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Published in:
Marine Policy

DOI:
10.1016/j.marpol.2021.104874

Publication date:
2022

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Spaniol, M. J., & Rowland, N. J. (2022). Anticipated innovations for the blue economy: Crowdsourced predictions for the North Sea Region. *Marine Policy*, *137*, 104874. [104874]. https://doi.org/10.1016/j.marpol.2021.104874

Marine Policy 137 (2022) 104874

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Anticipated innovations for the blue economy: Crowdsourced predictions for the North Sea Region

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ARTICLE INFO

Keywords:
Crowdsourcing
Forecasting
Innovation
Mission policy
Ocean infrastructure
Offshore wind
Ports
Shipbuilding
Sustainable blue economy
Wisdom of the crowd

ABSTRACT

The mission policy approach to the sustainable blue economy has identified as critical the ability to anticipate the emergence of a wide range of feasible innovations as they enter the transactional environment of organizations in the marine and maritime sector. This article contributes to that growing effort by harnessing the wisdom of the crowd and presents more than 60 crowdsourced, time-specific innovation forecasts expected to impact maritime, shipbuilding, ports, offshore wind, and ocean infrastructure. Data were collected in 2020 by the EU-funded Interreg VB PERISCOPE Project, a North Sea Region initiative to catalyze transregional innovation. The results can be used strategically to develop collaborative, transregional planning and policy for innovation based on data reflecting public expectations for the future. Years from now, this article can also act as a snapshot of public expectations at the onset of the decade.

1. Introduction

The mission policy approach to the blue economy has identified as critical the ability to anticipate the emergence of a wide range of feasible innovations as they enter the transactional environment of organizations in the marine and maritime sector. This article asks what innovations are anticipated to impact the marine, maritime, and ocean economies, and when in the future are they expected to materialize?

The mission policy approach presents an inspiring and ambitious vision of the future, for example, the United Nations' far-reaching sustainable development goals (Schot and Steinmueller [79]). Regarding specifically innovations, the premier challenge is to manifest "decentralized and dynamic innovation systems that include bottom-up innovation. beyond the control of central administrations" ([69]: 938). The underlying assumption is that societal-level problems can and should be broken down into discrete, manageable projects with clearly defined targets. Transitioning from "an open, multi-stage and selective process" capable of resulting in "a limited number of large-scale research and innovation initiatives; a process that would emphasize learning about a wide range of possible ideas for solutions from the early stage of programme implementation onwards" ([97]: 487). The challenge, therefore, scholars claim, is identifying feasible, tangible innovation opportunities within organizations' reach, that is, within their transactional environments [30,36,53–55,77].

This article contributes to that growing effort to anticipate innovations that will impact the blue economy by harnessing the so-called wisdom of the crowd. This presents crowdsourced, time-specific innovation forecasts in maritime, shipbuilding, ports, offshore wind, and ocean infrastructure. As its primary contribution, this article provides a series of sixty-three (63) forecasts based on nearly fifteen hundred (1461) discrete predictions produced by approximately five hundred (490) respondents. These public respondents, drawn from the North Sea Region, were asked to estimate the time to commercial availability of innovations relevant to marine policy, research, and industry. In the results section, the authors demonstrate how policymakers, researchers, and other organizational or governmental actors can utilize these results in the context of their efforts to shape a more sustainable blue economy.

The results section contains a highly summarized table featuring all of the forecasted innovations to provide a broad view of the many possible futures of the blue economy. For readers interested in more detailed forecasts, the results section contains another table – and additional tables, which are appendicized for sake of space – featuring forecasts expressed in terms of central tendency (i.e., median, mode[s], and mean), distribution (i.e., one standard deviation into the future),

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https://doi.org/10.1016/j.marpol.2021.104874
Received 31 May 2021; Received in revised form 15 October 2021; Accepted 11 November 2021
Available online 5 January 2022

and two additional vectors (i.e., the innovation is "already here" or that the innovation "will never happen"). Additionally, for readers preferring a visual representation of these data, in a series of figures, predictions for each innovation are depicted in violin plots. Finally, in a truncated subset of example presentation slides, the results section then blends details from the tables with violin plots to demonstrate how these data might be used in the context of a research or policy presentation or combined into figures appropriate for briefings, manuscripts, and grant application materials.

For ease of presentation, the forecasts are generally organized in five broad categories according to sector: 1) maritime navigation and operations; 2) shipbuilding, maintenance, and repair; 3) ports and cargo handling; 4) offshore wind, and 5) ocean infrastructure and harvesting. Note that data were collected in 2020 by the EU-funded Interreg VB PERISCOPE Project, a North Sea Region initiative to catalyze transregional innovation. The results can be used to develop much-needed collaborative, transregional policy and planning for innovation, as recommended in the literature on the blue economy from the mission policy perspective.

Additionally, years from now, this article will act as a snapshot of public expectations at the onset of the decade. In what follows, this article provides relevant background literature, describes the data collection and analysis techniques associated with the forecasts in the article, and then provides concluding remarks.

2. Background literature

This article draws on literature about an organization's transactional environment, broad policy and economic thought on blue growth, mission policy, and the increasing need for innovation policy portfolios.

2.1. Targeting the transactional environment

The useful distinction between an organization's internal operations and their contextual and transactional environments is most commonly associated with literature on strategic planning (see, e.g., [19,95]; Vasconcelos and Ramírez [92]). This research is vast, widely applicable, and dates back at least to Weber [98]). Organizations in the marine and maritime sectors devote significant time and resources to predict, forecast, and, thus, leverage their internal operations to generate measured, iterative gains. For example, research predicts demand for import services at ports [4] or shipping indices associated with freight rate forecasting [102], as well as temporal predictions for container dwell times [58] or ship arrival times [27,93].

Beyond managing internal matters, organizations also operate in two distinct environments, the contextual and transactional environments. According to Vascelos and Ramírez ([92]: 239), "from the point of view of the organization", the contextual environment is "composed of the factors affecting the organization, but upon which the organization has no power or even influence." These factors include, for example, macro trends, economic issues such as rising inflation, and new or existing legal regulations, to name but a few. Megatrends shaping the blue economy include, for example, shifts in "population growth, the rise of the middle class, and the rising demand for healthy and sustainable food products" ([75]: 6). The Marine Challenge Fund (2021) posited that the future of shipping innovation will be marked by the increased use of digital sensoring, the rise of larger mega-vessels, a shift toward greener ships, and the use of new energy sources in shipping. These driving forces are accompanied by thought on "sustainability as [a] megatrend" ([57]: 253). This aligns with Kersten et al.'s ([43]: 11) list of top megatrends shaping global logistics: sustainable practice, innovation, and the integration of information technology and security to create an even more networked economy. Other megatrends include artificial intelligence, robotics, big data analytics, virtual- and augmented reality, 3D printing, drones and autonomous vehicles, as well as blockchain (Friman et al. [32]; Pu and Lan [67]).

In comparison to an organization's contextual environment, their transactional environment is directly available; it is composed of actors and "elements with which the organization establishes direct contacts" and "with which the organization directly interacts" (Vascelos and Ramirez, [92]: 239). If the future of the blue economy is contingent upon technological advances in the marine sector, then this cannot be accomplished solely by close attention to external megatrends or internal operational forecasts. The goal must be to anticipate the entry of innovations into the blue economy that are within an organization's transactional environment. After all, operational forecasts are designed to optimize existing technology, and, typically, result in incremental rather than disruptive innovation. Megatrends will not yield concrete, actionable innovation for firms to make headway on blue growth.

2.2. Blue growth

A memorable phrase, Blue Growth is increasingly used worldwide. According to [8], "Blue Growth is underpinned by a discourse that frames a trajectory of development that can realize greater revenues from marine resources while at the same time preventing their degradation, overuse, and pollution" (see also, [21,22]). As such, [83] write, these "blue economy and blue growth concepts are at the heart of most maritime policy initiatives." But "blue growth is not a one-size-fits all concept;" it is, instead, "an adaptable framework that can be customized and applied differently across regions and to provide the most benefit to the stakeholders in each case" ([39]: 376).

The economic potential of Blue Growth rests on the notion that there is untapped potential in oceans, seas, and coasts (see, e.g., ECORYS, [17]). Ocean resources are thought to range from the physical, mineral, and biological, and are located above, below, and on the surface of the water, at the coastline, in the wetlands and shallow water, in the depths, and on the high seas and are designated as known, unknown, or known but yet unexploited. Typically, blue economies are categorized into two types: there are *mature* blue industries, such as maritime transport, shipbuilding, and port infrastructure, fishing, and offshore platforms for hydrocarbon extraction, and there are *emerging* blue industries, such as renewable marine energy production (or "blue energy"), marine biotechnology (or "blue biotechnology"), subsea mapping and mining, and numerous forms of aquaculture [18,48,66]. Most recently, the European Commission's Blue Economy Strategy has adopted the language of "sustainable blue economy," which "encompasses policies guiding the specific blue economic activities as well as the horizontal support instruments such as blue skills and careers, ocean knowledge and research & innovation, investment, ocean literacy and planning" (European Commission, [25]; see also, [90]: 293).

It is useful to imagine that the "blue" moniker parallels the shore-based "green" economy, in that both provide a framework for the holistic management of complex social-ecological systems and the preservation biodiversity to prevent their degradation, overuse, and pollution (Barbesgaard, [5]; [8]; FAO, [28]). For example, Burgess et al. [10] set ambitious goals to drive a blue socio-economic transition, which includes, according to [44], "smart, sustainable and inclusive economic and employment growth from the oceans, seas and coasts." In sum, the mission for a sustainable blue economy balances "economic activity […] with the long-term capacity of ocean ecosystems to support this activity and remain resilient and healthy" (*The Economist*, [85]: 7).

2.3. Mission policy

Mission policy emerged as a means to implement state-level goals thought to be of national importance. The Manhattan Project or Apollo Space Program are historical examples of such missions in the US context ([38]; Kaldewey, [103]; [97]). The ambitious vision of the future found in the UN's sustainable development goals are a good example of modern mission-oriented policies (Schot and Steinmueller [79]).

[69] differentiate between two types of mission-oriented policies; the type that "target the development of specific technologies in line with state defined goals" and a second type "administered by public agencies engaged in decentralized and dynamic innovation systems. beyond the control of central administrations." While historical examples tend to reflect political ambitions, recent mission policy has shifted to reflect an emphasis on economic competitiveness and sustainable innovation [11, 20,55,97]. The [23] current mission, for example, is "to make the blue economy more sustainable and climate-friendly, by promoting renewable and carbon-neutral technologies, reducing emissions from existing sectors and developing innovative solutions to reduce the environmental footprint of human activities."

2.4. Innovation portfolios

In this policy paradigm, scholars raise concerns over the political and institutional capacity to identify and manage, and this is crucial, a portfolio of innovation projects that can support the mission [29,97]. The concept of creating, monitoring, and anticipating mission policy portfolios of innovations is perhaps the most important challenge facing contemporary governments, corporations, and public organizations in the context of Blue Growth. According to Mazzucato (2018: 11), mission policy "set clear and ambitious objectives that can only be achieved by a portfolio of research and innovation projects."

The portfolio approach is a useful framework for conceptualizing the need to anticipate the emergence of a wide range of feasible innovations as they enter the transactional environment of organizations in the marine and maritime sector. After all, according to Mazzucato (2018: 12), finding new solutions to address mission objectives "requires a portfolio approach" characterized by a host of "different solutions" and diverse innovations that address "multiple actors, stimulating cross-discipline academic work,. collaborations across different industries; and. partnerships between the public sector, the private sector and civil society organisations." On balance, however, as Goldstein and Kearney [36] remind readers, in any portfolio of projects, including innovation portfolios, ultimately not all projects will necessarily be successful (see also, [76]). As we shall see, the combination of horizon scanning and crowdsourcing employed in the methods section of this article, is a practical approach for initiating a portfolio of potential future innovations appropriate for the practical execution of mission-oriented innovation policy (see, e.g.: [12]; EU, [25]; [35,56,62,89]).

3. Methodology

In this article, the authors deploy two methods. First, there was the *method of foresight*; using horizon scanning, the authors developed innovation vignettes embedded in a survey tool to gather public responses. Second, there was the *method of analysis* driving the presentation of data based on the wisdom of the crowd as informed by the results of the foresight process. Please note: while these two methods overlap significantly in practice, we distinguish between them for ease of presentation.

3.1. Scanning the horizon

In 2019, the PERISCOPE project, funded by the Interreg VB North Sea Programme, initiated horizon scanning activities. The EU (2017) defines horizon scanning as "the search for early signs of important changes in society, science and technology." The UK Cabinet Office [89] similarly summarizes horizon scanning as "an overall term for analysing the future" aimed at "considering how emerging trends and developments might potentially affect current policy and practice." The OECD [62] adds that horizon scanning is a "systematic examination of potential threats and opportunities, with emphasis on new technology." Horizon scanning, in sum, gathers information on current trends and signals in order to inform decision-making necessary to plan and coordinate activities in the near and distant future [12].

In the earliest phase of the horizon scanning process, the authors set the project's "heuristic search profile" ([3]: 210) by narrowing the scope of their scanning to exclusively marine- and maritime-relevant future innovations. Because the PERISCOPE project's objective is to catalyze innovation in blue economies, the authors exclusively identified technologies expected to impact these sectors (see e.g. [35]). As previously noted, to catalyze innovation in blue economies, collaboration within marine and maritime business ecosystems is increasingly required (O'Mahony and Karp [61]). Innovation-specific forecasts create the possibility or opportunity for actors that inhabit these business ecosystems to coordinate and plan. Alternatively, horizon scanning processes can also be undertaken in an attempt to articulate a series of broad trends, for example, technical or social trends, and subsequently plot those trends on a horizon line. This is effective when one firm is leading or otherwise at the center of the scanning process. This is because the individual firm already has a specific portfolio of innovations that they are planning to deploy at different points in the future. This does not work for groups of organizations that want to collaborate on future innovation opportunities. For actors in business ecosystems, while broad trends are not irrelevant, these actors simply cannot collaborate on trends; they can, however, coordinate their activities and orchestrate resources around potential innovations. To this end, the research team scanned the following sources for marine- and maritime-relevant future innovations: government ministries and agencies, non-governmental organisations, international organisations and companies, research communities, and on-line and off-line databases and journals. This process yielded a repository of 135 reports on the future of blue economies, dating back to 2009. These reports, in turn, yielded more than 200 potential innovations.

In the second phase, extensive background research was conducted on each potential innovation. This is necessary because potential innovations, as discovered during the first phase, do not appear "ready-made" and, thus, each needs to be processed and refined or reformulated. The creation of a catalog-like list of future innovations, which is not otherwise available in any industry, is a major research outcome of the PERISCOPE project and, thus, this article. Processing the raw text material from the first phase helped the research team to identify seemingly potential innovations that were, in fact, "already here." In an attempt to rescue these innovations from the proverbial dustbin, the research team attempted to reformulate them by asking, effectively, what's next? – to push them, creatively, to the edge of current understanding and, if possible, beyond (Könnölä et al. [45]). The reports, thus, were leveraged as inspiration from which technological capabilities and market applications could be extrapolated and formulated into novel innovation concepts. During the second phase, approximately 100 of the 200 + potential innovations were ultimately developed into consistently structured, comparable, descriptions of each innovation.

In the third phase, the formalized innovation descriptions were formatted into a survey, using the Qualtrics platform, and then rigorously pre-tested by the research team. Because our survey would ask respondents questions, the answers to which were forecasts, the innovation descriptions were revised to conform to the standards of good survey design. For example, we avoided asking questions with hidden contingencies and asked only one question at a time [31].[1] Additionally, the survey-based vignettes were tested for conformity with standards for the expression of technological forecasts (see, e.g., [52]), specifically, each description needed to:

1) articulate a single innovation capable of performing a functional task;
2) distinguish the new functional task from current practice;
3) justify the innovation in terms of potential benefit(s);
4) provide a non-technical description of the innovation; and
5) identify risks or barriers to the implementation of the innovation.

After this process, vignettes were consistently structured. If there was significant overlap between innovation vignettes, then those vignettes were merged such that all finalized vignettes were meaningfully different. Vignettes ranged between 100 and 300 words in length, averaging approximately 200 words each, supported by up to 10 external references, averaging between 5 and 6 references each. Each vignette was paired with a single, illustrative, high-definition image. By the end of phase three, the outcome was 63 total, finalized marine and maritime innovation vignettes.

3.2. Harnessing the wisdom of the crowd

Crowd-based decision-making has grown in popularity in numerous fields, ranging from management [9] to the arts [59]. This article adopts a sociologically-informed understanding of the wisdom of the crowd adapted for the purpose of creating innovation foresight. [84] argued in his landmark book, *Wisdom of the Crowd* – subtitled "Why the Many Are Smarter Than the Few and How Collective Wisdom Shapes Business, Economies, Societies and Nations" – that distributed decision markets should be effective in:

predicting certain social, political and economic events provided the following conditions are satisfied:

- a diversity of individual guesses must be amassed and aggregated; and
- guesses must be arrived at independently without group-level input and must not be centrally organized (i.e. must be decentralized).

Under these circumstances, the aggregate estimate of individual guesses is expected to, on average, outperform the best individual guess, hence the wisdom of crowds ([72]: 559–60).

While this summarizes Surowiecki's basic claim, there is a significant caveat. Surowiecki's model is based on discrete events with knowable or testable outcomes. Thus, the aggregate of individual guesses should outperform the best individual guess, for example, in identifying the location of a lost object or in estimating the raw count of objects in a container.[2]

According to Lanier [47], Surowiecki's model is a suboptimal approach to address problems that involve innovation or require creativity, and there is a fair and reasonable argument to be made that addressing, imagining, or otherwise predicting the future involves a modicum of innovative creativity. Moreover, according to Fowler's [31] touchstone text *Improving Survey Questions*, it is better to ask respondents questions based on firsthand information and personal experiences rather than hypothetical questions that require conjecture, guessing, or the estimation of something secondhand or based on something that has not yet happened in the future.

Still, as Lanier [46] also argues, the wisdom of the crowd is expected to work under circumstances wherein the answer or response is expressed or can be evaluated according to simple metric, number, or result, for example, "a single numeric value" such as a year or a date. Fowler [31] confirms Lanier's [46] insight on the utility of simplified answers, and suggests that while hypothetical questions should be generally avoided, they are by no means prohibited. Some questions, the answers to which are of considerable public interest, are unavoidably hypothetical in nature. For example, anticipating voting behavior by traditional polling methodologies or estimating the value of land, sea, or ocean environmental assets as a means to estimate policy support associated with, for example, increased taxes for environmental protection in the traditional contingent valuation method.[3] As such, asking respondents, using a discrete year as their response, to estimate the time to commercial availability of innovations relevant to maritime and marine industry, policy, and research both challenges and extends conventional thinking associated with the wisdom of the crowd as it is applied to the world of futures and foresight in this article.

In the survey, therefore, participants responded to the following prediction prompt for each of the finalized marine and maritime innovation vignettes: "On the sliding scale below, please estimate how many years from now the following innovation becomes accepted practice (i.e., is commercially available): that [task A is accomplished] with/by [technology B]." Actual examples include: "that containers are moved around in ports with heavy-lifting drones" or "sub-sea oil wells are plugged by thermite explosions." The sliding scale started at 0 and was bounded at 30 years. Respondents were instructed to place the scale indicator at 0 if they thought that the technology/solution was "already here." Respondents were also offered a checkbox to indicate if they thought that the technology/solution "will never happen." Please note that the combination of the bounded scale and checkbox was intentional. This forced respondents to differentiate between the event's plausibility and its possibility [68]. The respondent who rates the maximum of 30 years indicates that they believe the innovation will happen (i.e., that it is plausible). The respondent who selects the checkbox "will never happen" indicates that they believe the innovation is not possible, hence, the impossibility of the innovation. The point is to

[1] For example, a potential survey question, which did not last through the second phase of horizon scanning, asked "when will autonomous robots be used to clean litter out of inland waterways, and the plastic recycled into new products?" This potential innovation originated from our initial horizon scanning process, but additional background research confirmed that litter-collecting robots were emerging in numerous contexts, above and below sea level. Though dropped for other reasons, this example also violates another criteria, which is that good survey questions ask one question at a time, per standard practice in survey design [31]. In our case, each "question" is a forecast, and this question asked for multiple forecasts at once: (a) that robots collect litter; (b) that the litter be recycled; and (c) that the recycled litter be turned into new products. Because the survey asks participants to respond to the statement, "estimate how many years from now, that [technology x], used for [activity y], will become an accepted practice (i.e. commercially available) [0 = "already here"]," embedding multiple forecasts into a single question was not feasible. These sorts of potential questions were discarded or revised.

[2] For example, the simple, knowable, and non-obvious count of jelly beans contained in a large jar. The beans can, of course, be counted, and, thus, are surely knowable; however, with hundreds of small candies in a large jar, at first glance, the simple task of estimating the number of jelly beans in the jar proves to be a challenge. Under these circumstances, the average guess, for example, of 50 individuals guessing individually, is expected to be closer to the total number of jelly beans in the jar as compared to the "best" (i.e., closest) guess from any one individual. The upshot appears to be, per Suorwiecki's teachings, that there are some things that a group knows that no individual knows, and this may be one of the methods for assessing that potential reality.

[3] See, for example, Bateman and Wills, [104], Alberni and Kahn, [105], or McFadden and Train, [106].

distinguish innovations that are plausible, but in the distant future, from innovations that respondents believe are simply not possible on any timeline.

In sum, respondents were asked to estimate the time to commercial availability of innovations relevant to maritime and marine industry, policy, and research. In the results, forecasts for each innovation are expressed in terms of central tendency (i.e., median,[4] mode[*s*], and mean), distribution (i.e., one standard deviation into the future), and two additional vectors (i.e., the innovation is "already here" or that the innovation "will never happen"). We, thus, communicate the wisdom of the crowd based on measures of central tendency, which are also the most common measures for reporting forecasts [14,15].[5] Also, in this paper, it is crucial to understand that these results are not an "end" within themselves, but a means to spur additional future planning specific to the needs of an organization or forecasting efforts across multiple organizations [49].

To augment our numeric data presented in tables, and for ease of use, we also graphically display our results in efficient, highly-summarized visualizations. In particular, we employed a series of violin plots, which are similar to box (or so-called "box-and-whisker") plots, in that they visually demonstrate the distribution of, in this paper, individual predictions with the addition of a smoothed kernel density feature that improves visual interpretation.

4. Description of data

Data from our online survey were collected in November, 2020. A total of 490 respondents participated in the project from the North Sea Region, primarily hailing from the United Kingdom (49%), Denmark (24%), The Netherlands (4%), and Sweden (4%). In terms of age, respondents ranged from 18 to 64 years-old with an average age of 36 years-old. In terms of gender, 56% reported being male and 44% reported being female. Please note that while age and gender do not figure into the theoretical argument associated with the wisdom of the crowd, as compared to the North Sea Region as a whole, our respondents are, on average, younger than and more likely to be male than the general population. Each of the (63) potential innovations averaged 23.2 predictions, and ranged from 16 (the lowest) to 32 (the highest) total predictions.

The North Sea is relatively shallow and measures approximately 570,000 km2 [100]. It accounts for over 71% of all installed offshore wind power in Europe with an additional 48 GW expected to be installed by 2030 [99]. By the end of 2015, there were 1420 offshore oil and gas platforms in the North Sea [34]. Copenhagen-headquartered shipper Maersk accounted for around 17% of the world's merchant container fleet, owning 316 ships and chartering 422 more in September 2021 [82]. North of Scotland, the Orkney Islands claims to have tested 30 different wave and tidal energy system prototypes, more than any other single site in the world [63]. Additionally, the North Sea is home to three of the world's largest seaports: Rotterdam, Antwerp and Hamburg [100].

The results can be used strategically to develop collaborative, transregional planning and policy for innovation based on data reflecting public expectations for the future across the various sectors. In these data, respondents were, on the whole, of the public and, thus, "the crowd" and not experts, hence, the wisdom of the crowd. To understand respondents' familiarity of the technology and market in question, they were asked to indicate how often their work involved both the technology and market in question.[6] Regarding the technology in question, on average, 71% of respondents' work never involves the technology concerned.[7] Of the remaining, only 3% of respondents' work *very frequently* involved the technology in question. Similarly, regarding the market in question, on average, 73% of respondents indicated their work never involves the market under question.[8] Of the remaining, and 2% of respondents' work *very frequently* involved the market in question.

Additionally, to illustrate the range of predictions for the potential innovations in this study, 33 of the 63 innovations (or 52.4%) were rated by at least one respondent to occur at the maximum of the scale, at the year 2050. Using this metric, we distinguish "long tail" predictions from "short tail" predictions in that long tail predictions have one or more predictions set at 2050 (meaning the technology is plausible, not impossible, but set deep into the future) meanwhile short tail predictions have no predictions that reach the furthest edge of the window of future predictions. This distinction appears in each table as does a simple measure of distribution oriented toward the future, which, in this case, is expressed in terms of one standard deviation into the future beyond the median value.

There were 1461 total predictions. In terms of total number of predictions per segment, there were: 289 total predictions for maritime navigation and operations; 273 total predictions for shipbuilding, maintenance, and repair; 302 total predictions for ports and cargo handling; 293 total predictions for offshore wind; and 304 for ocean infrastructure and harvesting. In what follows are tables summarizing our results, violin plots that visually present them, and example presentation slides that demonstrate possible uses of results.

5. Results

Summary Table 1 presents each of the 63 innovation predictions in a single table. Each innovation is presented temporally, from the present to the more distant future, and organized according to five marine and maritime sectors, namely, navigation and operations; shipbuilding, maintenance, and repair; ports and cargo handling; offshore wind; and

[4] As a relevant historical aside, according to [96], Galton's [33] preferred measurement for central tendency is the median: "[a]ccording to the democratic principle of 'one vote one value,' the middlemost estimate expresses the *vox populi*, every other estimate being condemned as too low or too high by a majority of the voters." We include other measures of central tendency when harnessing the wisdom of the crowd; however, there is reason to believe that the median values are especially relevant in forecasting.

[5] Please note that "confidence intervals" have also been used in forecasting to indicate the range (i.e., an interval, for example, a price range) within which respondents are certain (i.e., are confident) that a value (e.g., an oil price) will fit within. This often takes the form of a response to a simple prompt such as: "please provide a range inside which you are 90% confident that you think oil prices will be at the end of the year." Confidence intervals, however, are not warranted in research on what [52] calls an innovation "breakthrough." This is because we are not predicting, in this article, a continuous growth curve or trend, extrapolated from past data, as in oil price predictions, wherein confidence intervals have been shown to be effective. While oil prices fluctuate, the breakthrough innovations do not; innovations are a binary outcome – by a certain date, they either have or have not emerged, if ever at all. This is sometimes considered the main difference between technology forecasting predicting interval outcomes and innovation forecasting predicting binary outcomes. There is essentially "no range" (or interval) for a binary outcome. Thus, the use of confidence intervals is inappropriate and lacks precedent for the innovation-oriented predictions that make-up our results, hence, they were not employed in this project.

[6] Respondents came from the following industries: Manufacturing (24.23%), Transportation and Warehousing (17.31%), Construction (13.46%), Scientific or Technical Services (13.08%), Telecommunications (9.62%), Software (5%), Utilities (4.62%), Information Services and Data Processing (3.08%), Market Research (2.69%), Oil and Gas (1.92%), other information industry (1.92%), other manufacturing, (1.92%), Government and public administration (0.38%), mining (0.38%), other education industry (0.38%).

[7] Additionally, 14% of respondents' work *rarely*, 7% of respondents' work *occasionally*, and 5% of respondents' work *frequently* involved the technology in question.

[8] Additionally, 13% of respondents' work *rarely*, 8% of respondents' work *occasionally*, and 4% of respondents' work *frequently* involved the market in question.

SUMMARY Table 1
Predictions, according to year (median), organized by sector into near-term (white, first-half, this decade), mid-term (light grey, second-half, this decade), and long-term (dark grey, beyond this decade).

Navigation*	Shipbuilding*	Ports & Cargo*	Offshore Wind*	Offshore Infra.*
2025: multi-purpose drone	**2025:** drone weld inspection	**2025:** smart port contracts	**2025:** turb. blade cleaning drones	**2022:** drone site inspection units
2025: drone rescue system	**2025:** drone vessel inspection	**2025:** drone document delivery	**2025:** wind farm inspect. drones	**2025:** drones protect fish farm
2026: aerial drone escort	**2025:** digital vessel twins	**2025:** AI-enabled RoRo shipping	**2025:** printed blade heaters	**2025:** robots repair platforms
2026: ship performance data	**2025:** anticipate passenger behav.	**2027:** 3D container scanning	**2027:** onsite 3D- printing	**2027:** wave-powered systems
2029: ships share weather data	**2026:** submers. scanning robots	**2030:** foldable containers	**2028:** autonom. de-icing drones	**2028:** smart weather buoys
2030: large ice-class vessels	**2026:** drones scan tight spaces	**2030:** autonom. subsea dredgers	**2028:** e-vessels recharge at farms	**2029:** reusable screw piles
2031: unmanned supply delivery	**2028:** remote operated vessels	**2030:** drone lashing operations	**2028:** drone maint. robots	**2030:** laser based communication
2031: renewable methanol	**2029:** repair hull underwater	**2030:** heavy-lifting drones	**2030:** wave/wind co-location	**2030:** fully electric fish farms
2031: air-based ship lubrication	**2030:** autonomous navigation	**2030:** light-weight container	**2030:** charging platform, subsea	**2030:** robotic decommissioning
2033: autonomous ships	**2030:** anti-fouling foil	**2030:** offshore container term.	**2031:** blades 3D-printed on-site	**2030:** sealing seafloor oil wells
2035: tide power offshor. refuelling	**2030:** fire-proof composite hulls	**2030:** micro-grids at large ports	**2034:** mobile wind platforms	**2032:** sustainable decommissioning
2040: underwater hyperloop	**2030:** use of anti-fouling robotics	**2030:** fully robotic lashing	**2035:** offshore wind kite farms	**2033:** thermal vent mining
		2035: ports run on renew. energy		**2035:** solar powered vessels
				2035: thermal power platform

*Each marine or maritime sector has a more detailed description of each innovation in Appendix A replete with more detailed prediction measures. Additionally, each marine or maritime sector has innovations visually depicted in violin plots available, by sector, in Appendix B.

infrastructure and harvesting. The results are further broken down according to near-term, mid-term, and long-term, based on differentiating between innovation predictions anticipated to materialize in the first-half of the next decade from the second-half as well as innovations anticipated beyond the next decade. Twenty-four percent of innovations are expected by the public within the five years following data collection in 2020. Fifty-four percent of innovations are expected in the mid-term, between five and ten years from data collection, thus, more than three-quarters (78%) of the 63 innovations presented to respondents were expected to materialize by the end of the decade. Twenty-two percent of innovation predictions, thus, are expected in the longer term, beyond this decade.

Each marine and maritime sector can also be understood, as individual sectors, in terms of how many innovations are expected to materialize in the near-, mid-, and long-term. For example, innovations in navigation and operations are expected on the farthest time horizon from the present – one-half of predictions are long-term and this sector features the most distant innovation from the present in 2050, the notion that an underwater hyperloop is used to transport cargo. Alternatively, innovations in shipbuilding, maintenance, and repair were all expected to materialize within the decade, but with only one-third (33%) expected within five years of data collection in 2020. Note that we caution readers from reading too much into the distributions of innovation by sector given that respondents were presented with a set of feasible, potential innovations based on a horizon scanning foresight process based on information available leading up to the year 2020 – we, therefore, caution readers to take this into account as they consider and use these results.

Innovations in each sector are also available in greater detail in additional tables, for example, Table 1 "Predictions for Maritime Navigation and Operations, baseline 2020 (N = 289)", below, and all of the detailed tables appear in Appendix A. Note that, in the title of each table, "N" refers to the total number of predictions, which is equal to the total number of respondents. Each innovation is expressed as a text-based "innovation concept" replete with a median year of prediction for the innovation, which is the basic information shared in the summary table.

Table 1
Predictions for Maritime Navigation and Operations, baseline 2020 (N = 289)* .

Innovation concept	Median (year)* *	Short or long tail	Mode (s)* **	Mean	avg + 1 std dev	% here already	% never happen
Commercial vessels are equipped with multi-purpose drones	2025	short	2025	Nov/2026	Jun/2032	4%	4%
Drone-delivered rescue systems respond to "man overboard" alarms	2025	short	2030	Jan/2027	Aug/2031	0%	3%
Aerial drones escort very large container vessels through the Northern Sea Route	2025.5	short	2020 (2030)* ** *	Dec/2028	Feb/2036	13%	4%
A central data repository is established to monitor global ship performance data	2026	short	2025	Jul/2027	Dec/2031	8%	13%
Weather data collected by ships is openly shared across shipping companies	2029	short	2025	Dec/2029	Feb/2036	4%	4%
Very large ice-class container vessels traverse the Arctic routes	2030	short	2025	Oct/2034	Aug/2043	0%	17%
Unmanned vessels deliver supplies and simple services to remote offshore installations	2030.5	long	2030	Feb/2034	Sep/2041	0%	4%
Renewable methanol is used as a fuel for powering long-distance ocean-going vessels	2031	short	2030	Jun/2033	Mar/2039	0%	0%
Ocean-going vessels' hulls and propulsion systems are designed for air lubrication	2031	long	2030	Jul/2034	Jan/2043	6%	6%
Containers navigate autonomously from the sea to their final destination and back	2033	long	2030	Aug/2034	Mar/2043	5%	32%
Hydrogen, produced at tidal plants, becomes commercially viable for powering 1 MW vessels	2035	long	2035	Mar/2035	Aug/2044	6%	9%
An underwater hyperloop is used to transport cargo	2040	long	2050	Jul/2039	Aug/2048	0%	4%

*Note that "N" refers to the total number of predictions, which is equal to the total number of respondents.
* * Medians expressed not as a single, discrete year (e.g., 2025.5) reflect a situation where the median – in this case, middle prediction – exists between two values when there is an even number of respondents. For example, a median of 2025.5 with a sample size of 20 implies that prediction 10 and 11 were 2025 and 2026.
* ** For bi-modal distributions, the second mode is expressed in parentheses after the first mode.
* ** * In this instance, there are three modes, all appearing equally in our data, which are: 2020, 2025, and 2030; we included the earliest and the latest to reflect the extension of the tail for these predictions.

Medians expressed not as a single, discrete year (e.g., 2025.5) reflect a situation where the median – in this case, middle prediction – exists between two values when there is an even number of respondents. For example, a median of 2025.5 with a sample size of 20 implies that prediction 10 and 11 were 2025 and 2026. Additionally, each innovation is labeled as a "short tail" or "long tail" prediction based on whether or not a respondent predicted that the innovation would materialize at the furthest possible year from the present, in this case, 2050. Innovations with a 2050 prediction were deemed "long tail" predictions and those without "short tail" predictions, which bear out visually in the violin plots, for example, in Fig. 1 (below). Mode and mean are also presented in the tables. For bi-modal distributions, the second mode is expressed in parentheses after the first mode. The mean estimate is presented in more granular detail than a single, discrete year, communicating at what point in the year, as expressed in months, the innovation was expected by respondents during data collection in 2020, with a baseline of January 2020. To present distribution oriented toward the future, the table also contains a date set one standard deviation beyond the mean, in this case, also expressed as both month and year. Finally, respondents were asked if the innovation was "already here," and the percentage of participants that selected this option is presented; respondents were asked if they expect that the innovation was "never going to happen," and the percentage of participants that selected this option is also presented. For example, for "Commercial vessels are equipped with multi-purpose drones," the median prediction from respondents indicates that they expect the innovation to materialize in 2025, none indicated that they thought the innovation would materialize at the far end of the date range (i.e., 2050); the mode prediction was 2025 and the average prediction positions the innovation as materializing in later 2026; the standard deviation was between four to five years, making the prediction based on distribution mid-2032; finally, 4% of respondents thought the innovation was already here and 4% thought it never would happen.

Results are also visually depicted in Fig. 1, and appear as violin plots. The median value is presented visually as a firm dashed line and quartile values are presented visually with a dotted line. The violin plots

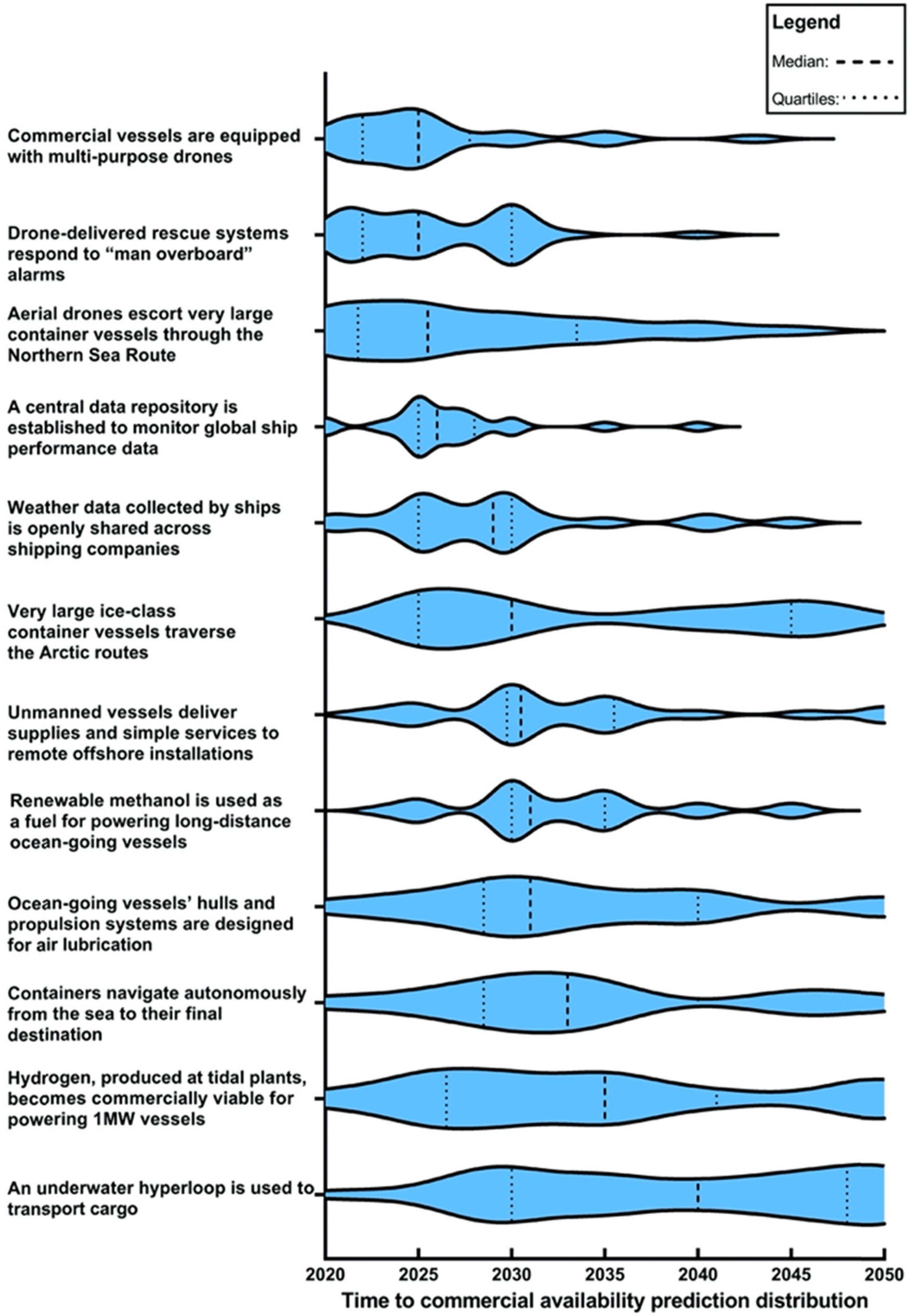

Fig. 1. Maritime Navigation and Operations.

demonstrate the frequency of predictions for each year; the wider the violin plot, the more predictions at that year; the thinner the violin plot, the fewer predictions at that year; if there are no predictions for a given year, it appears blank in the figure. The figure is organized according to the median year; violin plots at the top have median scores closer to the date of data collection, meanwhile the violin plots toward the bottom of the figure have median values further into the future.

One productive way to utilize these results is to combine aspects of the tables and figures to produce presentation slides or sets of slides, for example, of the drone innovations featured in this study. For example, in Slide 1 (below), ice-thickness measurement drones describe an opportunity where (as described in Table 1 and Fig. 1 above) *aerial drones escort very large container vessels through the Northern Sea Route* (or "aerial drone escort" in Summary Table 1). Presentation in such format allows for additional description, images, descriptive statistics, and descriptive statistical visualization (such as the violin plot) to be combined into informational material for presentation or printed and distributed as hand-outs. In this case, for example, if emphasis is on a particular aspect or quality of one of the innovations, then "aerial drone escort" could be reconfigured and relabeled for a specific audience, in this case, interested in how drones might assist ships in an escort capacity via sending data on ice-thickness in the North Sea (or elsewhere). Hence, these results are flexible and can be relabeled and arranged in a relatively sizable number of formations and configurations.

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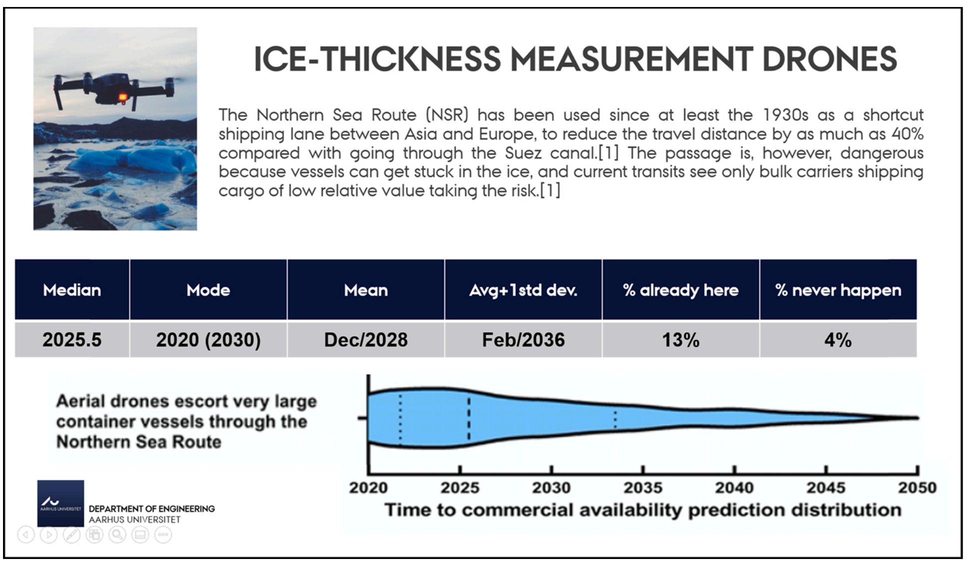
policy that is hard to reverse when new realizations and learnings come after its implementation. Acting too late can result in preventable danger and unnecessary accidents, or missed targets, such as emission reduction targets. If an anticipated technology is far away, but strategically important to achieving goals of the policy body (for example CO2 emissions reduction), policies can be made to speed up its development or market uptake. If an anticipated technology is on the doorstep, resources and priorities can be shifted to design policy to accommodate the new technology. If an anticipated technology is forecasted far in the future, then a policymaker can deprioritize addressing it, giving the market time to develop it, and thus gather more information before crafting better-informed policy.

Policymakers, in the end, will choose to focus on the technologies that are relevant for them in their jobs. Are they concerned about emissions reductions ? Or allocation of marine resources? Or the regulation of airspace? Or security/cybersecurity? Their domains of concern and thus the innovations of interest cut across the geographic divide that we have presented in this paper.



Please note that there are a variety of ways, beyond those presented in this article, to present, share, and manipulate or modify these results. The results are flexible and can be used selectively or in full. The authors are also available to create custom tables, figures, and slides for interested readers.[9]

6. Discussion and limitations

Predictions are useful to policy makers because it can improve the timing of policy intervention. Acting too early may lead to misinformed

While these results are a touchpoint for anticipating future innovation in blue economies, there are limitations to these findings which warrant further consideration:

We do not expect all innovations to impact all sea and ocean regions equally. Because these data were drawn for the North Sea Region, based on a horizon scanning process which overwhelmingly emphasized innovations expected to impact the North Sea Region, these findings may be used to initiate a discussion on innovation in any marine and maritime geolocation, but they should not be expected to apply to all geolocations equally.

As these results do not apply to every marine and maritime geolocation, they also do not include every potential innovation relevant to the marine and maritime sectors. Forecasts, thus, can be selectively grouped to reveal future and present gaps between innovations (e.g., cross-over technology or mediating innovations). While the initial horizon scanning process was robust, potential innovations in this study were down-selected based on their market potential in future transactional environments of relevant organizations involved in the Blue Growth transition. As such, important but not market-relevant innovations were excluded from this project (e.g., techniques to remove ocean plastic).

The method employed in this study associated with harnessing the "wisdom of the crowd" for the purposes of prediction is justifiable, but still experimental for innovation forecasting. As such, the authors stress

[9] Note to readers: All results can be rendered in textual format for e-readers. Textual summaries of our results may be useful for individuals using e-readers and also members of differently abled communities that may not easily navigate our tables or read our violin plots. They are available upon request. The basic formula, by way of example, is here:*Aerial drone charging stations are installed at offshore oil and gas platforms to enable remote operation***.** This innovation has a short-tailed bi-modal distribution. The median prediction for this innovation is 2022. The most common response was 2020; the second most common response was 2022. The average prediction was 7 months into 2023. At one standard deviation beyond the mean, into the future, the innovation, places this innovation at 7 months into 2028. 29% of respondents claimed this innovation is already here in 2020, while 5% claimed this innovation will not happen by 2050.

to readers that the results of this study are most useful for starting a conversation about innovation. These results are not definitive claims about innovation or even firm predictions for the future of any one innovation in particular. Each potential innovation needs to be monitored and updated as new information emerges. Again, these results serve as a starting point, for example, to initiate additional analysis and exploration through focus groups or Delphi studies. These results are not investment advice.

7. Conclusion

This paper reported on the results of the EU-Interreg VB North Sea Region PERISCOPE project, whose objective is to identify and forecast future business opportunities in the maritime and marine sectors. The paper's contribution consisted of 63 innovations for blue economies. Acknowledging the caveats that come with prediction, the pertinent question for readers is "what can I do with these predictions?" In what follows are options, by no means exhaustive, for the use of these predictions to understand the innovation space of the marine and maritime sectors now and into the future.

7.1. Roadmaps

Roadmaps are a flexible tool used to plot the pathway to achieve a goal, such as product development, and is commonly used in strategic and long-range planning [64]. This article's results can be used selectively or in full to initiate roadmaps for a wide range of applications, for example, policy-innovation roadmapping [56], industrial strategy roadmapping for governments [65], and roadmaps to internally manage corporation strategy [1]. Organizations of many types can also use the forecasts to create their own custom roadmap within their sector (e.g., ports) or a technology family (e.g., drones), or using a forecast to inform a technology roadmap of single opportunity. Alternatively, the results could be used to stress-test or augment existing roadmaps.

7.2. Radars

Foresight radars integrate and then display information about incoming events, technologies, and opportunities on a dashboard. Cisco [7] and Deutsche Telecom [70] use radars to manage strategic and competitive intelligence. Radar are useful for clustering innovations together into segments in order to display their relational qualities (see, e.g., DHL's radar[10]). This article's results can be plotted on a radar, and, over time, updated periodically as organizations and policymakers monitor incoming innovation in their transactional environments.

7.3. Business case

Strategic prioritization and management of innovation projects in firms help create new business and ensure future competitiveness [87]. Forecasts can be used to vet the business case for projects in an innovation portfolio. Firms can (and are) advised to further develop thinking around the concepts and forecasts, for example, by undertaking Delphi studies, in which experts attempt to reach a consensus on a series of forecasts over multiple rounds of discussion [71], or by undertaking key technology analysis to streamline enhanced capability development [40].

7.4. Pedagogical use

The results of this article can be used with students – graduate or undergraduate – to inform pedagogical activities associated research projects. In terms of scope, student-level research in various disciplines, touching on aspects of Blue Growth (biology, business, economics, engineering, etc.) could draw on these results as background literature. Likewise, in courses on planning and management, students could use these forecasts to initiate projects or exercises in horizon scanning [13], roadmapping [64], radars [70], and technology assessment [86].

7.5. Historical reflection

From a historical perspective, these results, many years from now, can provide a view into expectations at the turn of the decade. The intellectual linkages between historical analysis and futures and foresight science have strengthened in recent years, both among scholars (e.g., [16,78,80,81]) and, in time, conceivably, even in higher education curriculum [73,74]. Research on "counterfactual reasoning" (e.g., [26, 60]) and "futures past" (e.g., [6,51,73]) are a growing area of interdisciplinary research that these results could inform, in particular, on the promise of Blue Growth.

Additionally, the results from this study can be compared to future research on the blue economy employing the same (or a similar) methodology. Likewise, the methodology of this study could be reproduced in other sectors of the economy, in other places in the world, and, in particular, other mission-policy relevant initiatives.

Acknowledgement

EU-Interreg VB North Sea PERISCOPE Project, Grant/Award Number: J-No.: 38-2-13-17.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2021.104874.

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