studies on global developments in the blue economy.

Connectivity on the seas

Trend Projections by 2030:
Advances in ocean robotics, digitalisation and artificial intelligence facilitate data management and exchange. Automation and digitalisation represent the single most important marine technological development opening new avenues for research and innovation (e.g., in shipping, e-administration, etc.,). Data platforms aggregate decentralised data into a common searchable database on ocean resources, processes and activities providing actionable up-to-date data in near real time to predict extreme events, natural hazards, and climate and how these events impact human health.

Opportunities & Challenges:
There has been an explosion of new tools for marine exploration: submarines, underwater drones, etc., that have developed thanks to digitalisation and automation technologies. Augmented reality could provide the 'technological leap' needed for marine and coastal planning, surveillance and management. There is a big opportunity for a data revolution where ocean data is shared openly and transparently, allowing decision-makers to access data but also empowering the public to make decisionmakers accountable.
Large-scale efforts in ocean observations enable the establishment of a global ocean monitoring system for scientific discovery, environmental analysis and surveillance at sea.

Multi-use of ocean space

Trend Projections by 2030:
The sea is congested with many different activities and industries exploiting the ocean space, including for energy generation, sea mining, oil and gas exploration, fishing, new conservation and mining areas, and new aquaculture ponds. However, small-scale fishers find it hard to co-exist with the expanding development of these blue industries. Multi- use of the ocean space in many cases incorporates effective resource management and nature conservation needs. However, the extraction of fossil fuels continues to expand as common ocean infrastructures are used for offshore drilling and new alternative energies.
Maritime spatial planning is the principal planning tool to boost synergies between different sectors and across borders. An ever-growing number of marine and coastal-based activities become concentrated along the coasts.

Opportunities & Challenges:
Clear rules and collaborative approaches are needed for the multiple use of ocean space to accommodate various functions safely without additional burdens on the environment. In particular, synergies between the oil and gas industry and the generation of sustainable (wind) energy need to be achieved. Information sharing, capacity-building and technology transfer are required across emerging areas of the blue economy including marine bioprospecting, blue biotechnology, offshore aquaculture and deep-sea extractive industries.

Ocean Accounting and the value of Marine Ecosystem Services

Trend Projections by 2030:
The demand for ecosystem services grows exponentially. The oceans become the primary source of fish protein for human consumption, active compounds for nutraceuticals and pharmaceuticals, and rare earth elements. Next generation end-to-end ecological models develop improved descriptive and predictive capabilities to monitor the impacts of human activity on ecosystem services as well as the social and economic consequences and trade-offs. These models can account for the impacts of climate change on the "good environmental status" of the oceans and coasts that support ecosystem goods and services.

Opportunities & Challenges:
A lot needs to be done to generate “ready-to-use” knowledge and support decision/policymakers and scientists in futures planning on marine-based activities. Comprehensive marine ecosystem models that combine data from physical sciences and biological sciences, to understand ecosystem responses and their interactions with human activities represent an opportunity for ecosystem services to boom. New ecosystem service indicators that integrate both the monetary and non-monetary value of ecosystems, need to be developed; these need to reflect the impact of such services on culture and social wellbeing.

The -omics revolution

Trend Projections by 2030:
-Omics approaches and the high throughput sequencing of genomes lead to the commercial development of novel pharmaceuticals, and novel foods and cosmetics attracting the interest of significant venture capital. Besides genomics (DNA data), other approaches continue to develop including proteomics (protein data), metabolomics (metabolite data), and many others. The Arctic seabed and planktonic organisms offer new and immense opportunities to create innovative medicines, cosmetics and food. Genomic sequencing uncovers the evolutionary and ecological processes that equip species with a capacity to adapt to their changing environment. Synthetic molecules and organisms become widely adopted in industrial processes, as advances in scientific research shed light on the organisms to use in large-scale industrial production.

Opportunities & Challenges:
Current knowledge of marine genetic diversity is limited, and the development of industrial applications and innovations is not being realized to the full. There is a need to combine big data analytics and techniques to collate and analyse large amounts of biological and genetic data.

Blue Tech clusters flourish

Trend Projections by 2030:
Emerging technologies – including robotics, Information & Communication Technology (ICT), nano-biotechnologies - revolutionize the blue economy providing cost-effective solutions in diverse marine sectors including environmental monitoring, defence and security, and traditional maritime industries such as fisheries.
Innovations in the field of robotics enable scientists to venture deep into the oceans, in previously unexplored and remote regions. The miniaturization of biogeochemical sensors leads to innovative applications developed in marine genomics geared to monitoring contaminants and the state of health of the ocean. Innovations from the field of ICT such as hybrid data infrastructures and cloud find new applications for marine safety, resource management and conservation.

Opportunities & Challenges:
Maritime clusters based on innovative blue technologies promote cooperation between small and medium sized enterprises, large companies, research institutes and entrepreneurs. Ports become hubs for research and innovation, and collaboration with research laboratories, innovative start-ups and big industry. These initiatives attract investors to sustain innovative blue value chains.

Blue natural capital is the new asset class

Trend Projections by 2030:
Coastal ecosystems are acknowledged as important carbon sinks in the fight against climate change. Blue carbon sinks become recognized in carbon trading schemes and blue carbon banks and blue bonds are set-up. An ocean risk index and carbon resilient credits enable companies and communities alike to develop effective responses to ocean risks and restore protection to limit risks of flooding.

Opportunities & Challenges:
The standards for blue carbon markets are still in their infancy. New accounting systems are needed that index and measure the social and ecological value of blue capital. Market-based approaches based on trading blue assets develop in collaboration with private sector actors and 'blue capital investors' to finance a transition toward sustainability. Examples include blue carbon offset markets and introducing payments through tourist-fees.

Aquaculture and the future of food security

Trend Projections by 2030:
As wild fish stocks continue to decline considerably, and the oceans experience changing distributions and abundances of commercially valuable fish stocks, integrated multi-trophic aquaculture becomes established as the main source of protein for food production. Marine value chains based on the production and use of low trophic level species relieve pressures on the higher trophic levels and contribute to increasing the availability and production of food and feed.
At the same time, the effects of climate change on water temperatures and on the diversity of species lead to declining native species being replaced by new species that reduce the quality of farmed fish and shellfish.

Opportunities & Challenges:
Jointly developing open ocean aquaculture and offshore wind energy is a business opportunity.
Increased aquaculture production adds more pressure on wild capture fish used to produce fish meal. The way forward is to use biotechnology to improve fish health and reduce dependence on wild fish catches for feed.
Large scale aquaculture competes for space with coastal activities – a shift to open ocean aquaculture could help curb this challenge.

The Many Shades of Green

Trend Projections by 2030:
Mass cultivation of algae becomes the source of a variety of high-value commercial products including biofuels, animal feeds, pharmaceuticals and health products. Algal lab technology leads the discovery of innovative biomaterials, reducing our reliance on petrochemicals. Modern molecular biological techniques lead to advances in plant breeding and production techniques. The widespread use of algae as a source of single cell protein for food use becomes a substitute for animal-based protein. A new threat emerges as some biobased materials and biobased foods obtained from seaweed and microalgae accumulate toxic compounds.

Opportunities & Challenges:
The high diversity of algal species could help develop a host of new biobased products and replace non-renewable raw materials.
An opportunity for small islands and remote territories is to exploit biomass from the sea to secure their energy supply and as a food source.

A long drink of water

Trend Projections by 2030:
Securing adequate quantities of clean and safe water continues to be a challenge. As many regions struggle with changing weather patterns and decreased precipitation, they face increasing pressures to meet the demand for freshwater. The market for desalination keeps growing, with large scale plants based on reverse osmosis technology commissioned. However, desalination capacity is met with significant trade-offs in terms of energy requirements, carbon emissions and environmental impacts. High energy requirements and environmental impacts related to desalination technologies, drive the development of technologies for water reuse and new energy recovery systems.

Opportunities & Challenges:
Research and innovation spearhead the development of water reuse technologies and smart leakage reductions. Renewable energy driven desalination plants are promising, only if developed on a very large scale (as mega-desalination plants).

Harnessing energy from the sea

Trend Projections by 2030:
Ocean energy systems start to realize their full potential and make big leaps towards commercialization thanks to breakthrough technology developments especially in battery storage technology. The development of tidal energy is still limited by the availability and access to suitable marine sites; and blade technology does not yet ensure necessary durability in the ocean environment.

Opportunities & Challenges:
A grid structure is required that facilitates the integration of large-scale renewable energy and advancements in energy storage, with the aim of delivering energy for the residential and commercial markets.
Offshore energy wind services in the way of the operation, maintenance and service sector of offshore wind infrastructures are a means of harnessing the potential of ocean and renewable energy technologies and creating new value-added services.

Out with the old, in with the new?

Trend Projections by 2030:
Knowledge, R&D and experience from traditional maritime activities are exploited to create synergies with and enable growth of emerging sectors. Tourism, supports traditional sectors (such as fisheries, ports) and boosts activities in emerging sectors (linked to blue biotechnology, renewable energies). New synergies between coastal tourism and port activities arise through sharing best practices in innovation, competitiveness and sustainability strategies. Establishing efficient transport and waste processing facilities and logistics helps promote the cascading/circular economy.

Challenges & Opportunities
Many local innovations are led by innovative start-ups and small and medium sized enterprises that are the economic engine of coastal economies. The opportunity is for these to increasingly exploit indigenous and local knowledge and resources from traditional and artisanal sectors and develop innovations that drive the economies in coastal regions and lead cutting-edge research and innovation in emerging maritime activities.

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