9. Sustainable Blue Economy and Ecosystem Services

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9.1. Scope and Context

The Blue Economy (BE) explicitly recognises the use of the ocean space and its resources as an essential component of global economic growth and prosperity. At the centre of the concept is the conscious decoupling of socio-economic development and environmental degradation, and while the concept has many definitions and a range of names (Sustainable Blue Economy, Sustainable Oceans Economy, Blue Growth) it is a significant deviation from the past paradigm where the marine environment is an unregulated source of value and a waste dumping location with costs, financial and environmental, generally externalised from economic calculations. The BE is predicated on the utilisation of a range of provisioning and non-provisioning ecosystem services without depleting the natural capital on which they depend. Although estimates of the value of the BE vary, it is clear that the oceans play a crucial role in the global economy; around 90% of global trade is moved by ships[i], 3 billion people rely on the oceans for a significant proportion of their protein intake[ii], and the production of food from the ocean employs an estimated 237 million people (Teh and Sumaila, 2013). Further to their direct economic value, the oceans provide a range of ecosystem services crucial to humanity's wellbeing such as absorbing excess heat generated by global warming, providing 50% of the planet's oxygen[iii], drawing down globally significant quantities of carbon dioxide from the atmosphere (approx. 3 billion tonnes per year; Friedlingstein et al., 2022), and protecting coastal communities from some natural hazards. It is also home to a number of economic activities, such as tourism, renewable and non-renewable energy generation, and resource extraction. Between now and 2050, it is expected that the level of activity, the value and societal importance of the BE will significantly increase, with some estimates showing a double in the economy value by 2030 alone (OECD, 2016).

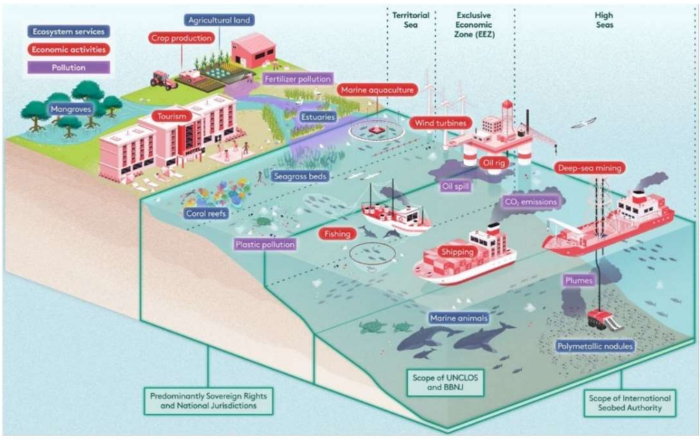
Commented [AS1]: General comment for all chapters: Not enough utilisation of emerging innovations in low cost ocean sensing systems. We have a once in a generation opportunity to change our understanding of the ocean, moving away from only having buoys, manned ships or satellites as our observing tools. It would be good to see a stronger focus on using these newer platforms as part of future infrastructure, supplementing the current network.

More earth science content.

Need to articulate UK research priorities, strengths and opportunities.

Commented [AS2]: Positively reviewed as a good start to this chapter - strong and clear on the nature of the problem (and data potential)!

Figure 9.1: The ocean economy, comprising marine ecosystem services, economic activities, selected polluting effects and international governance zones (Almeida and Reitmeier, 2024).



Source: Authors.

The knowledge requirements of the Blue Economy can be effectively conceptualised into two forms:

1. Those required by society to ensure that industries within the Blue Economy do not deplete the natural capital on which they and a range of other (global) stakeholders depend on. This requires that the impacts of the industries are effectively monitored and fed back to regulators within appropriate timeframes to avoid significant or unacceptable impact. When considering this requirement, it is crucial to understand the global nature of many sectors such as the fishing industry and in many cases their operation beyond national boundaries.
2. Those required by participants in the Blue Economy (including those investing within the BE) to ensure sustainability across all three pillars (economic, social and environmental). The knowledge required is multifaceted both in terms of spatial and temporal extent, and in terms of the parameters, and are often highly sectorial specific. These knowledge requirements are broader than the operational requirements of the industry and extend into the information required by financial institutions such as banks and insurers as well as investors to ensure the industries are meeting either internal Environmental, Social, and Governance (ESG) requirements or external drivers such as the European Sustainability Taxonomy or the Task Force for Nature-related Financial Disclosures.

It is also important to recognise that the Blue Economy represents an unparallelled opportunity for collecting ocean observations. The industry already collects vast amounts of data that could be utilised by researchers. Furthermore, the infrastructure and activity with the Blue Economy offers a unique platform for instrumentation, data collection and collaborative research.

9.2. Anticipated Scientific Developments by 2040

Commented [AS3]: Add in emerging issue of mineral extraction and info on changing climate impacts on marine infrastructure

Emerging science priorities (e.g. driven by societal needs, emerging applications, advances in understanding, model developments requiring improved process understanding)

The Blue Economy developments up to 2040 differ significantly from other themes within the Grand Challenge. Encompassing drastically different areas of research from Aquaculture to Shipping and Marine Logistics, development can come from a wide variety of areas. The consensus across the community is maximising our capability whilst minimising our environmental impact. Outlined in this section, we will discuss some of the overarching anticipated research areas that will become more prevalent by 2040.

Higher resolution monitoring and forecasting using remote sensing, such as satellite platforms, and in-situ measurements is a key area that is expected to develop, affecting all the Grand Challenges but of particular importance to the Blue Economy. Observing the changing climate and understanding how this could affect many of the Blue Economy areas is of vital importance, with examples such as: how will climate change affect aquaculture species in terms of growth and diseases; marine logistics and shipping being subject to more extreme weather events, such as rogue waves and extreme storms; and coastal maintenance changing with sea-level rise and changing tidal patterns. These examples act as only a few in a long list of areas where higher resolution monitoring and forecasting is key. Advances in machine learning applications are already demonstrating weather forecasting capabilities that are outcompeting conventional techniques, allowing the amalgamation of data across different spatial and temporal scales (e.g. Atmospheric Model and Discrete Aerial Vehicle), but this work is expected to expand to include ocean modelling and coupled atmospheric-ocean modelling.

Long-term environmental understanding requires data to be collected in the right location to encompass the most effective understanding of the changing environment. This data can comprise everything from scientific experimentation for oceanographic parameters, to direct collection of environmental information about the ecosystem. The current method in marine logistics is to plan data collection ahead of time, as scientific cruises or experiments, and then update our current understanding in models or as independent information after returning from the cruise. To collect the data most effectively, we should aim to reduce the amount of time between the planning and data collection to maximise science gain per day of operation. Anticipating changes up to 2040, we expect the marine science fleet to include more autonomous platforms, requiring planning across a much larger fleet of vehicles that must be reactive to the data being collected, updating their planning schedules to maximise the science gain whilst minimising inactive time, and subsequently Carbon cost. To achieve this anticipated development, we require automated planning methods that leverage Artificial Intelligence that can act as a decision support aid to operational planners to quickly plan new marine vessel schedules. During the data collection, the information can act to update our understanding of the changing environment, as we are already seeing with the development of digital twins, anticipated to be a key component of ocean understanding and forecasting by 2040.

9.3. Key Future Science Questions, Knowledge Gaps and Uncertainties

Summarise list (Noting we are making the case for both sustained and experimental Capability)

9.3.1. Fundamental Knowledge Gaps:

Future-Proofing Infrastructures Against Climate Change

- Research into dynamic marine spatial planning that incorporates environmental changes and sectoral impacts. For example, combining sea surface temperature data from various sources to create accurate global environmental maps.
- There is a need to develop methods to assess the cumulative impacts of multiple activities (e.g. offshore wind farms, shipping routes) on marine ecosystems. Understanding these cumulative impacts will support effective environmental management and policy making.
- There is a gap in research underpinning sectoral investment in offshore carbon storage. This area is currently driven by the private sector, and more scientific research is needed to validate and optimise these efforts.

Commented [AS4]: There is quite a bit of academic research in this area including in the UK, so would be good to bring onboard someone in the UK working on this.

Building a Unified Blue Economy

- Uniting the currently fragmented efforts of different sectors (e.g. energy, aquaculture, shipping, tourism) to establish collaborative frameworks that will help promote integrated approaches to marine research and management through sharing knowledge, resources, and best practices. This can be achieved through joint research initiatives, shared data platforms, and interdisciplinary working groups.
- Communicating the impacts of policy decisions, cutting-edge techniques and data to the wider, non-scientific community is essential. There is a need to develop more public engagement and education programs that translate scientific data and research findings into accessible information for the general public. This can help in raising awareness and creating sustained long-term support for marine conservation and sustainable practices.
- Research is needed to understand the ecosystem level trade-offs between different food production systems and ecosystem services. This includes evaluating how these systems can coexist sustainably, balancing food production with the preservation of coastal ecosystems.

Centralising Data Storage

Commented [AS5]: Add in info/ideas on central platform for sharing data

- There is a need to centralise data storage by bringing together private sector data, research data, and legacy data into unified repositories. This consolidation of data would enhance accessibility, integration, and utility across various sectors.
- Many valuable datasets only exist in non-digital formats. Digitising this legacy data and incorporating it into modern databases will boost the available data pool and provide historical context for current and future research.

9.3.2. Sector Specific Knowledge Gaps

Offshore Energy

- There is a knowledge gap in biodiversity baselining, which is necessary for understanding the environmental impacts of offshore energy projects. Research is needed to connect local and global environmental data to provide accurate assessments.

Aquaculture

- Understanding the impacts of environmental changes on species growth, disease, and ecosystem interactions within aquaculture is needed. To support the management of these impacts, developing ecosystem-wide models that integrate aquaculture data with broader environmental data will be needed.

Shipping

- The potential impacts of climate change on shipping patterns needs to be studied. This includes understanding how the zero-carbon shipping agenda and changes in port infrastructure will affect the environment and shipping logistics.
- Autonomous ships and enhanced requirements for metocean information/digital twins for operations/routine instrumentation of vessels?

Coastal Maintenance

- Research is needed to develop accurate long-term coastal forecasts to predict the effects of climate change, such as sea-level rise, on coastal regions. These forecasts can help in planning and implementing adaptive measures to protect coastal communities and ecosystems.

9.4. Future Observation/Product Requirements

In understanding the future observations and products, it is vital to understand the essential ocean variables (EOVs), their space-time scales and accuracies. Outlined in the Global Ocean Observing System (GOOS), there is a series of EOVs that must be collected to allow delivery of ocean forecasts and climate projections (e.g., currents, sea level, temperature, salinity, waves, ice, and biochemical variables; Ciliberti et al., 2023). Throughout this section, we will discuss some of these key EOVs and their dependence/connections to aspects of the Blue Economy.

Currently, key ~~physical~~ ocean variables (e.g. Sea State, Sea Ice, Surface currents, dissolved materials, biomass and diversity parameters) are collected from a series of different observation platforms: remote sensing satellite data, floats and drifters and ships of opportunity, marine autonomous platforms or fixed buoys/moorings. One positive change in future observations would be an expansion of the Ships Of Opportunity Programme[iv] (SOOP), where a core set of observations are mandated from all vessels, acting to reinforce measurements for these key ~~physical~~ ocean variables. Collecting these datasets repeatedly over time allow both for the establishing of a baseline to measure change against, and a record of changes to the environment on longer timescales. Additionally, the integration of physical, chemical and biological datasets

Commented [AS6]: Add in subject of climate / climate change impacts on marine infrastructure e.g. wind farms, seafloor cables

Commented [AS7]: What can we do to contribute increasing efficiencies of offshore (green) energy? This is part of UK marine research activity.

Commented [KH8]: Ideally this section would focus on the requirements for variables and products, process understanding (not drift into platforms and networks, which is section 4).

Commented [AS9]: Add in info on seafloor or sub-seafloor data that would be needed. Seafloor morphology, shallow samples, subsurface imaging and sampling - all relevant for marine infrastructure (its impacts and impacts on it), subsurface CO2 storage, seafloor/subseafloor resources (its impacts, or our sustainable extraction if we or industry go down this route).

Commented [KH10]: The EOVs in their entirety are designed to deliver to Climate, Operational Services and Ocean Health applications. Are you referring to a subset here?

Commented [KH11]: THere is already an established global ships of opportunity programe - Ship of Opportunity Programme (SOOP) – Global Ocean Observing System (goosocean.org) - I have started stimulating discussions with colleagues in the UK about what the future SOOP would look like - particularly as more observations become autonomous! Though these are not mandated (It has been discussed....)

Commented [KH12R11]: Perhaps reword to acknowledge the existing SOOP network to build on?

Commented [KH13R11]: The Australian SOOP programme is is a good example of a multidisciplinary SOOP programme. Ships of Opportunity - IMOS

Commented [AS14R11]: Added in refs for above

Commented [KH15]: Why only physics? See Australian SOOP programme (above) as an example (and link to 'ecosystem services' applications).

Commented [AS16R15]: Some potential text added for this enables a holistic understanding of ecosystem processes and functions, ultimately providing and understanding of the prevalence of ecosystem services, which have global implications (e.g., biogeochemical cycling, thermohaline circulation, climate regulation). Similar aspects have already been achieved in the aviation field, with all commercial passenger flights using Rolls-Royce engines having data collected and used in Met Office Climate models. Data collected underway from marine vessels would allow for data at a finer resolution temporal scale (hourly) but sparse spatial coverage along vessel tracks. Beyond the data collected, future requirements would have to leverage observational data at very different spatial and temporal scales, as is already being investigated in the realm of physics and observational informed machine learning and could be leveraged by the ocean physical models.

Understanding and supplying decision support to the Blue Economy to minimise the effects on fragile environments is key to mitigating anthropogenic effects on wildlife. This will call for information on wildlife-aware ship routing, requiring multiannual, time-stamped location data for migratory species and those local to the area, along with historical vessel strike occurrence data; damaging effects of ship equipment, using passive acoustic monitoring in overlapping areas of high vessel and species traffic; and wind farm/aquacultural effect on local ecosystems, requiring data on biogeochemical parameters across the impacted area. A future product requirement could be the inclusion of science in policy, leading restrictions and regulations, where toolkits are supplied to marine vessel operators to check that they maintain compliance. This would require a detailed connection between EOV forecasting to the maritime sectors. One sector where this is most applicable is marine shipping, where climate change is leading to the opening of new shipping routes through the Arctic. Environmental aware routing would allow governmental officials to minimise the detrimental effect of this shipping by supplying routes that both minimise the carbon cost, but also take into account the vicinity to migrating wildlife or close proximity to fragile environments (e.g. Sea-Ice Front).

Commented [KH17]: What information is needed? Noise/passive accoustics data? Others?

Commented [AS18R17]: Some potential text added for this

Marine logistics and management are required in order to meet Net Zero, with current operational planning applied only for one ship at a time, generally without the inclusion of real-time marine environmental variables. As technology develops and our ocean marine variable forecasts increase both spatially and temporally, it allows us the opportunity to develop tools that can minimise our non-productive use of marine vessels globally (e.g. ship alongside) by maximising the science collected per tonne of carbon emitted. These tools will also allow for cases where a ‘vessel of opportunity’, where data could be collected whilst providing another research cruise, minimising the requirement for standalone science cruises in that case.

9.5. General Description of Key Capabilities Required

Commented [AS19]: Point to the opportunities for greater engagement and collaboration and potential avenues for that.

I have suggested organising slightly around our physical infrastructure, digital infrastructure, and human capability.

Can we hone in on some actionable recommendations that could guide both NERC FMRI investment and how we target partnerships (I like the Platforms of opportunity one!)

This will help us collate some concise actionable recommendations!

Consider in general terms how satellite, in situ observations, models will contribute to addressing requirements. (optional).

The key capability requirements for the Blue Economy can be split into two basic categories that span both of the knowledge requirements identified in section 1 (those required by society and those required by the participants of the BE). The first broad category of capability requirements concerns platforms and sensors. The second category is around data collection, storage, integration, interrogation, synthesis and utilisation.

9.5.1. Observational Infrastructure

In terms of the platforms and sensors, the Blue Economy offers unparallelled opportunities to provide a platform for ocean data collection. This data will either be collected as an operational or regulatory requirement of the industrial activity, or using the infrastructure associated with the Blue Economy as platforms of opportunity (in a way that is analogous to 'Ships of Opportunity'). In either case, there is a clear need for better partnership between research institutions and the various actors of the Blue Economy.

9.5.2. People, Skills and Partnerships

Through the process of stakeholder engagement, it is clear that there is relatively low levels of engagement between the UK scientific community and the Blue Economy. A few examples exist, notably the ECOWIND and ECOFLOW projects. ECOWIND and ECOFLOW explore how offshore wind farm (ECOWIND), and renewable energy structure (ECOFLOW) development can coexist with the conservation of marine biodiversity and energy flow through ecosystems, developing our understanding of how offshore structures impact marine habitats and how to mitigate or avoid this, ensuring that the transition to cleaner energy sources does not come at the expense of marine ecosystems.

If the huge potential of the private sector for marine data acquisition is to be realised as a driver of marine science, then greater partnership between the two sectors needs be built. This partnership will require long-term investment in the human capital that is required to build meaningful relationships between the various parties involved and to build the trust that ultimately allows access to data and infrastructure. On top of the human capital investment required, the use of platforms of opportunity will require significant development of sensors that are suitable for these platforms, and compatible with the operational conditions on the platforms. Furthermore, if industry data is to be made available for scientific purposes, then there is a clear need to be able to access and use that data in a meaningful manner, which leads on to the second broad category of capability requirement.

9.5.3. Digital Infrastructure

To paraphrase Cliff Stoll and Frank Zappa, 'data is not information, information is not knowledge' and although data acquisition in the Blue Economy as described above offers huge potential, the value will only come if the data can be transformed into meaningful information and knowledge (and hopefully understanding and wisdom). The tools required to integrate, interrogate and interpret data were emphasized as key capabilities from the Blue Economy workshops and broadly fell into three groups.

1) **Internet of Things (IoT)**: The real-time acquisition of data from multiple platforms requires high levels of connectivity in the offshore space, along with the ability to store and integrate these data. This level of integration needs significant technological development for offshore and subsea environments.
2) **Artificial Intelligence (AI)**: AI is well suited to the development of insights from large heterogenous data in close to real time and can be used to support informed decision-making for industry, regulators and researchers.

Commented [KH20]: Nice!

Commented [AS21]: Positively reviewed as a good element of the chapter

Commented [AS22]: Include more info on UK levels of activity.

Commented [KH23]: I would generally agree that engagement in the Blue Economy is less of a focus in the UK compared to other countries. BUt what about projects such as ECOWIND and ECOFLOW?

Commented [AS24]: Potential text on ECOWIND/ECOFLOW projects

3) **Ocean Digital Twins**: Advanced modelling, reparametrized in close to real time from ocean observations, offers huge potential to predict environmental behaviour and the impacts of ocean-based activities. This can be used both for risk management and management scenario development, along with hypothesis generation for future research areas.

Specifically, the following examples were highlighted at the workshops:

★ Digital information and AI could support site usage optimisation, providing wide access to data (including from competing private sectors).
★ AI will be vital for optimal maintenance of energy and equipment, route and logistics optimisation, better site selection and licencing, and to integrate data from multiple sectors and sources.
★ Long-term forecasts can provide a better understanding of coming changes with a shifting baseline.
★ Real-time monitoring of ocean environments enables quick responses to hazardous events.
★ Creating a digital twin of offshore infrastructure can help the national grid forecast with changing weather conditions.

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NOTES

Science Requirements Framework Draft

Useful references for framing:

- ★ OECD – Marine Economy in 2030 https://doi.org/10.1787/9789264251724-en
- ★ The marine economy of the United Kingdom - ScienceDirect
- ★ The blue imperative: understanding interactions between the ocean, climate and economy - CETEx - compelling diagrams

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[i] https://www.ics-shipping.org/shipping-fact/shipping-and-world-trade-world-seaborne-trade/

[ii] https://www.worldbank.org/en/topic/oceans-fisheries-and-coastal-economies#:~:text=In%202019%20aquatic%20foods%20provided,the%20brink%20from%20anthropogenic%20impacts.

[iii] https://oceanservice.noaa.gov/facts/ocean-oxygen.html#:~:text=It's%20important%20to%20remember%20that,use%20oxygen%20for%20cellular%20respiration.

[iv] https://goosocean.org/who-we-are/observations-coordination-group/global-ocean-observing-networks/ship-of-opportunity-programme-soop/