INSPIRe Integrity

High Level Cost Benefit Analysis

D9.1 WP9 Report

FINAL

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2 ACRONYMS

2.1 Acronyms

Table 2-1 Acronyms and definitions used in D9.1 report

Acronym	Definition
AWS	Archimedes Waveswing
BCR	Benefit-Cost Ratio
CAPEX	Capital Expenditure
CBA	Cost-Benefit Analysis
CCS/CCUS	Carbon Capture and (Underground) Storage
CO_2	Carbon Dioxide
DFMC	Dual Frequency Multi Constellation
DNV	Det Norske Veritas
EEZ	Exclusive Economic Zone
EGNOS	European Geostationary Navigation Overlay Service
EMEC	European Marine Energy Centre
ERRV	Emergency Response and Rescue Vessel
ESA	European Space Agency
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GVA	Gross Value Added
INSPIRe	Integrated Navigation System-of-Systems PNT Integrity for Resilience
IMO	International Maritime Organisation
MaRINav	Maritime Resilience and Integrity of Navigation
MGRAIM	Maritime General RAIM
MPA	Marine Protected Area
MPS	Marine Power Systems
MRAIM	Maritime RAIM
NAVISP	Navigation Innovation and Support Program
NCMPA	Nature Conservation MPA
NPV	Net Present Value
NSTA	North Sea Transition Authority
OEUK	Offshore Energies UK
OPEX	Operating Expenses
PNT	Positioning Navigation and Timing
RAIM	Receiver Autonomous Integrity Monitoring
SAR	Search And Rescue
SBAS	Satellite-Based Augmentation System
SoL	Safety of Life
SouthPAN/SPAN	Southern Positioning Augmentation Network
STS	Ship-To-Ship
UK	United Kingdom
UKMED	UK Marine Energy Database
USD	United States Dollar
WP	Work Package

3 INTRODUCTION

3.1 INSPIRe project and report aims

This report presents the results of a Cost-Benefit Analysis (CBA) of the INSPIRe concept. This concept has been defined in other Work Packages of the INSPIRe project, which has been undertaken on behalf of the European Space Agency via the Navigation Innovation and Support Programme (NAVISP). The INSPIRe project builds on an earlier NAVISP-funded project named MarRINav.

The INSPIRe project defines, implements, and tests various technologies which monitor the integrity of a marine vessel's PNT information and can act together to issue an alert when the vessel's GNSS information should not be used for navigation. The objective of this report is therefore to provide information on the affordability and overall socio-economic benefits to the UK that could be delivered by the development of such a maritime user-level integrity solution.

3.2 Scope of the analysis

The analysis underpinning this report consists of a Cost-Benefit Analysis that considers a number of use cases in the maritime domain, with a primary focus on the socio-economic benefits that these use cases generate for the UK and how these are impacted in scenarios where integrity information could be critical for operations. These operations include safety of life operations, which are expected to increasingly benefit from autonomous activities and hence increase the value of integrity information over the next few decades.

The use cases are drawn from Work Package 1 of the INSPIRe project. INSPIRe has classified maritime use cases according to integrity need by attributing each use case to navigation phase performance bands established by the International Maritime Organisation's (IMO's) standards A.1046 and A.915.

The CBA considers the central economic case of the wider UK socio-economic benefits. The benefits measured account for the difference between the estimated loss of economic value resulting from the specified navigation failure events that occur due to a lack of integrity information[1] and the reduction in this estimated loss attributable to the INSPIRe solution. The cost data is drawn from the reports of Work Packages 5, 6, and 7, and covers upfront investments necessary to develop and deploy INSPIRe, annual delivery costs, and any other recurring costs.

Three separate approaches to providing integrity as part of the INSPIRe solution have been investigated elsewhere in the INSPIRe project and reported in deliverables D5.1, D6.1, and D7.1. The analysis presented in this report considers the ability of each of these to provide sufficient integrity information for each use case, with their respective estimated development timelines and theoretical capabilities serving as critical inputs.

3.3 Methodology

In this analysis we draw on estimated costs associated with the development of various approaches to delivering the INSPIRe integrity functionality. These costs are compared with the benefit such a functionality would provide to the maritime industry and wider UK society. These benefits are specifically the socio-economic loss that is avoided through the provision of integrity information at the point where navigational errors occur.

A scenario-based approach is used to estimate the costs and avoided loss of economic value. For example, if £100k of economic loss is expected per hour of navigation errors in a UK port, and INSPIRe-provided integrity information is expected to limit the loss of

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[1] An event where a lack of reliable integrity information in a specified area means that navigational errors occur

operational capacity by 50%, then the benefit provided would be estimated as £50k per hour of each navigation error expected. The definition of these navigation error events and the provision of integrity information is considered in more detail in Section 6.

Given that costs and benefits are distributed over time, it is necessary to discount their value to account for the time value of money, and thereby ensure comparability. We use a discount factor of 3.5% per year (following standard UK Government practice as specified in The Green Book) to compute the Net Present Value (NPV). The NPV is the difference between discounted benefits and discounted costs. If the value of NPV is positive, then the investment opportunity is recommended; if the NPV is negative then the reverse is true.

The results of the analysis also include the benefit-cost ratio (BCR) which can be used to compare the relative profitability of projects. If the resulting BCR is greater than one this indicates that the project is economically worthwhile; if it is less than one then it is recommended that alternative projects are investigated.

4 TECHNICAL INPUTS

4.1 Work Package 1: Systems Engineering support

Work Package 1 included consolidation of requirements into a single set to form the basis for the rest of the project. It further verified the fact that the various technical solutions can be brought together in a system-of-systems solution.

4.1.1 Use cases

This Work Package provided a set of use cases considered applicable to INSPIRe. The use case activities focus on above-water vessel operations. This list is defined based on the analysis of MaRINav results.

This list of use cases was further down-selected so that only those where the integrity need was found to be 'High' on a 'High-Moderate-Low' scale were assessed in this report.

4.2 Work Package 5: Develop prototype EGNOS monitoring software

Work Package 5 designed, developed, and estimated key future development parameters for a prototype EGNOS monitoring software that enables EGNOS to be used for critical applications and to provide timely warning messages to users when needed.

4.2.1 Development costs

One key set of inputs from this Work Package were estimates of the development costs associated with moving from a prototype of the EGNOS Monitor service to a fully functional service. These costs were estimated in the D5.1 EGNOS Monitoring report, and are summarised in Section 8 of this report.

In addition to the nominal amounts of spending required to achieve functionality and wider service roll-out, the timing of these costs are crucial inputs for a Cost Benefit Analysis. These inputs were derived from the D5.1 EGNOS Monitoring report.

4.2.2 Development timeline

As the EGNOS Monitor service is developed it is expected that it will improve performance in a series of continuous steps. Estimates for this performance were derived from the WP5 report and discussion with technical experts who input on the same report.

Guidance on an indicative development timeline suggests that such an EGNOS monitoring service network could be built within two years of the end of the INSPIRe project. Despite this technically marking the point where the service is operational, zero practical functionality is expected from the system until Satellite-Based Augmentation System (SBAS) aviation approaches are re-established in the UK. This is because no other UK users are expected to require an institutional Safety-of-Life (SoL) liability guarantee to be in place to be able to operate and use SBAS – and it is this demand that will drive the uptake of such a service. It is anticipated that these aviation SoL SBAS approaches are able to be re-established for UK airports around one year after the network is built – or within three years of the end of the present INSPIRe project phase. The EGNOS monitoring service is therefore expected to provide zero functionality until 2027 – when it begins to deliver 100% of its potential.

4.3 Work Package 6: Develop prototype RAIM availability prediction tool

Work Package 6 modelled the availability of Receiver Autonomous Integrity Monitoring (RAIM) for combinations of GNSS frequencies and constellations, building on the RAIM algorithms developed in WP2 and WP3. The tool aims to predict RAIM availability across the UK to the limits of the Exclusive Economic Zone (EEZ).

4.3.1 Development timeline

As the M(G)RAIM service moves through development phases it is expected that it will achieve gradually increasing performance levels, relative to the expected performance once the infrastructure is fully implemented at the system level, tested, and finally implemented at the user level. Estimates for this performance relative to development phase are important to gain a sense of how much value is provided by the technology throughout its development phase. These estimates were derived from the WP6 report and discussion with technical experts who input on the same report.

A diagram summarising the various development stages of the proposed service is included in D6.1, and is presented below. To summarise at a high level, the first stage lasts at least 18 months, is followed by the second stage, and this second stage lasts at least 10 years (including time for increasing penetration of the solution – the technical development is expected to be shorter than this). The second stage includes ‘penetration of… proposed solution’, and hence it is assumed that the solution is partially functional at the beginning of this second stage.

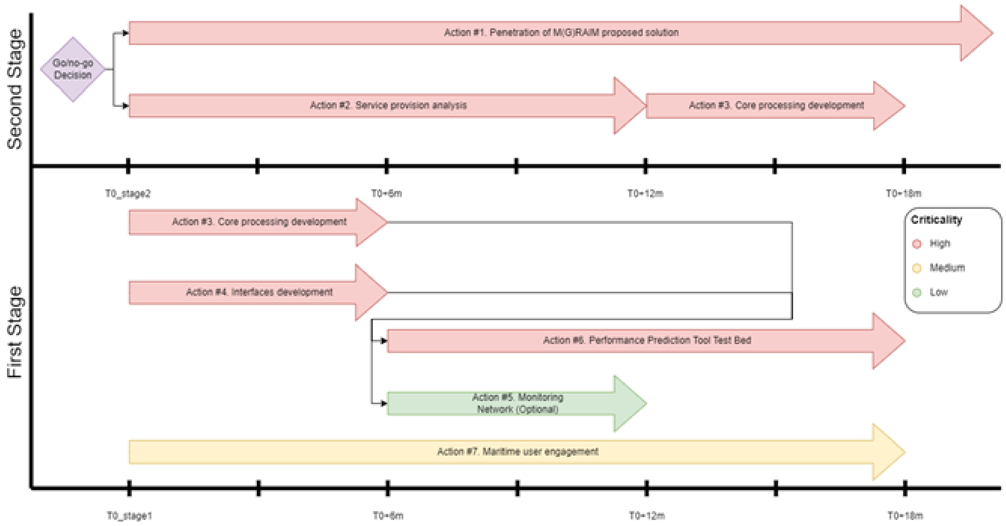

Figure 1 – M(G)RAIM Service development timeline schematic

The development timeline is modelled as the M(G)RAIM solution providing 0% of its potential to users until at least 18 months following the end of the current INSPIRe project – set as 2026. Following this we model 90% of potential functionality as being provided, growing rapidly over the next 2 years to 100% in 2028 as the proposed solution finishes development.

4.3.2 Development costs

One key set of inputs from this Work Package is estimates of the development costs associated with providing the M(G)RAIM service. These costs are estimated in the D6.1 RAIM prototype report, and are summarised in Section 8 of this report.

In addition to the nominal amounts of spending required to achieve functionality and wider service roll-out, the timing of these costs are crucial inputs for a Cost Benefit Analysis. These inputs were derived from the D6.1 RAIM prototype report.

4.4 Work Package 7: Develop & test DFMC integrity monitoring

Work Package 7 investigated the concept and specification of an integrity monitoring system for dual frequency multi-constellation (DFMC) GNSS over the UK EEZ based on UK onshore monitoring assets only. It ultimately produced estimates of the cost and development timeline of such a DFMC Monitoring Service.

4.4.1 Development costs

One key set of inputs from this Work Package were estimates of the development costs associated with providing the DFMC service. These costs were estimated in the D7.1 - GNSS DFMC Integrity Monitoring Report, and are summarised in Section 8 of this report.

In addition to the nominal amounts of spending required to achieve functionality and wider service roll-out, the timing of these costs are crucial inputs for a Cost Benefit Analysis. These inputs were derived from the D7.1 - GNSS DFMC Integrity Monitoring Report.

4.4.2 Development timeline

As the DFMC Service moves through development phases it is expected that it will achieve gradually increasing performance levels, relative to the expected performance once the infrastructure is fully implemented at the system level, tested, and finally implemented at the user level. Estimates for this performance relative to development phase are important to gain a sense of how much value is provided by the technology throughout its development phase. These estimates were derived from the D7.1 - GNSS DFMC Integrity Monitoring Report and discussion with technical experts who input on the same report.

The indicative timeline for the GNSS DFMC integrity monitoring service is primarily based on the development timeline of the Southern Positioning Augmentation Network (SouthPAN / SPAN). This under-development network is a joint initiative from the Australian and New Zealand Governments to provide SBAS services for the two countries – including a DFMC service to provide improved integrity. This specific service was chosen due to its approximately concurrent timing (development from 2022), the similarity of its safety and assurance objectives, and because its cost and development schedule information is in the public domain. The difference in planned coverage area for SPAN versus the UK is recognised in the choice by D7.1’s authors to apply a 30-40% reduction in development costs. We consider this an appropriate measure to ensure it is a reasonable proxy for the GNSS DFMC monitoring service, and apply a conservative 40% factor to the total value in the cost modelling. A less conservative estimate would be closer to the 30% (lower end) of the range. The system is expected to have an approximately 6-year development timeline to full operational capacity, with no operational capacity expected before this point. This is specifically modelled as a 6-year development period 2024-2029 followed by 20% achievement of potential 2030-2032 and 100% achievement of potential from 2033 onwards.

4.5 Collated INSPIRe development timelines

Table 4-1 Collated INSPIRe development timelines

Proposed solution	2024	‘25	‘26	‘27	‘28	‘29	‘30	‘31	‘32	‘33	‘34	‘35
EGNOS monitoring service	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%
RAIM availability prediction tool	0%	0%	90%	93%	100%	100%	100%	100%	100%	100%	100%	100%
DFMC integrity monitoring	0%	0%	0%	0%	0%	0%	20%	20%	20%	100%	100%	100%

5 INTEGRITY USE CASES

Work Package 1 of the INSPIRe project identified a set of marine activities of interest. These are use cases where there is both a high degree of relevance to the UK's socioeconomic interests and a (perceived) high degree of dependence on integrity information in their operations.

This report section gives an overview of these use cases and introduces some of the integrity information-dependent activities within each.

5.1 Aquaculture

Aquaculture or 'aquafarming' refers to the farming of aquatic life, including fish, molluscs, crustaceans, and aquatic plants such as seaweed[2]. This sector is an increasingly important contributor to global food production, with demand only set to increase in the coming decades. To underscore this importance, the sector is considered 'one of the UK's key strategic food production sectors'[3] by the Government's Department for Environment, Food and Rural Affairs (DEFRA). The UK's commitment to developing a sustainable and growing aquaculture sector is clear, with varying approaches required to tailor support to its regions.

UK finfish production figures have historically been dominated by Scottish farmed Atlantic salmon, which is primarily based at sea. However, freshwater production and aquaculture that focuses on shellfish and trout production does occur across the rest of Scotland and the UK. A 2012 regional breakdown of UK aquaculture (comprising finfish and shellfish) by value and region is presented below. 2020 statistics from Seafish, a non-departmental public body supporting the UK seafood industry, suggest that UK aquaculture produces approximately £1.0bn of aquatic life at present[4].

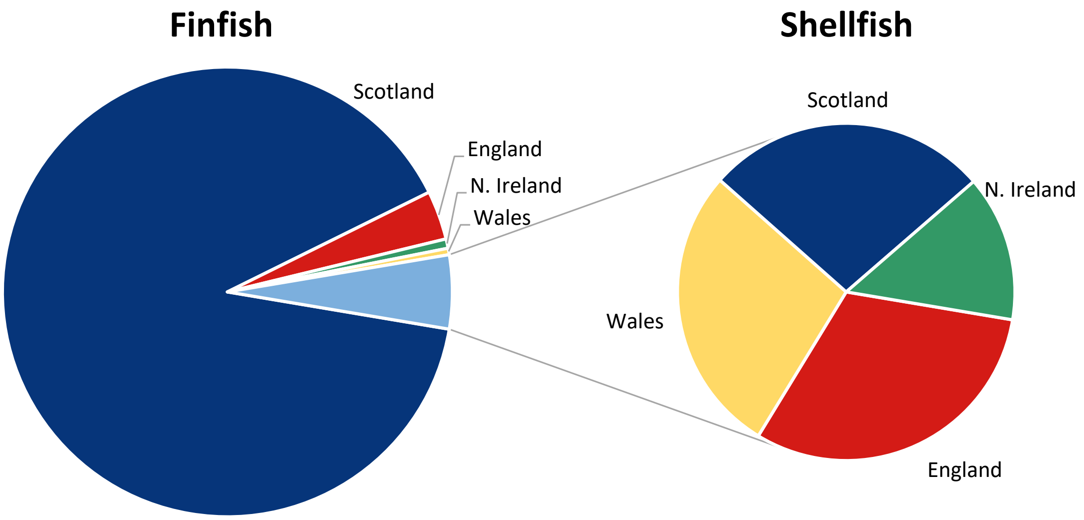

Figure 2 – UK Aquaculture market share by subcategory (2012 data)

Sources: Department for Environment Food & Rural Affairs (2015). 'United Kingdom multiannual national plan for the development of sustainable aquaculture'

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[2] Uberoi, E., Hutton, G., Ward, M., and Ares E. (2022). 'UK Fisheries Statistics', House of Commons Library.

[3] Department for Environment Food & Rural Affairs (2015). 'United Kingdom multiannual national plan for the development of sustainable aquaculture'.

[4] Seafish (2023). 'UK seafood supply chain overview', accessible at: https://www.seafish.org/insight-and-research/uk-seafood-supply-chain-overview/

Note: Total value of 2012 UK Aquaculture in chart is approximately £611m, 90% of which was generated by Scottish Finfish activities. Shellfish comprised a total of 5.3% of UK aquaculture.

The dominance of Scottish Finfish activities in UK aquaculture is spread across much of Scotland's coastline, as highlighted by the map below that was produced by the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) in 2015.

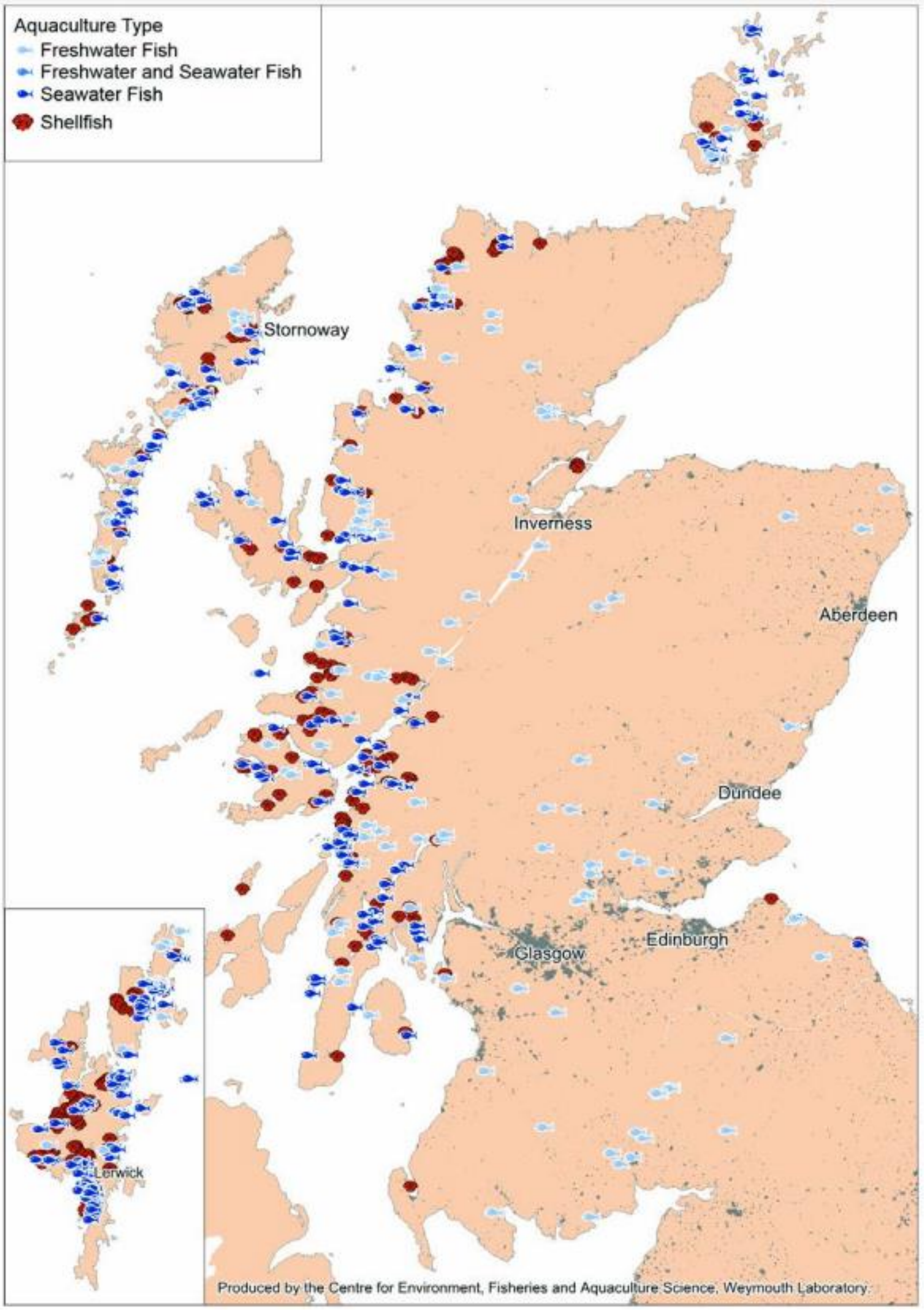

Figure 3 – Scottish Aquaculture sites

Source: Department for Environment Food & Rural Affairs (2015). 'United Kingdom multiannual national plan for the development of sustainable aquaculture'.

Aquaculture operations along the Scottish coastline and in open water incorporate modern PNT information from GNSS or other sources in a few key activities. Farm infrastructure planning and ongoing management takes precise position inputs to initially determine and work around structures including pens, cages, and nets. Monitoring and control activities to ensure feeding schedules, environmental conditions, and potential hazards are all dealt with appropriately are also critically dependent on a solid understanding of precisely where the various infrastructures making up a farm are located. As interest grows in automating these and other aquaculture activities through the use of autonomous workboats, integrity information that prevents navigational mishaps will become essential in order to assure continuous operations.

Another important aquaculture activity will be the ongoing assurance of worker safety during operations. Work is already being carried out by a Scottish company, Zelim, to use a network of semi-autonomous unmanned rescue vessels to save lives at sea in industries adjacent to aquaculture such as the offshore energy sector[5]. When accidents do happen offshore, automated Search and Rescue missions will be critically dependent on integrity information to carry out their activities.

5.2 Ship-to-Ship

Transfers of liquid fuels between vessels at sea are critical for the UK's energy security, meeting demand, and generally ensuring efficiency of operations in the UK's energy supply chain. Ship-to-ship (STS) transfers are typically carried out for cargo such as crude oil, liquified gas (petroleum or natural), and other petroleum products. Such activities can be done for a variety of reasons, ranging from lightening a vessel to in-operation refuelling of ships, or simply saving time by transferring cargo without having to reach a land-based terminal.

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[5] Offshore Renewable Energy Catapult (2022). 'Sea rescue system that could save lives of offshore wind workers successfully trialled', accessible at: https://ore.catapult.org.uk/press-releases/sea-rescue-system-that-could-save-lives-of-offshore-wind-workers-successfully-trialled/

Figure 4 – Ship-to-ship transfer in action

Source: G-Valeriy / Shutterstock.com

Operations can be carried out at sea or in port, with the latter under the jurisdiction of the relevant port or harbour authority. In this case one ship is secured to an onshore installation to facilitate the transfer and other vessels then moor alongside it. In either case, stringent safety standards are in place to minimise the risk of accidents and emergencies. Many of these pertain to ensuring that vessels are correctly positioned relative to each other and remain that way for the duration of the transfer. According to Skuld, a marine insurer, the 'most common incident to occur during STS operations is a contact/collision between the two ships while manoeuvring alongside each other, or upon departing'[6]. These collisions can be assumed to be downstream of a failure to fully appreciate when the vessel positioning information should not have been trusted by those in charge of said positioning. Such incidents 'can cause fatal injuries to crew members, as well as damage or failure of the cargo hose', with any spillages of fuels of course increasing the risk of fires and explosions, and causing damage to the environment.

Given the importance of the UK's offshore oil and gas industry (see Section 5.7 of this report), the relevance of ship-to-ship transfers in continuing to uphold sector-wide efficiencies and safety standards is key. Integrity information may help to ensure that these operations can be carried out in UK waters with sufficient safety.

5.3 Ocean Energy

Ocean energy refers to renewable energy derived from the ocean and is also known as 'marine energy'[7]. This includes waves, tides, currents, and thermal gradients. The predictability and large potential size of the energy sources make it an attractive option for nations with appropriate ocean access. The UK is one such nation, given its extensive coastline and access to both tidal and wave energy. This supply-side access is set to be increasingly exploited in the coming years; the UK's commitments to Net Zero and the transition to a more renewable energy mix has led to interest and investment into developing ocean energy technologies.

Technologies aiming to harness tidal stream energy, are estimated to be able to produce around 11% of current UK electricity demand. These technologies include turbines attached to a floating device. Tidal stream energy projects are forecast to contribute £17bn to the UK economy by 2050[8]. Wave energy potential in UK waters could amount to over 20GW, equivalent to over 20% of the UK's current electricity demand[9].

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[6] Skuld (2020). 'Ship to ship transfer safety', accessible at: https://www.skuld.com/topics/cargo/liquid-bulk/ship-to-ship-transfer-safety/

[7] UK Marine Energy Council (2023). 'UK Potential', accessible at: https://www.marineenergycouncil.co.uk/marine-energy/uk-potential

[8] Offshore Renewable Energy Catapult (2022). 'Tidal stream energy could dive to record low cost if opportunity is seized', accessible at: https://ore.catapult.org.uk/press-releases/tidal-stream-energy-could-dive-to-record-low-cost-if-opportunity-is-seized/

[9] Jin, S. and Greaves D. (2021). 'Wave energy in the UK: status review and future perspectives', Renewable and Sustainable Energy Reviews, vol. 143 (June), pp. 110932.

Figure 5 – Pelamis P2 device, pictured at European Marine Energy Centre, Orkney, in July 2011.

Source: Pelamis Wave Power, via Wikimedia Commons

Interestingly, wave energy technologies are considered highly complementary with offshore wind generation. They can be co-located, with wave energy technologies deployed 'between wind turbines, or even cohabit[ing] floating wind platforms'[10]. Benefits stem from the fact that the generation profiles of each technology can be very different – spreading out the power generation timing and intensity and reducing the impact of intermittent wind generation on the UK power grid. There is further potential to reduce costs and improve the efficiency of marine space usage, with benefits stemming from shared infrastructure, substations, and marine vessels.

With the potential benefits from increasing the density and complexity of power generation infrastructure at these co-located sites also comes increased risks. As a move towards autonomous Search and Rescue missions continues[11], an increasingly complex operating environment only increases the need for integrity information to assure the safety of ocean energy operations and operators.

5.4 Fisheries

Fisheries include all activities that involve the *collection* of *wild* aquatic life (rather than farming). This, similar to aquaculture, includes fish, molluscs, and crustaceans. Fisheries play a significant role in the UK's economy, culture, and food supply, particularly in coastal communities. In 2021 fish caught ("landed") by fisheries were worth a combined £713m, less than the £1bn of fish farmed in UK aquaculture[12]. As in the aquaculture sector, Scotland dominates fishery economic output. 2021 statistics show that the Scottish fishing industry contributes just under 50% of the UK total by value[13].

One key topic that the UK fishery sector is actively seeking to address is labour automation and its effects on the fishery supply chain[14]. It is noteworthy that there are a range of anticipated issues with the availability and cost of labour over the next 10 years driven by an

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[10] UK Marine Energy Council (2023). 'Wave energy', accessible at: https://www.marineenergycouncil.co.uk/marine-energy/wave-energy

[11] Roly McKie (2023). 'Maritime Autonomous Surface Ships (MASS) and SAR', International Maritime Rescue Federation, accessible at: https://www.international-maritime-rescue.org/news/maritime-autonomous-surface-ships-mass-and-sar

[12] Seafish (2023). 'UK seafood supply chain overview', accessible at: https://www.seafish.org/insight-and-research/uk-seafood-supply-chain-overview/

[13] Seafish (2023). 'Fishing data and Insight', accessible at: https://www.seafish.org/insight-and-research/fishi-data-and-insight/

[14] Garrett, A., Cooper, L., Tattersall, L. (2019). 'Automation and the UK seafood industry: (Summary report)', Seafish.

ageing population, shrinking workforce, tight UK labour market, changing migration conditions and the impact of this on low wage jobs, and ongoing perceptions of the seafood industry as unattractive. These issues are likely to be in contrast to the availability and cost of automating technology. In a 2019 report[15], large whitefish and pelagic vessels operating in the UK were identified as already incorporating sophisticated automation. Longer term opportunities for automation include environmental monitoring sensors and blockchain technology that improves transparency, traceability, and automates some customs checks.

Another key opportunity for increased automation, which can directly improve safety, potential-worker perceptions of the industry, and efficiency in one, is in Search and Rescue of fishing vessels. Much of the UK fishery sector's 4,000-plus active fleet are at near-daily risk of accidents that require interventions. Most vessel types increased their number of days at sea in 2021 as COVID-19 lockdown measures were eased – the average days at sea for English, Scottish, and Welsh vessels (>24m in length) surpassed 190. This means that more than half of the year was spent at sea for the average large fishing vessel. The workers on these vessels are thus exposed to the hazards of their environment for longer, and when accidents do ultimately happen it is Search and Rescue operatives that must respond quickly and accurately.

5.5 Bio-economy

The marine bio-economy refers to the economic activities and industries that utilise biological resources found in the marine environment. It includes oceans, seas, and coastal regions and includes the production of biologically-based products and materials, tourism and recreation, and other activities.

One important element of the UK's bio-economy are Marine Protected Areas (MPAs). These effectively function as national parks or nature reserves do on land, in that they are set up to ensure the wellbeing of particular animals, plants, and habitats at sea. This extends to the ongoing recovery of 'blue carbon' habitats that absorb and store carbon. There are currently 371 MPAs in the UK's seas that cover 38% of UK maritime zones[16].

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[15] Garrett, A., Cooper, L., Tattersall, L. (2019). 'Automation and the UK seafood industry: (Summary report)', Seafish.

[16] Marine Conservation Society (2023), 'An introduction to Marine Protected Areas (MPAs)', accessible at: https://www.mcsuk.org/ocean-emergency/marine-protected-areas/why-marine-protected-areas-are-important/

Figure 6 – Marine Protected Areas around the UK

Source: Marine Conservation Society (2023), 'An introduction to Marine Protected Areas (MPAs)', accessible at: https://www.mcsuk.org/ocean-emergency/marine-protected-areas/why-marine-protected-areas-are-important/While fishing is allowed in some form in almost all MPAs, it must be carefully monitored to ensure that it doesn't compromise the species or habitats that the area is intended to protect. In particular, fishing practices that involve 'bottom-trawling (dragging weighted nets across the seabed) or dredging (using heavy-duty metal framed nets)'[17] can cause immense damage to the seabed and ecosystems that depend on it. A 2021 report found that bottom trawling took place in 98% of the UK's offshore MPAs (by number) that are intended to protect seabed habitats[18], with severe bio-economy and hence socioeconomic consequences. Indeed, a Cost Benefit Analysis from the Marine Conservation Society highlights a net benefit of between £2.57-3.50bn over the period 2023-2043 from banning so-called bottom-contact fishing from the UK's MPAs[19].

Cost-effective monitoring and surveillance of MPAs is critical to their success, and there is a meaningful opportunity for autonomous vessels and sensors to provide key data inputs here. Another related use case for automation comes in ensuring that autonomously navigated fishing vessels do not accidentally stray into protected areas, causing unintended socioeconomic damage in the process. Finally, another piece of the MPA monitoring puzzle is the Search and Rescue operations that ensure the safety of human operatives out at sea

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[17] Marine Conservation Society (2023), 'An introduction to Marine Protected Areas (MPAs)', accessible at: https://www.mcsuk.org/ocean-emergency/marine-protected-areas/why-marine-protected-areas-are-important/

[18] Frith, D., & Solandt, J-L. (2021), 'Marine unprotected areas – A case for a just transition to ban bottom trawl and dredge fishing in offshore Marine Protected Areas', Marine Conservation Society.

[19] Marine Conservation Society (2023), 'A socio-economic analysis of a bottom-contact fishing ban in the UK'.

conducting surveys, monitoring fishing activities, and otherwise performing essential activities in MPAs. A move towards automation in these SAR activities can bring increased efficiency, lowering costs and further improving the socioeconomic returns to protecting these areas.

5.6 Offshore Wind

Offshore wind energy entails siting wind turbines in bodies of water, generally oceans or seas, in order to generate electricity. Locating these turbines offshore often results in them experiencing stronger and more consistent winds[20], with obvious production advantages relative to onshore windfarms. The typical technological approach involves wind turbines fixed to either the seabed or floating structures, which are then connected to the power grid by cables[21]. Currently offshore wind turbines can only be used in shallow waters – with current and near-term technology supporting depths of up to 50m – beyond this it becomes difficult to fix turbines to the seabed[22].

The UK has become the global leader in offshore wind energy, with more capacity installed than any other country[23], largely due to taking advantage of extremely favourable geographical conditions. An extensive coastline that extends with relatively shallow waters into the particularly high-wind North Sea create ideal conditions for high-productivity offshore windfarms[24]. Offshore wind is already playing a key role in the nation's transition towards renewable energy sources, and a Government plan is in place to increase the capacity by 400% by 2030 to generate more electricity than is currently used in UK homes[25] The North Sea's advantages for offshore windfarms can be clearly seen in statistics on UK windfarm locations.

Table 5-1 UK Wind Turbines and their capacity

Rank	Windfarm	Location	Number of Turbines	Capacity (MW)
1	Hornsea Two	**North Sea**	165	1,386
2	Hornsea One	**North Sea**	174	1,200
3	Triton Knoll	**North Sea**	90	857
4	East Anglia One	**North Sea**	102	714
5	Walney Extension	Irish Sea	87	659
6	London Array	Thames Estuary	175	630

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[20] National Grid (2022). 'Onshore vs offshore wind energy: what's the difference', accessible at: https://www.nationalgrid.com/stories/energy-explained/onshore-vs-offshore-wind-energy

[21] Jiang, Z. (2021). 'Installation of offshore windfarms: A technical review', Renewable and Sustainable Energy Reviews, vol. 139 (April), pp. 110576.

[22] UK Research and Innovation (2022), 'Harnessing offshore wind', accessible at: https://www.ukri.org/news-and-events/responding-to-climate-change/topical-stories/harnessing-offshore-wind/

[23] UK Research and Innovation (2022), 'Harnessing offshore wind', accessible at: https://www.ukri.org/news-and-events/responding-to-climate-change/topical-stories/harnessing-offshore-wind/

[24] Hjelmeland, M. and Noland, J. K. (2023). 'Correlation challenges for North Sea offshore wind power: a Norwegian case study', Scientific Reports, vol. 13(1) (October), pp. 18670

[25] Department for Business, Energy & Industrial Strategy (2020), 'New plans to make UK world leader in green energy', accessible at: https://www.gov.uk/government/news/new-plans-to-make-uk-world-leader-in-green-energy

Rank	Windfarm	Location	Number of Turbines	Capacity (MW)
7	Greater Gabbard	**North Sea**	140	500
9	Gwynt y Môr	North Wales	160	576
10/11	Beatrice	Moray Firth	84	588
10/11	Race Bank	Coast of Norfolk	91	573

Source: Ukpanah, I. (2023). 'UK's Wind Power: A Gust of Growth in the Renewable Energy Sector', accessible at: https://www.greenmatch.co.uk/green-energy/wind

Marine vessels play crucial roles at different stages of offshore wind farm development, installation, and maintenance. Initial surveys and site assessments are carried out by specialised survey vessels, with data on the seabed and surrounding ecological environment considered critical inputs pre-installation. Installation vessels transport and install the various components, with extreme precision required throughout despite challenging marine conditions. Finally, ongoing operations, including inspections and maintenance, require service vessels to transport workers and equipment to and from windfarms.

Autonomous and/or unmanned surface vessels can offer significant benefits to the ongoing operations phase. Remote routine inspections can survey and detect offshore turbines without risking human safety in challenging marine environments, while in the future minor maintenance tasks and repairs may be performable by automated vessels. Logistical trips such as equipment transport are also expected be automated, increasing efficiency and safety.

As referenced in Section 5.3, co-location of offshore wind turbines and wave energy turbines may bring significant benefits and risks in tandem. In the context of increasing automation in marine Search and Rescue operations[26] it is expected that the provision of integrity information will be a critical input into future safety-critical activities.

5.7 Offshore Oil and Gas

Offshore oil and gas is specifically defined as extraction (or 'production') of these substances from offshore areas. These areas happen to account for approximately 100% of UK output, with Wytch Farm in Dorset, England the only potential exception (though even there, some of the wells extend offshore). Offshore Energies UK (OEUK) estimated that over 30,000 direct and an additional 90,000 indirect jobs were supported by the UK oil and gas industry[27]. UK oil and gas production comes from approximately 300 separate sites, or 'fields', many of which are small and/or technically complex. Despite this, by the end of 2022 some 47bn barrels of oil equivalent have been extracted from the UK and UK Continental Shelf. Production volumes peaked in 1999 at 4.4m barrels per day and declined to current levels of around 1.3-1.4m barrels per day in 2021 and 2022[28]. The figure below highlights the fact that, in general, production of oil from operating fields decreases over their lifetime – this is largely due to falling reservoir pressure. This implies that increases in the overall level of oil production in the UK will require more fields or more wells in existing fields to be brought online.

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[26] Roly McKie (2023). 'Maritime Autonomous Surface Ships (MASS) and SAR', International Maritime Rescue Federation, accessible at: https://www.international-maritime-rescue.org/news/maritime-autonomous-surface-ships-mass-and-sar

[27] Offshore Energies UK (2022). 'Workforce insight 2022'

[28] NSTA based on DESNZ data. Available on request from the UK EITI Secretariat

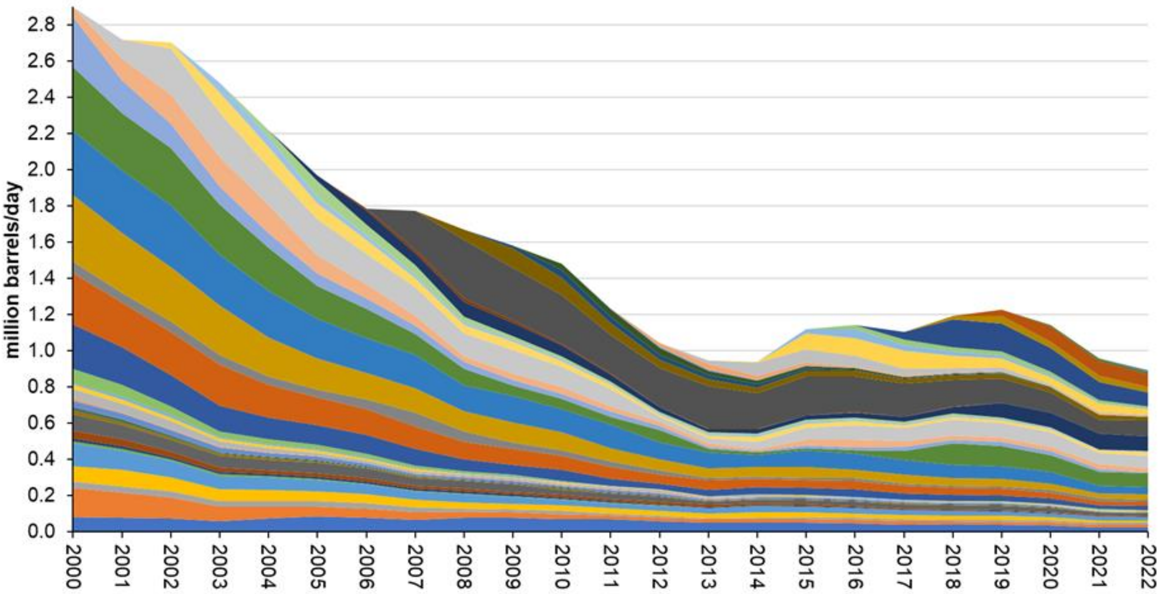

Figure 7 – UK crude oil production by start-up year of field

Source: NSTA, Petroleum Production Reporting System, March 2023

This downwards mechanism is compounded by forecasts of falling production rates for oil and gas, as more recent discoveries of new fields tend to be smaller. This only serves to increase the sector-wide drive for greater efficiencies to ensure financial and economic returns remain positive.

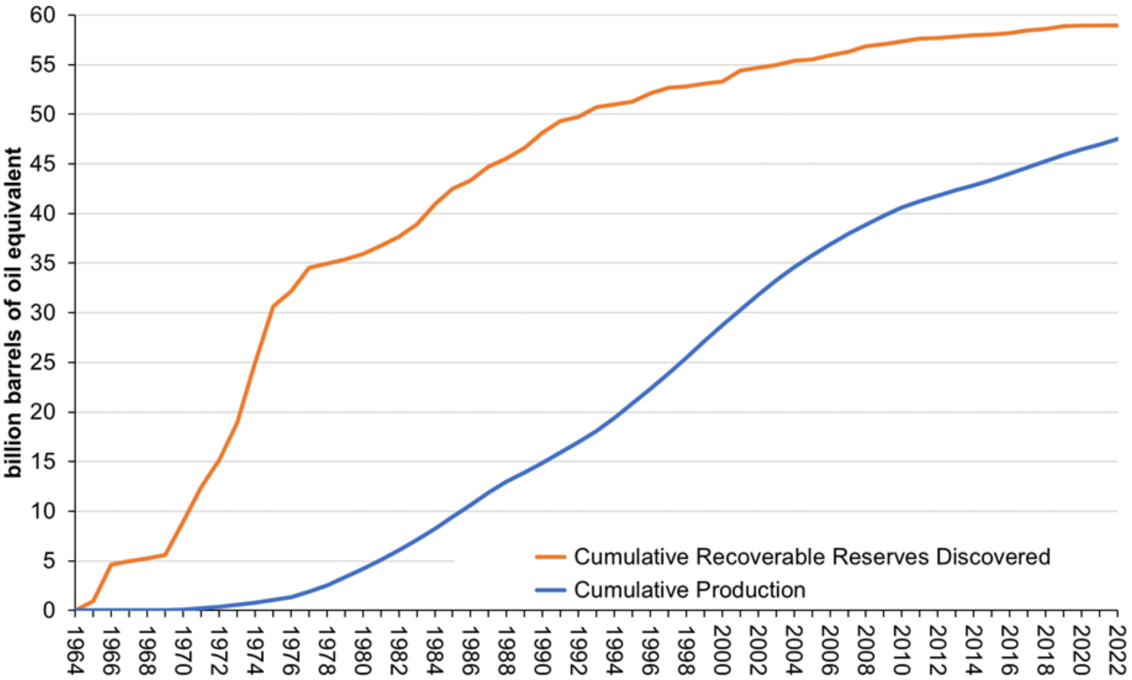

Figure 8 – Recoverable UK oil and gas reserves discovered and produced

Source: NSTA analysis of Lens data from Wood Mackenzie, January 2023

One much-touted avenue for increased efficiencies is in the marine vessels and other vehicles that monitor and service the UK's offshore oil and gas rigs. The use of autonomous systems in the offshore oil and gas sector 'is well established'[29] for environmental monitoring and change detection. Drones in particular are expected to play a significant role in the near future as they offer immediate capacity to perform visual inspections of equipment, pipelines, and other structures[30]. In the longer term remote-controlled or autonomous robots onboard vessels that are themselves human-, remote-, or automatically-controlled create opportunities for vast labour cost savings and reductions in human time spent in hazardous situations.

Before the maintenance stage, dynamic positioning floating rigs are already in use to set up rigs. These systems, when operating correctly, make deep water drilling possible by enabling offshore drilling units to automatically maintain their position above the well location. Such systems typically utilise GNSS (with RTK or PPP augmentation) to maintain precise positioning in often-difficult environmental conditions[31]. The value of integrity information for these floating rigs is high as they are in position for extended periods and require ongoing position correction and hence confidence in their incoming position information. The user requirements of the accuracy of this integrity information are extremely precise, however.

A final source of potential efficiencies in offshore oil and gas is the introduction of autonomous Search and Rescue operations. Most offshore fields are required to have emergency response and rescue vessels (ERRV) on constant standby to evacuate personnel in the event of an emergency[32]. The mandated 9-15 crewmembers on board these vessels must be appropriately trained, have limited operating periods, and must be able to demonstrate good understanding of the English language[33] – all of which increase the cost associated with providing such a service on top of the rescue vessel itself. Automation of these operations is therefore subject to much interest, with progress made by Scottish company Zelim in developing a system that autonomously detects, tracks, and recovers casualties in the water[34].

5.8 Carbon Capture and Storage

The Paris Agreement, Glasgow Climate Pact, and the UK's existing 2050 net zero commitment require more than just cleaner energy production and more efficient energy use. Hard-to-abate sectors that underpin modern infrastructure, such as steel and cement production, will continue to emit high levels of CO_2. Some estimates suggest that to achieve the UK's climate targets the nation needs to remove approximately 6-7 gigatonnes of CO_2 from the atmosphere every year by 2050. One option that is being actively explored is the long term storage of CO_2 emissions underground, with seabed reservoirs identified as ideal candidates. The practice of moving new emissions underground for long term storage is referred to as 'Carbon Capture and (Underground) Storage' – 'CCS' or sometimes 'CCUS'.

As one industry player, DNV Maritime Advisory, notes, "A large proportion of the total volume, at least in the initial stages, will need to be transported by ship, making marine transport a key holistic component". The use of seabed reservoirs means that much of the

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[29] Institute of Marine Engineering, Science & Technology (2016). 'AUV0064 – Evidence on autonomous vehicles'.

[30] Moshouk, M. (2023). 'Drones set to transform oil and gas operations', Offshore, accessible at: https://www.offshore-mag.com/special-reports/article/14297564/saudi-aramco-drones-set-to-transform-oil-and-gas-operations

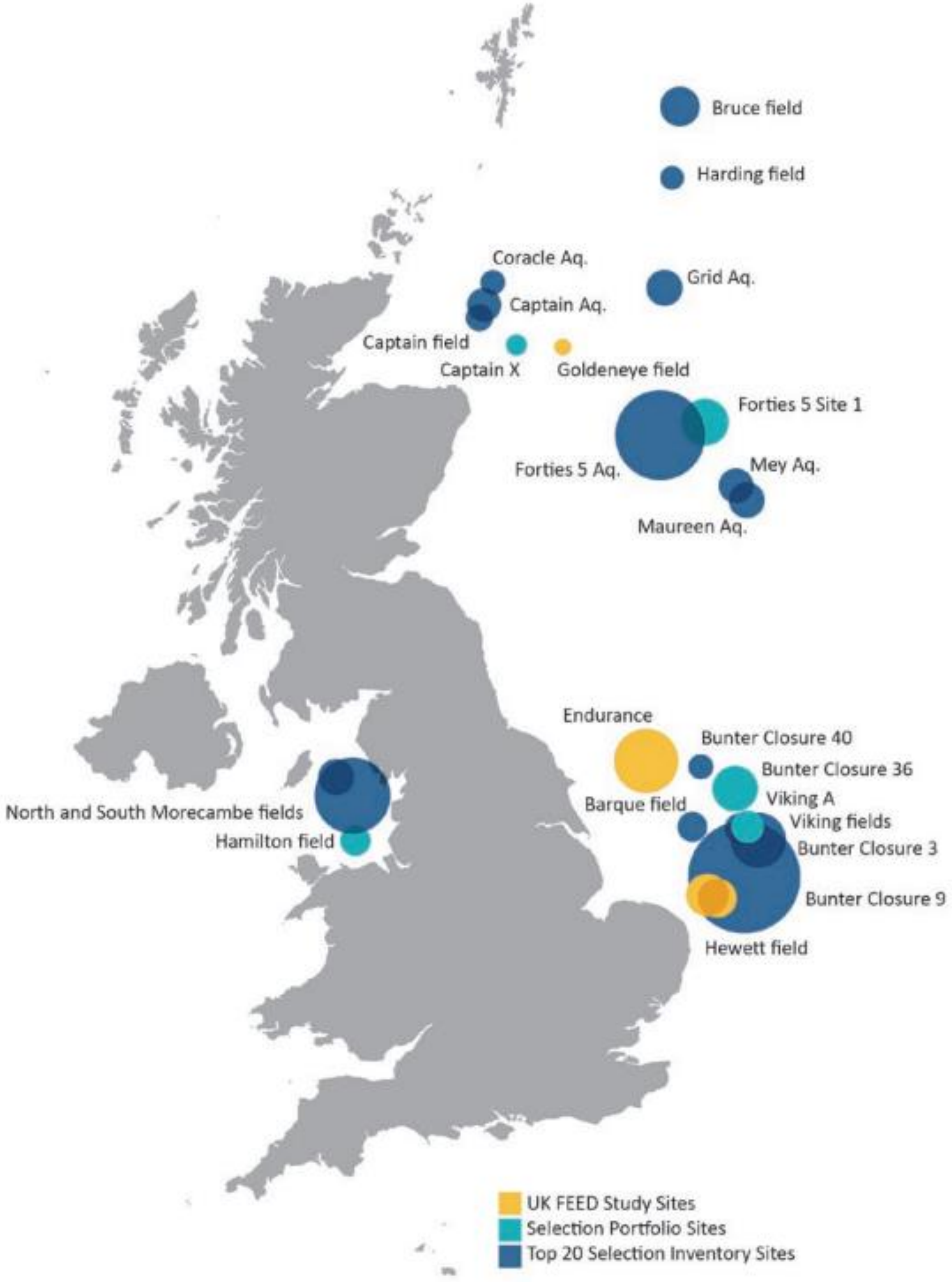
[31] Veripos (2023). 'Dynamic Positioning – Drilling', accessible at: https://veripos.com/applications/dynamic-positioning-drilling

[32] See the UK HSE's legislative requirements to ensure a "good prospect of recovery" from persons on board offshore oil and gas infrastructure in line with the Prevention of Fire, Explosion and Emergency Response Regulations (1995)

[33] Oil & Gas UK (2018). 'Emergency Response and Rescue Vessel Management Guidelines'.

[34] Offshore Renewable Energy Catapult (2022). 'Sea rescue system that could save lives of offshore wind workers successfully trialled', accessible at: https://ore.catapult.org.uk/press-releases/sea-rescue-system-that-could-save-lives-of-offshore-wind-workers-successfully-trialled/

operational activities are to be conducted at sea. The UK's Department for Business, Energy and Industrial Strategy noted in a 2021 report[35] that the UK is in 'an enviable position' due to the size of its CO2 storage potential relative to other countries. A 2016 report[36] identified areas of CO2 storage resource potential in UK waters that amount to 78 billion tonnes of emissions – equivalent to 200 years of UK annual emissions.



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[35] Department for Business, Energy & Industrial Strategy (2021). 'CCUS Supply Chains: a roadmap to maximise the UK's potential'.

[36] Pale Blue Dot Energy and Axis Well Technology (2016). 'Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource – A Summary of Results from the Strategic UK C0$_2$ Storage Appraisal Project', ETI.

Figure 9 – UK Carbon Capture and Storage potential sites

Source: **Pale Blue Dot Energy and Axis Well Technology (2016). 'Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource – A Summary of Results from the Strategic UK C02 Storage Appraisal Project', ETI.** When drilling and evaluating wells to be used for underground storage of carbon, one approach is to use 'dynamic positioning' to place the rig and equipment (and remain in place) above the well. This ensures that the pipes and other equipment remain properly positioned to avoid loss of time, efficiency, and avoid any potential hazards associated with the rig wandering too far from the well. To achieve this dynamic positioning it is crucial that the positioning of the rig remains within a certain distance of the well despite tidal movements and any other disturbances. This necessitates constant adjustments based on live positioning information. Integrity alerts that indicate that this positioning information may not be trustable are thus key to ensure continued proper positioning.

Another important activity related to CCS will be the ongoing assurance of worker safety during operations. These workers must deal with hazardous wind and waves while working on high-precision operations far from shore, and when accidents happen fast and accurate responses from Search and Rescue operatives are essential to minimise harm to humans and equipment. This is an area where automated vessels are expected in the coming years.

5.9 Autonomy in UK maritime operations

As highlighted in a number of the integrity use cases sections in this section, autonomy within the UK maritime sector is expected to increase over the coming years. The UK Government has explicitly set out an ambitious automation agenda, named Maritime 2050[37]. This agenda seeks to use smart shipping and autonomy to make the maritime sector 'cleaner, safer, and more efficient'[38]. While specific instances of automation in use today or in the future have been covered in some detail above, and will be analysed in later report sections, another category of use is worth considering.

The use of Marine Autonomous Surface Ships, or 'MASS' is expected to increase dramatically over the period to be covered by this Cost Benefit Analysis. Specifically, the UK's share of the value generated by these operations could be as high as $15bn by 2030[39]. A key use case of these ships is in the 'ocean' phase of maritime transport. Aside from the specific use cases outlined elsewhere in this report, the United Nations' International Maritime Organisation (IMO) identifies four degrees of ship autonomy, termed 'degree 1' through to 'degree 4'[40]. These are:

- Degree 1 – a ship has automated processes and algorithmic decision support, but onboard crew members are still needed to operate the systems (albeit with less supervision).
- Degree 2 – ships are controlled remotely, but still with onboard crew members.
- Degree 3 – ships are controlled remotely with no seafarers on board.
- Degree 4 – the ship is fully autonomous, but with shore-based emergency over-ride.

The relevance of integrity information is greatest in those cases where there is no onboard crew member, as this makes the ability to sound integrity alerts crucial for ensuring safe navigation. This identifies Degree 3 and 4 as the most relevant degrees of ship autonomy for integrity information, though the other degrees could still benefit to some extent. Indeed,

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[37] Department for Transport. (2019). 'Maritime 2050: navigating the future'

[38] Department for Transport. (2023). 'Maritime Autonomy and Remote Operations – Impact Assessment'

[39] Allied Market Research. (2020). 'Autonomous Ships Market'. Available at: https://www.alliedmarketresearch.com/autonomous-shipsmarket

[40] IMO. (2021). 'Autonomous shipping'. Available at: https://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx

One study[41] estimated the operating cost reductions that MASS could bring over a 25-year operating period are around USD$4.3m – or 3.4% per year. These reductions come as a combination of fuel consumption reduction and reduced spend on crew supplies and salaries. These benefits are fundamentally underpinned by being able to trust these autonomous ships to operate with reduced or no human crews – for which integrity is a key input.

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[41] Kretschmann, Burmeister, Jahn. (2017). ‘Analyzing the economic benefit of unmanned autonomous ships: An exploratory cost-comparison between an autonomous and a conventional bulk carrier’

6 NAVIGATION FAILURE SCENARIOS

6.1 Conceptual introduction

Integrity is a measure of how much trust can be placed in a navigation system's outputs. It is often understood best as a timely warning that users of a particular navigation system should cease relying on said navigation system for navigation purposes. Integrity requirements therefore generally involve an alert or alarm at the time where a system's performance has degraded to the point where further reliance on this performance will create material risk to the user. Integrity as a concept is a 'real-time decision criterion for using or not using the system'[42].

An integrity failure event occurs when navigation information cannot be trusted, navigational errors are made, and no alarm is raised within the acceptable 'time to alert'. This means that the position information provided by a navigation system has been unreliable for so long that the user's reliance upon it is creating material risk.

These integrity failure events can have multiple causes, to which this report is agnostic. The provision of integrity information, enabling alarms to be raised, can reduce or entirely mitigate the material risk created by navigation issues that would result from incorrectly trusting incorrect navigation information.

6.2 Definition of scenarios

The overarching goal with scenario design was to achieve the following:

1. Cover the various use cases identified in WP1 of this INSPIRe project such that the theoretical technical impact of integrity information on navigation failure events can be estimated;
2. Align theoretical use case impacts due to the scenarios to the reality of the UK maritime sector by identifying real hubs for marine activities, enabling…
3. Hypothetical scenarios developed that map to real-world impacts and hence evidence-based estimates of socio-economic impact from integrity information provision in navigation failure scenarios

With these goals serving as guidance, two distinct scenarios were developed.

In each case they are **assumed to be entirely unexpected**, meaning that the use cases are entirely dependent on the systems they have in place at the time.

Across the entirety of a given year many navigation failure events that could be prevented with the provision of integrity information are expected. While each event may only last for seconds or minutes, the cumulative sum of each is far greater. For each maritime subsector we estimate a rate of relevant navigation failure events that enables assessment of current, emerging, and future use cases against the developing profile of INSPIRe solutions as time passes.

Of relevance for both scenarios is the UK's exclusive economic zone. This denotes the area where the UK has jurisdiction over both living and non-living resources – with obvious importance for the use cases outlined in Section 5. The UK's exclusive economic zone relevant to the current study (i.e. to Scenarios 1 and 2) is highlighted in green in Figure 10.

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[42] European Space Agency (2011). 'Integrity', accessible at: https://gssc.esa.int/navipedia/index.php/Integrity

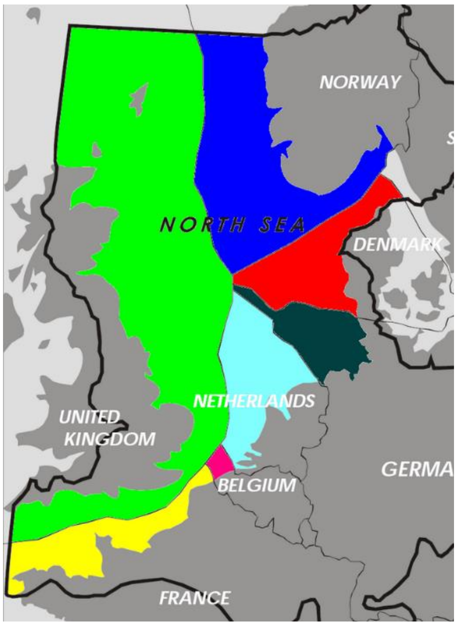

Figure 10 – UK Exclusive Economic Zone relevant to Scenarios 1 and 2 (marked in green)

Source: Wikimedia Commons

6.2.1 Scenario 1: North Sea incidents

The first area of interest is off the east English coast. Specifically, a 125km radius circle, centred on the English coastline due north of Norwich (i.e. approximately the coastal town of Cromer), defines the studied area. This circle encompasses the Lincolnshire and Norfolk coasts, the Wash bay, the mouth of the Humber tidal estuary, and approximately 30,000 square kilometres of North Sea where the UK has an exclusive economic zone.

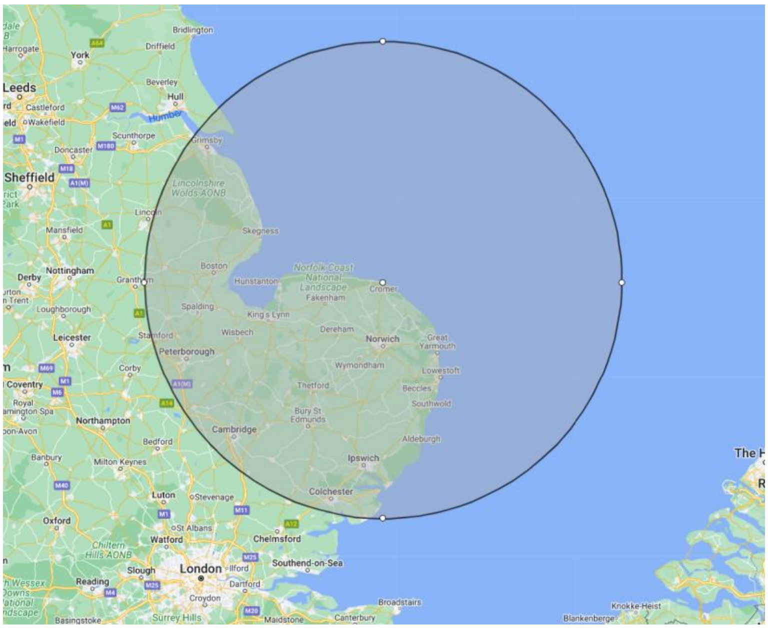

Figure 11 – Scenario 1: North Sea area

The area is home to approximately 15 active ports, and to a significant portion of the UK's maritime economic activities. These will be explored in more detail in Section 7.

6.2.2 Scenario 2: Orkney Archipelago incidents

The second area of interest is off Great Britain's north-eastern tip, in the Orkney Archipelago. Specifically, a 50km radius circle centred on the Rousay, the sixth-largest of around 70 islands making up the Orkney Islands, defines the focus area. This circle encompasses all the Orkney islands, six separate Marine Protected Areas, four active ports, and a wealth of natural resources.

Figure 12 – Scenario 2: Orkney Archipelago area

7 ECONOMIC VALUE GENERATED BY INTEGRITY USE CASES

7.1 Approach

Section 5 provided an overview of 8 distinct use cases where integrity can add value to UK marine operations. Section 6 provided geographical boundaries, via two geographic areas of interest, within which the various use cases will be assessed.

This section will summarise an assessment of the socio-economic value generated by each use case, for use in later sections as a starting point for consideration of the value of integrity information and INSPIRe specifically. This value is estimated for the 20 year period of 2024-2043 (inclusive of 2024 and 2043), meaning that values incorporate anticipated changes in ways of working and longer-term economic trends.

Two sources of socio-economic value are estimated: operational value and emergencies. The first encompasses value that accrues from day-to-day activities. The second type, emergencies, begins to estimate the value generated by emergency operations when accidents occur outside the day-to-day activities that make up a use case. This is done by calculating the value that would be generated if the accidents that do occur in the course of a year were to be avoided. In multiple cases the ratio of use case GVA contribution relative to the total UK maritime GVA is used to estimate the accident rate from national maritime accident statistics.

7.2 Aquaculture

The UK's 2015 'multiannual national plan for the development of sustainable aquaculture'[43] maps aquaculture sites of various types (freshwater fish, saltwater fish, shellfish). The highest density of all three types is found along the Scottish coast, and the Orkney Archipelago provides a unique mix of both density and diversity of aquaculture activities. For this reason aquaculture benefits will be assessed for the Orkney region.

Two sources of value are estimated for Orkney's aquaculture: operational benefits and emergencies costs. These were identified as relevant use cases in WP1.

Given UK-wide and Scottish projections of Gross Value Added (GVA) over the period to 2043, a 9% (of Scotland) share is allocated to Orkney. This share is allocated using Orkney's share of Scottish salmon farming,[44] which was seen in Section 5 to dominate UK aquaculture by value. This amounts to a nominal GVA of £68m per year in 2043, or £1.1bn over the 20-year period – this is the estimated value that aquaculture will generate in the Orkney Archipelago. This amount reflects the growth rate of Scottish aquaculture from 2011-2020 applied to the most recently available data, with ongoing growth delivered in part by increasingly automated practices among Orkney's aquaculture operations.

Each year in the UK there are approximately 10 serious injuries and there is one death every 5 years in incidents requiring Search and Rescue vessel involvement. Orkney aquaculture is estimated to contribute around 0.1% of the UK's marine economy GVA. Apportioning accidents according to this, an estimated 0.01 serious injuries and 0.00002 deaths per year are expected in the Orkney aquaculture sector. Using UK Government figures for the value of prevention of road casualties[45], the value of avoiding these accidents can be monetised at approximately £4,500 per year – or £89,000 in nominal terms over the period 2024-2043. Additional financial damages are likely avoidable – a limited number of offshore service vessels do collide with infrastructure each year due to navigation issues.

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[43] Department for Environment Food & Rural Affairs (2015). 'United Kingdom multiannual national plan for the development of sustainable aquaculture'.

[44] Scottish Government (2022). 'Scotland's Marine Economic Statistics 2019'.

[45] Department for Transport (2021). 'A valuation of road accidents and casualties in Great Britain: Methodology note'.

7.3 Ship-to-Ship

Ship-to-ship transfers are restricted by law to take place in either a single specific point in the British North Sea area ("the permit area" near Southwold) or within harbour authority waters. One such particularly active harbour authority area is Orkney Harbour Authority. The Authority, which is responsible for the operation of 29 piers and harbours, includes Scapa Flow among its controlled areas. Scapa Flow is a hub for oil and gas operations, with a history of ship-to-ship transfers of crude oil spanning 40 years. In the last decade alone more than 28 million barrels of oil have been safely transferred in Scapa Flow[46]. For this reason ship-to-ship benefits will be assessed for the Orkney region.

One source of value is estimated for Orkney's ship-to-ship sector: operational benefits. These were identified as relevant use cases in WP1.

Scapa Flow statistics for recent years indicate oil port revenues of £2-3m per year. These are partially derived from the 70-80 ship-to-ship transfers conducted each year, and we allocate 20% of the revenues derived to such transfers. Taking guidance on Scapa Flow's future performance into account, and in particular a predicted pattern of decline in ship-to-ship transfers from 2030, an estimated £19.2m in revenues are expected over the 2024-2043 period. These transfers are expected to incorporate increasing automation over the period, propping up profit margins while overall revenues decline throughout the 2030s.

7.4 Ocean Energy

RenewableUK compile wave and tidal sites in their UK Marine Energy Database[47], including decommissioned and inactive sites. While there are numerous sites around the UK, particularly on the west coast, there is a significant cluster in the Orkney Archipelago. This includes both tidal stream and wave projects, with 47 individual sites – compared to 77 identified projects across the rest of the UK. For this reason ocean energy benefits will be assessed for the Orkney Archipelago.

16 of the Orkney sites are active, under development, or have official consent to begin development. These sites are summarised below.

Table 7-1 Orkney ocean energy sites

Project	No. of Turbines	Project Capacity	Technology	Commerciality	Project Status
EMEC Blue Horizon	1	0.01	wave	Part-scale / Part-function prototype	Operational
EMEC AWS Waveswing	1	0.02	wave	Large Scale Prototype	Under construction
EMEC Orbital Marine Eday 1	2	2.4	tidal stream	Commercial	Consented
EMEC Orbital Marine Eday 2	1	4.8	tidal stream	Commercial	Consented
EMEC Aquantis	12	0.16	tidal stream	Test Site / Demonstration Zone	Consented
EMEC MPS	1	2	wave	Commercial	Consented
Orbital Westray Firth	1	30	tidal stream	Part-scale / Part-function prototype	Development
Lashy Sound Phase 1	1	10	tidal stream	Commercial	Development
Lashy Sound Phase 2	30	20	tidal stream	Large Scale Prototype	Development

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[46] Orkney.com (2023), 'Oli & Gas', accessible at: https://www.orkney.com/life/energy/oil-gas
[47] Renewable UK (2023), 'UK Marine Energy Database', accessible at: https://www.renewableuk.com/page/UKMED2/UK-Marine-Energy-Database.htm

Project	No. of Turbines	Project Capacity	Technology	Commerciality	Project Status
EMEC Orbital Marine Eday 3	200	2.4	tidal stream	Commercial	Consented
EMEC Orbital Marine Eday 4	1	4.8	tidal stream	Commercial	Consented
Westray South	1	200	tidal stream	Commercial	Development
EMEC Stronsay Firth	Unknown	100	tidal stream	Commercial	Development
EMEC Magallanes 2	Unknown	1.5	tidal stream	Part-scale / Part-function prototype	Operational
EMEC Orbital O2	Unknown	2	tidal stream	Commercial	Operational
EMEC Magallanes Berth 1	Unknown	1.5	tidal stream	Unknown	Consented

Source: UK Marine Energy Database (UKMED)

One source of value is estimated for Orkney's ocean energy sector: emergencies costs. These were identified as relevant use cases in WP1.

Each year in the UK there are approximately 10 serious injuries and there is one death every 5 years in accidents where marine Search and Rescue operatives are involved. Orkney's tidal and ocean energy sector is estimated to have contributed around £130m of GVA 2003-2023[48], at a rate of around £6.5m per year. Apportioning accidents according to the share of this of overall UK maritime GVA, and using UK Government figures for the value of prevention of road casualties[49], the value of avoiding these accidents can be monetised at approximately £13,000 in nominal terms over the period 2024-2043. Additional financial damages are likely avoidable – a limited number of offshore service vessels do collide with infrastructure each year due to navigation issues.

7.5 Fisheries

The UK Marine Management Organisation's 2019 'UK Sea Fisheries Statistics' finds high levels of fishing activity off the north east coast of Scotland (see maps below). In addition, in 2021 46% of UK fishers were based in England and 40% in Scotland[50], with 2.5% of all UK fishers based in Orkney[51]. For this reason fisheries benefits will be assessed for the Orkney Archipelago.

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[48] European Marine Energy Centre (2023). '20 years of EMEC instigates UK wide economic impact', accessible at: https://www.emec.org.uk/20-years-of-emec-instigates-uk-wide-economic-impact/

[49] Department for Transport (2021). 'A valuation of road accidents and casualties in Great Britain: Methodology note'.

[50] Marine Management Organisation, UK Sea Fisheries Statistics 2021, Table 1.6a

[51] Marine Management Organisation, UK Sea Fisheries Statistics 2021, Table 1.6a

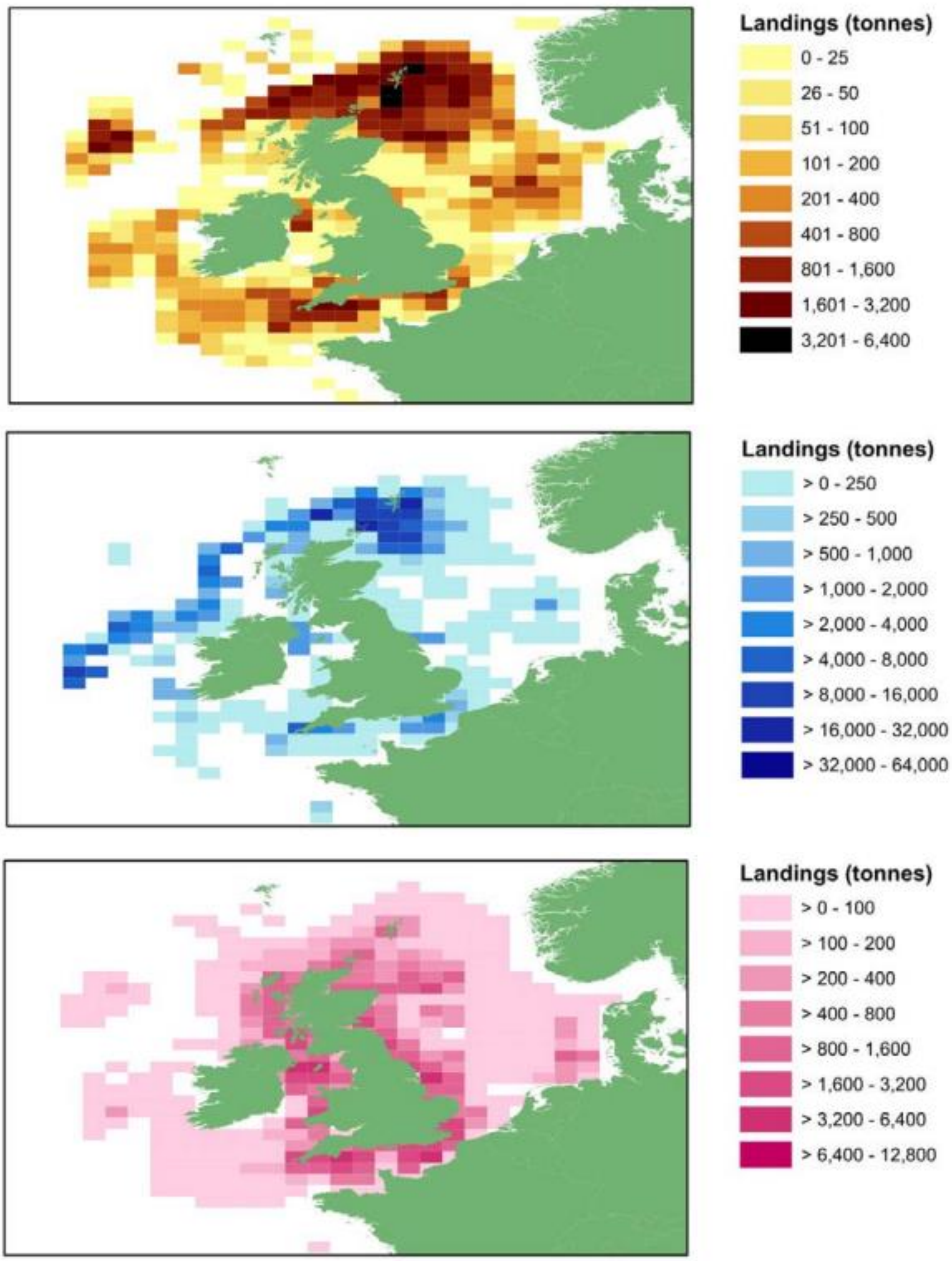

Figure 13 – UK fisheries activity by location

Source: Marine Management Organisation (2020). 'UK Sea Fisheries Statistics 2019'.

One source of value is estimated for Orkney's fisheries sector: emergencies costs. These were identified as relevant use cases in WP1.

There are three sources of emergencies cost that are estimated for Orkney's fisheries. First, fishery-specific damage to human life: each year in the UK there are approximately 30 serious injuries and 5 deaths in accidents involving commercial fishing vessels[52]. Orkney's fisheries sector is estimated to have contributed around £8m of GVA in 2021[53]. Costs can be estimated by apportioning accidents according to the share of this £8m of overall UK fishing GVA. This same GVA contribution is used to further allocate a share of overall UK maritime accidents to the sector, generating the second source of emergencies costs. Finally, the third source is an estimate of the value of lost fishing vessels in Orkney, which is a share of the approximately 1 vessel lost per year in the UK. In combination, the value of avoiding these accidents can be monetised at approximately £34.9m in nominal terms over the period 2024-2043.

7.6 Bio-economy

The Marine Conservation Society records Marine Protection Areas, identifying six in the Orkney Archipelago[54]. Among these is the relatively large North-West Orkney (NCMPA) as well as the smaller 'Wyre and Rousay Sounds' and 'Sanday' protected areas. The latter two of these prohibit bottom-towed fishing gear. The range of sizes and types of MPAs in such a small area are the reason for assessing bio-economy benefits for the Orkney Archipelago.

Two types of benefits are estimated for Orkney's bio-economy sector: operational benefits and emergencies benefits. These were identified as relevant use cases in WP1.

The successful protection of Scottish Marine Protection Areas (MPAs) following an upcoming 2024 ban on bottom-trawling was estimated to bring net socio-economic benefits of £881m over a 20 year implementation period[55] from 2025. Given Orkney's share of Scottish MPAs by number and area, 10% of these benefits are apportioned to Orkney, amounting to £82.2m over the 20 years from 2024 in nominal terms[56]. These are projected socioeconomic benefits that could be significantly impacted by bottom-trawling vessels that enter protected areas.

This £82.2m of value can be used to apportion the UK-wide annual expected 10 serious injuries and 0.2 deaths in accidents where marine Search and Rescue operatives are involved to Orkney's bio-economy sector. This results in approximately £171,000 of emergencies cost value: this is the value that could be generated by avoiding the expected number of accidents in Orkney's bio-economy sector over the period 2024-2043.

7.7 Offshore Wind

The Wind Energy Network produced a 'UK Offshore Windfarm Map 2023'[57], which identifies a few areas of intense activity within UK waters. One of the densest of these areas is around the Norfolk coast in the North Sea. For this reason offshore wind benefits will be assessed for the North Sea area.

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[52] UK Government. MAIB Annual reports (various). Available at: https://www.gov.uk/government/collections/maib-annual-reports

[53] Scottish Government (2023). 'Scotland's Marine Economic Statistics 2021'.

[54] Marine Conservation Society (2023), 'An introduction to Marine Protected Areas (MPAs)', accessible at: https://www.mcsuk.org/ocean-emergency/marine-protected-areas/why-marine-protected-areas-are-important/

[55] Marine Conservation Society (2023), 'A socio-economic analysis of a bottom-contact fishing ban in the UK'.

[56] Note that the discrepancy between '10% of £881m' and '10% of the benefits accruing in the 20 years from 2024' are due to the £881m of benefits beginning to accrue in 2025.

[57] Wind Energy Network Magazine (2023). 'Offshore wind farm map 2023', accessible at: https://www.windenergynetwork.co.uk/wp-content/uploads/2023/03/UK-Offshore-Windfarm-Map-2023-V2.pdf

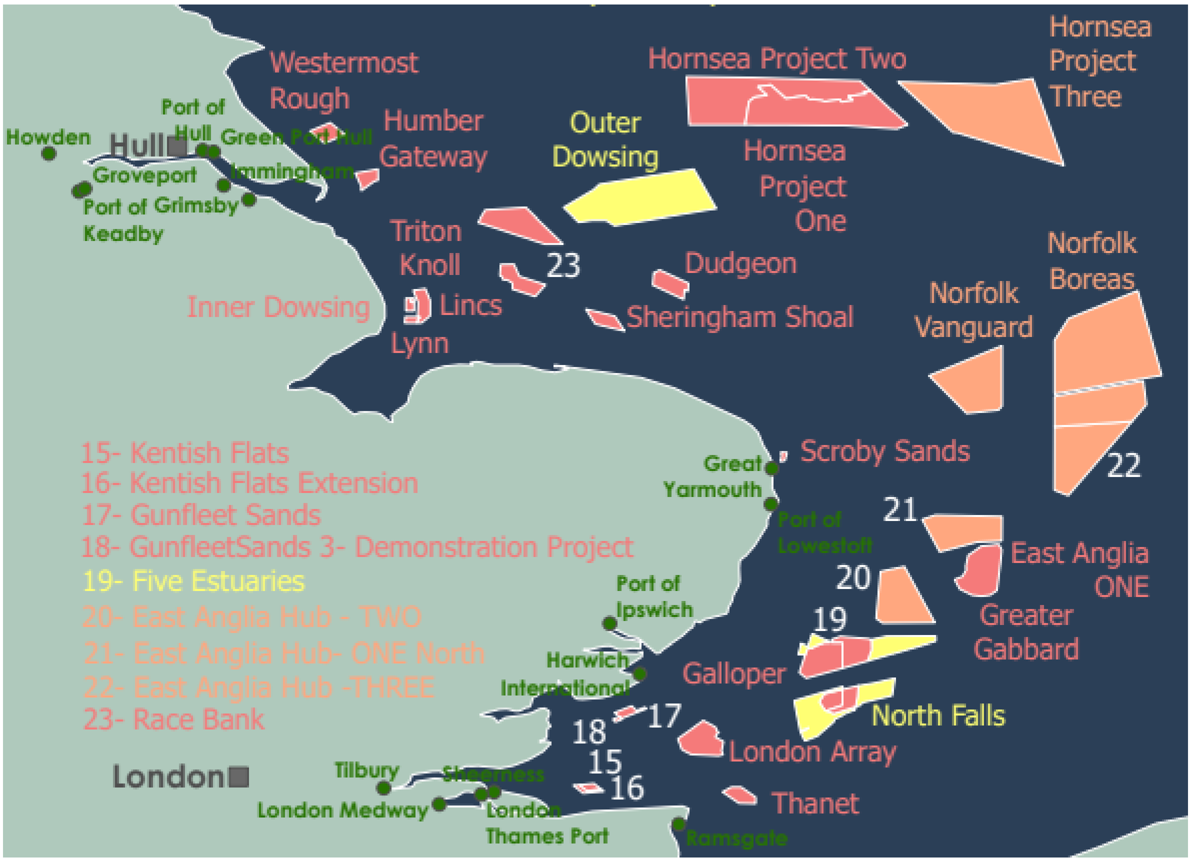

Figure 14 – UK offshore wind farm locations

Source: Wind Energy Network Magazine (2023). 'Offshore wind farm map 2023', accessible at: https://www.windenergynetwork.co.uk/wp-content/uploads/2023/03/UK-Offshore-Windfarm-Map-2023-V2.pdf.

One type of value is estimated for North Sea offshore wind within the Scenario 1 area: emergencies costs. These were identified as relevant use cases in WP1.

Each year in the UK there are approximately 10 serious injuries and there is one death every 5 years in non-fisheries accidents where marine Search and Rescue operatives are involved. The North Sea area defined by Scenario 1's offshore wind energy sector has an estimated value of approximately £300m per year[58]. Apportioning accidents according to the share of this of overall UK maritime GVA, and using UK Government figures for the value of prevention of road casualties[59], the value of avoiding these accidents can be monetised at approximately £574,000 in nominal terms over the period 2024-2043.

Additionally, each year there are around 20-60 incidents globally involving offshore wind turbines requiring Search and Rescue operations[60]. As the UK's share of these is likely to be substantial given its share of overall wind generation, it is likely that further non-injury-related avoidable costs are incurred in terms of resource expenditure to respond to UK-based offshore wind emergencies.

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[58] Office for National Statistics (2021). 'Marine accounts, natural capital, UK:2021', accessible at: https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/marineaccountsnaturalcapitaluk/2021

[59] Department for Transport (2021). 'A valuation of road accidents and casualties in Great Britain: Methodology note'.

[60] G+ Global Offshore Wind Health and Safety Organisation (2022). '2022 incident data report'.

7.8 Offshore Oil and Gas

The UK's discovered deposits of offshore oil and gas are primarily found in the North Sea. A particularly tight grouping of offshore oil and gas platforms is located off the coast of Norfolk. For this reason benefits for offshore oil and gas are assessed for the North Sea area.

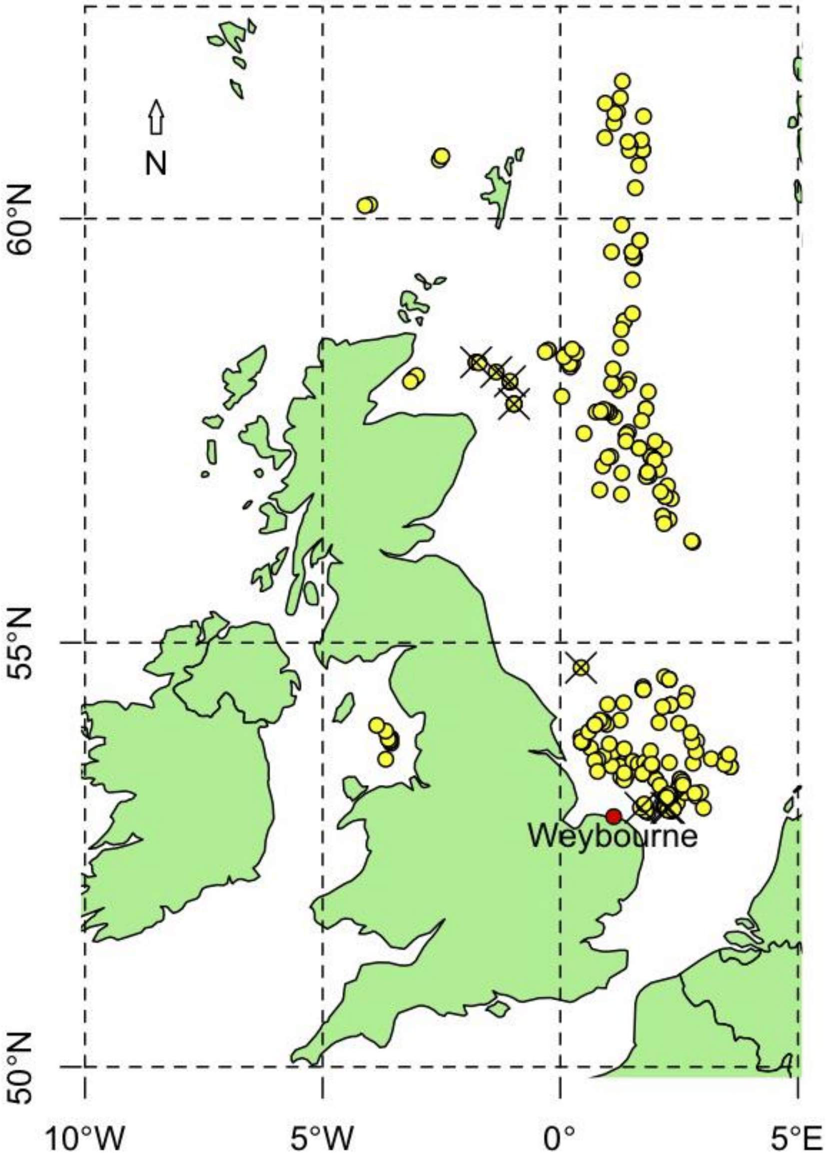

Figure 15 – UK offshore oil and gas platform locations

Source: Riddick, S., Mauzerall, D., Celia, M., Harris, N., Allen, G., Pitt, J., Staunton-Sykes, J., Forster, G., Kang, M., Lowry, D., Nisbet, E. and Manning, A. (2019). 'Methane emissions from oil and gas platforms in the North Sea. Atmospheric Chemistry and Physics. Vol. 19, pp. 9787-9796.

Two types of values are estimated for North Sea offshore oil and gas within the Scenario 1 area: operational benefits and emergencies costs. These were identified as relevant use cases in WP1.

North Sea offshore oil and gas represents a significant portion of the UK total value generated in oil and gas, amounting to approximately 66%[61] of the 2022 UK total GVA of £30.2bn[62]. Despite declining oil and gas stocks in known fields, and newly discovered wells tending to yield smaller total volumes, the long-term decline in GVA per year is expected to be slowed by technical innovation such as increasing use of dynamic positioning. This in turn

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[61] Offshore Energies UK (2023). 'North Sea Oil & Gas: Unlocking Potential'.

[62] Adjusted for 2022 values from source data in: Oil & Gas UK (2021). 'Economic Report 2021'.

allows for more floating wells to be dug in deeper water. The projected GVA produced over the period 2024-2043 amounts to £304bn in nominal terms at an average of £15.2bn per year.

Each year in the UK there are approximately 180 accidents on oil or gas rigs that require emergency medevacs via helicopter[63]. Using GVA as a proxy for activity and hence accidents, we estimate approximately 120 accidents within the North Sea area of focus per year. At around £10,000 per trip[64] there is an estimated emergencies cost of at least £120,000 per year. In total the estimable value of avoiding these accidents can be monetised at approximately £2.36m in nominal terms over the period 2024-2043.In addition there is a cost due to injuries and casualties – though the rate of these is not known for the UK oil and gas industry. The rate of injuries and deaths attributable to North Sea offshore oil and gas is estimated by apportioning accidents according to the sector's share of overall UK maritime GVA. These create a socioeconomic cost of approximately £38.8m which could potentially be avoided with more efficient SAR operations. In total these values sum to £38.2m.

7.9 Carbon Capture

The North Sea Transition Authority launched the UK's first carbon storage licensing round in June 2022, with 13 areas of potential storage available. The areas included coastal areas in the North Sea and East Irish Sea. These new areas combine with areas with existing carbon storage licenses. There is a geographical cluster in the North Sea near the Norfolk coast, and for this reason benefits for carbon capture and storage are assessed for the North Sea area.

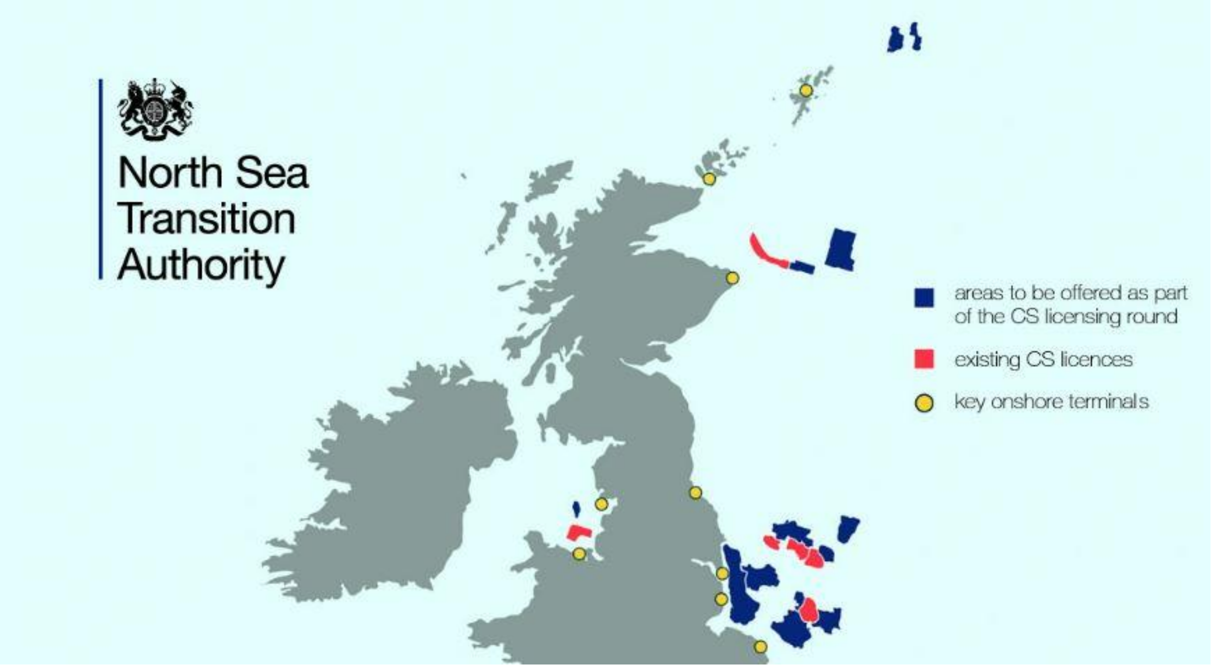

Figure 16 – UK offshore carbon capture and storage locations

Source: Offshore energies UK (2022). 'Burying CO2 forever: UK announces first licensing round for up to 100 geological storage sites for permanently storing CO2', accessible at: https://oeuk.org.uk/burying-co2-forever-uk-announces-first-licensing-round-for-up-to-100-geological-storage-sites-for-permanently-storing-co2/.

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[63] Oil & Gas UK (2021). 'Health and Safety Report 2021'.

[64] Hamilton, D. (2019). 'Copter Costs: Rescue helicopters sent to Scots oil rigs 340 times in last three years – with each trip costing £10k', The Scottish Sun, accessible at: https://www.thescottishsun.co.uk/news/3888332/rescue-helicopter-north-sea-oil-rigs-taxpayers/

Two types of value are estimated for North Sea carbon capture and storage within the Scenario 1 area: operational benefits and emergencies costs. These were identified as relevant use cases in WP1.

Following the announcement in summer 2022 of new licensing opportunities in the North Sea, the Government released a carbon capture and underground storage supply chains roadmap that lays out their plan for the future of UK CCS[65]. This roadmap outlines the desire for at least two industrial clusters to be operational by the mid-2020s and four by 2030 at the latest. The East Coast Cluster is one of these clusters, covering Teesside and the Humber[66]. For the sake of the present analysis it is assumed that this cluster thus represents 50% of the UK's capacity for CCS until 2030, at which point it becomes one of four clusters and represents just 25%. Only the Humber portion of this area is within scope for the present analysis, and it is hence assumed that only 50% of the East Coast Cluster's capacity will be within scope. The whole-UK GVA contribution of CCS is expected to peak at around £5.9bn in 2040[67]. Using the allocation to the Humber area as outlined the estimated GVA generated over the 2024-2043 period is equal to £17.6bn in nominal terms. Similar to offshore oil and gas, dynamic positioning is expected to underpin much of this value by enabling wells to be used in deeper water.

Each year in the UK there are approximately 10 serious injuries and there is one death every 5 years in accidents where marine Search and Rescue operatives are involved. The North Sea area defined by Scenario 1's carbon capture and storage has an estimated value of approximately £1bn per year. Apportioning accidents according to the share of this of overall UK maritime GVA, and using UK Government figures for the value of prevention of road casualties[68], the value of avoiding these accidents can be monetised at approximately £1.9m in nominal terms over the period 2024-2043.

7.10 Marine Autonomous Surface Ships: ocean transport

As discussed in Section 5.9, autonomy in the maritime sector is expected to be widely taken up in operations that entail movement of cargo in the ocean phase. This phase is particularly amenable to automation as the accuracy requirements and environmental complexity are not as stringent as for port or coastal operations.

MASS cost savings per year are estimated at 3.4%[69] and the UK's value generated from ocean-phase shipping estimated at around £6.2bn in 2024. With a growing share of UK ships assumed to be MASS, the economic value to the UK of these ships is conservatively estimated at around £20m per year in 2024. This is expected to increase over time as MASS increases as a share of the UK maritime stock, and as the overall value of UK ocean transport activities increases. The total value in nominal terms over the period 2024-2043 is estimated at slightly over £2bn.

7.11 Integrity use cases: value summary

Additional to the costs measured throughout this section in relation to emergencies cost, a 2012 source suggests that the average cost of an investigation into a marine accident is

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[65] Department for Business, Energy & Industrial Strategy (2021). 'CCUS Supply Chains: a roadmap to maximise the UK's potential'.

[66] East Coast Cluster (2023). 'East Coast Cluster', accessible at: https://eastcoastcluster.co.uk/

[67] The Department for Business, Energy and Industrial Strategy (2019). 'Energy Innovation Needs Assessment. – Sub-theme report: Carbon capture, utilisation and storage'.

[68] Department for Transport (2021). 'A valuation of road accidents and casualties in Great Britain: Methodology note'.

[69] Kretschmann, Burmeister, Jahn. (2017). 'Analyzing the economic benefit of unmanned autonomous ships: An exploratory cost-comparison between an autonomous and a conventional bulk carrier'

£30,000[70]. Historical data from the Marine Accident Investigation Branch indicates around 20 investigations are started per year. An additional £600,000 of emergencies cost is therefore added to each year’s total, split equally between the two geographical locations. This amounts to an additional £12m over the 20 years.

Across the eight use cases examined, MASS, and the additional search and rescue cost outlined above, a total of £329bn operations benefits and £90.7m emergencies costs are considered within scope for this analysis. £1.3bn are located in the Orkney Archipelago and £325.7bn in the North Sea area defined in Scenario 1. These results are largely driven by the outsized contribution of the offshore oil and gas industry, and to a lesser extent the nascent carbon capture and storage industry, to the UK maritime economy. Offshore oil and gas represents 92% of the value captured by the use cases.

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[70] Department for Transport on behalf of the Marine Accident Investigation Branch (2012). ‘The Merchant Shipping (Accident Investigation and Reporting) Regulations 2012’.

8 ECONOMIC IMPACT: SCENARIO ANALYSIS

8.1 Approach

Section 6 defined two scenarios; geographic areas of interest for the UK maritime economy in England and Scotland respectively. For each of these areas, annually-occurring navigational errors in a circle of known radius are studied. .

Section 7 defined a range of use cases in the UK maritime sector where integrity information provides tangible socio-economic benefits, and estimated the magnitude of these on an annualised basis.

This section applies the scenarios defined in Section 6 to the use cases modelled in Section 7 to understand the impact of integrity information on the use cases' abilities to continue to deliver socio-economic value. Estimates are provided of the evolving share of benefits generated by each use case that are dependent on integrity information, based on the qualitative analysis in Section 5 and Section 7. These estimates generally lie between 25-75%, with those use cases expected to integrate more automation scoring closer to the upper limit.

Importantly, the degree to which each of the technologies explored as part of INSPIRe can potentially contribute the requisite integrity information to support these socio-economic impacts will also be estimated. This degree of mitigation will be based on multiple factors, including:

- Binary (Yes/No) selection on whether the technology is capable of fulfilling the user accuracy requirement for that use case
- Percentage contribution estimate (0-100%) based on system functionality from development schedule (see Section 4 for more detail)

Mitigated socio-economic losses attributable to the INSPIRe solution(s) will be considered economic benefits that could realistically be generated by INSPIRe.

8.2 Scenario 1: North Sea

The first scenario, encompassing North Sea navigation failures, amounts to a 125km radius circle centred on the town of Cromer. This area encompasses the Lincolnshire and Norfolk coasts, the Wash bay, the mouth of the Humber tidal estuary, and approximately 30,000 square kilometres of North Sea where the UK has an exclusive economic zone.

This scenario is modelled as impacting the following use cases:

- **Offshore wind**: High density of wind farms near Lincolnshire / Norwich coast including Hornsea Projects One, Two, and Three; Dogger Bank South; Norfolk Vanguard; Norfolk Boreas; Humber Gateway; East Anglia ONE; Greater Gabbard[71]
- **Offshore oil and gas**: High density of oil and gas rigs[72]
- **Carbon capture and storage**: High density of facilities utilising existing oil and gas infrastructure[73]

Offshore wind

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[71] Wind Energy Network Magazine (2023). 'Offshore wind farm map 2023', accessible at: https://www.windenergynetwork.co.uk/wp-content/uploads/2023/03/UK-Offshore-Windfarm-Map-2023-V2.pdf

[72] Riddick, S., Mauzerall, D., Celia, M., Harris, N., Allen, G., Pitt, J., Staunton-Sykes, J., Forster, G., Kang, M., Lowry, D., Nisbet, E. and Manning, A. (2019). 'Methane emissions from oil and gas platforms in the North Sea. Atmospheric Chemistry and Physics. Vol. 19, pp. 9787-9796.

[73] Offshore energies UK (2022). 'Burying CO2 forever: UK announces first licensing round for up to 100 geological storage sites for permanently storing CO2', accessible at: https://oeuk.org.uk/burying-co2-forever-uk-announces-first-licensing-round-for-up-to-100-geological-storage-sites-for-permanently-storing-co2/

Emergencies costs

As discussed in Section 6, it is expected that in future offshore wind farms will be have ocean energy projects co-located amongst turbines. The operating environment in and around offshore wind farms will thus drastically increase in complexity. This means that operatives in emergencies will be highly dependent on integrity information. Adjusting the emergencies cost for ocean energy to account for the assumed rate of navigation failures and allocating between 25% (near-term) and 75% (longer-term) of benefits to integrity, we estimate **£273,000 of benefits over the 20-year period 2024-2043**.

INSPIRe is expected to be capable of supporting integrity-dependent activities in ocean energy and particularly for wind farms as the operating environment complexity increases, given the user 95% accuracy requirements of 10m. As a result we estimate benefits from INSPIRe of **almost £241,000 over the same period**.

Offshore oil and gas

Operations benefits

The potential value of integrity information in the oil and gas sector is expected to grow quickly over the next decade, as fields further offshore are explored and exploited. This will necessitate greater use of dynamic positioning for floating rigs and hence integrity information as a continuous input into this. The estimated reliance of normal operations on integrity information is thus modelled as remaining low until the early 2030s at which point it steadily increases to underpin 30% of oil and gas activities by the end of the period in 2043. This results in an **estimated value of integrity information of almost £28bn** over the 20-year period, with 50% of this coming in the final 5 years.

The 95% accuracy requirement in the WP1-derived user requirements for offshore oil and gas are set at 0.1m. INSPIRe is not expected to deliver this level of accuracy, and so **cannot claim any of the integrity value** in this use case.

Emergencies costs

The emergencies costs for offshore oil and gas are largely driven by the number of medevac helicopters that are required throughout the year. Integrity information is expected to reduce the overall accident rate due to navigation issues in and around rigs, resulting in fewer call-outs and saved costs. These saved costs are estimated at **£460,000** over the 20-year period.

Contrary to the operations user requirements, INSPIRe is expected to be able to provide sufficient accuracy for emergency operations in the oil and gas sector. This results in an estimated **benefit from INSPIRe of almost £400,000** from 2024-2043.

Carbon capture and storage

Operations benefits

The progression of carbon capture and storage activities into using floating rigs to utilise storage areas further offshore is expected to trail the same trajectory of offshore oil and gas. That is, as fields are exhausted this creates capacity for further storage. We thus model the share of benefits attributable to integrity as approximately the pathway of uptake of these floating rigs. This results in an **estimated £2.53bn of benefits over the 20-year period**.

The 95% accuracy requirement in the WP1-derived user requirements for carbon capture and storage are set at 0.1m. INSPIRe is not expected to deliver this level of accuracy, and so **cannot claim any of the integrity value** in this use case.

Emergencies costs

Section 7 found over £1.7m of emergencies cost within carbon capture and storage in the specified North Sea area over the 20-year period. We model integrity benefits as reaching remaining at a moderate level – around 25% - throughout the period. We estimate that the potential losses from integrity-relevant navigation failure events **amount to just under £475,000 over the 20-year period**.

Contrary to the operations user requirements, INSPIRe is expected to be able to provide sufficient accuracy for emergency operations in the carbon capture and storage sector. This results in an estimated **benefit from INSPIRe of approximately £380,000** from 2024-2043.

8.3 Scenario 2: Orkney

The second scenario, covering navigation failures in the Orkney Archipelago, is defined by a 50km radius circle centred on the island of Rousay. This area encompasses all of the approximately 70 Orkney islands, six separate Marine Protected Areas, four active ports, and a wealth of natural resources.

This scenario is modelled as impacting the following use cases:

- **Ship to Ship**: Scapa Flow natural harbour[74] has extensive history and continues to experience high volumes of ship to shup transfers of crude oil, liquified natural gas, and liquified petroleum gas
- **Ocean energy**: High density of ocean energy locations.[75]
- **Aquaculture**: High density and large variety of aquaculture types[76]
- **Fisheries**: Some of the highest density fishery areas in the UK's waters[77]
- **Bio-economy**: Six separate Marine Protected Areas near Orkney, including two that prohibit bottom-towed fishing gear and the relatively large North-west Orkney MPA[78]

Ship-to-ship

Operations benefits

Ship-to-ship operations are highly dependent on integrity information: the precise positioning of ships relative to one another while at sea, while changing relative weights as cargo is exchanged, and while attached via pipes is critical for successful operations. The value per individual transfer at Scapa Flow was approximately £46,000 in 2019, with between 50-80 transfers occurring each year. Assigning 75% of the value of each transfer to be underpinned by integrity information we find a **value of integrity in the ship-to-ship use case of £14.4m**.

The 95% accuracy requirement in the WP1-derived user requirements for ship-to-ship are set at 0.5m. INSPIRe is not expected to deliver this level of accuracy, and so **cannot claim any of the integrity value** in this use case.

Ocean energy

Emergencies costs

As discussed in Section 6, it is highly likely that in future wave-based ocean energy projects will be co-located with other infrastructure such as offshore wind farms. This introduces greater complexity into the operating environment when accidents occur, and in turn means that operatives in emergencies will be highly dependent on integrity information. Allocating between 25% (near-term) and 75% (longer-term) of benefits to integrity, we estimate negligible monetised benefits over the 20-year period 2024-2043.

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[74] Orkney Islands Council Harbour Authority (2017). 'STS transfers in Scapa Flow', accessible at: https://www.orkneyharbours.com/news/sts-transfers-in-scapa-flow

[75] Renewable UK (2023), 'UK Marine Energy Database', accessible at: https://www.renewableuk.com/page/UKMED2/UK-Marine-Energy-Database.htm

[76] Department for Environment Food & Rural Affairs (2015). 'United Kingdom multiannual national plan for the development of sustainable aquaculture'.

[77] Marine Management Organisation (2020). 'UK Sea Fisheries Statistics 2019'.

[78] Scottish Government (2023). 'Marine Protected Areas (MPAs)', accessible at: https://www.gov.scot/policies/marine-environment/marine-protected-areas/

INSPIRe is expected to be capable of supporting integrity-dependent activities in ocean energy and particularly for wave energy in and around wind farms, given the user 95% accuracy requirements of 10m. However, the benefits driven by INSPIRe are also negligible.

Aquaculture

Operations benefits

An estimate of the cost of accidents and outages in aquaculture can be constructed from the reported USD$1.5m socio-economic damage done by a large-scale collision between a vessel and aquaculture infrastructure in Denmark in 2016. This estimate results from the direct financial as well as environmental damage caused by the escape of around 80,000 farmed trout. Adjusting the financial value for inflation and currency differences, this is around £1.35m in 2023 values. We assume that these are relatively rare events, and hence happen on average every 3 years. We further assume that smaller scale events, causing 25% of the socio-economic damage, happen 4 times per year. These values are each annualised, with the rates of occurrence held stable. This produces an estimated annualised loss due to such navigation errors of £1.8m in 2023 and £47m over the period 2024-2043. 9% of this value is attributed to Orkney specifically, in line with Orkney's relative contribution to aquaculture GVA figures for the UK – this results in an estimated £0.17-£0.25m of losses over the period. The portion of these losses that are believed to be due to a lack of integrity information is assumed to begin relatively low, at 25%, and grow over time to 70% in 2043. This increase is driven by a belief in greater levels of automation in Orkney's aquaculture sector over this period, and hence an increased reliance on integrity information – other sources of mistakes such as human error will fade over time as this automation increases. This results in an estimated **£1.43m of integrity-failure driven socio-economic losses** over the 20-year period 2023-2043.

INSPIRe is expected to be capable of supporting aquaculture operations, and hence preventing some of the integrity failure driven losses modelled above. The user requirement is 10m accuracy for the integrity information, which we model as being reliably available once two of the proposed INSPIRe technologies are operational. We therefore estimate **nominal benefits to INSPIRe of £1.25m** over the 20-year period.

Emergencies costs

In Section 7, £74,000 of emergencies costs were estimated for the aquaculture sector. Following the same development timeline of integrity relevance as for aquaculture operations, we expect that the portion of these that are preventable due to improved integrity information begins relatively low (at 25%) but increases over time as automation is more widely taken up in the search and rescue response. For example, automated response vessels are expected to reduce call-out costs and hence save more of the costs further into the future – but this will increase the dependence on integrity information. The estimated nominal savings due to this are very low at slightly less than £44,000 over the period.

INSPIRe is expected to be capable of supporting search and rescue operations in aquaculture, and hence is anticipated to be responsible for a significant portion of the (small) integrity-related cost savings estimated above. The estimated nominal savings due to INSPIRe are thus estimated at **£38,000.**

Fisheries

Emergencies costs

Section 7 found a total of £35m of emergencies cost within Orkney's fisheries over the 20-year period. Much of this fishing is done in relatively open waters, making for an ideal environment for increasingly automated marine search and rescue operations. We thus model integrity benefits as reaching high levels – around 75% - by 2040. We estimate that the potential losses from integrity-relevant navigational failures event **amount to almost £18.8m over the 20-year period**.

INSPIRe is expected to be capable of supporting search and rescue operations in fisheries, and hence is anticipated to be responsible for a significant portion of the integrity-related cost savings estimated above. The estimated nominal savings **due to INSPIRe are thus estimated at £16.8m.**

Bio-economy

Operations benefits

Marine Protected Areas are highly susceptible to damage from bottom-trawling vessels. Such activities are banned in a number of the MPAs, and the impact of accidentally or deliberately ignoring this ban is expected to be catastrophic for the supposedly protected ecosystem. The value of integrity information close to the borders of MPAs is thus extremely valuable to ensure that trawlers do not stray beyond the allowed navigable area. The resulting estimate of potential losses from an integrity failure event are equivalent to **£6.7m over the period**.

INSPIRe is expected to be capable of providing users with sufficient accuracy to enable avoiding MPAs, and is hence modelled as providing a significant portion of the benefits outlined above. This is calculated as **£6.1m of value over the 20-year period 2024-2043**.

Emergency costs

Section 7 found a total of £158,000 of emergencies cost within Orkney's bio-economy over the 20-year period. As with fishing, much of these emergencies are expected to occur in the relatively open waters of Orkney's Marine Protection Areas, making for an ideal environment for increasingly automated marine search and rescue operations. We thus model integrity benefits as reaching high levels – around 75% - by 2040. We estimate that the potential losses from annual integrity failure events **amount to £97,000 over the 20-year period**.

INSPIRe is expected to be capable of supporting search and rescue operations in fisheries, and hence is anticipated to be responsible for a significant portion of the integrity-related cost savings estimated above. The estimated nominal savings **due to INSPIRe are thus estimated at approximately £86,000.**

Marine Investigations

Following Section 7.10's inclusion of marine investigation costs, a lack of integrity information is expected to be the driving force behind some share of marine accidents. The value, therefore, of integrity information is in reducing the number of incidents and hence the number that require investigation – saving costs here. The estimated benefit provided by integrity in general is £6m and by INSPIRe specifically £5.1m over the period.

8.4 Economic impact: broader picture

This section has thus far focused on estimating the socio-economic benefits of integrity information in general, and INSPIRe specifically, in the context of the two defined scenarios. These were chosen to highlight realistic integrity-relevant navigation failure scenarios aligned to real-world marine activity. It is also valuable to consider the impact of such scenarios if the geographical restriction is lifted and the integrity information provision occurred at a national scale – the same scale at which INSPIRe could be provided.

The share of each use case and specific geographic context, i.e. "aquaculture in the Orkney Archipelago" has been estimated (see the table below). These figures are used as scaling factors to approximate the value to the UK as a whole if integrity information were to be provided to the entire country rather than the (more realistic) geographically-bound scenarios.

In this section the value of MASS is included, as this is considered at a national level rather than within either of the geographically-bound scenarios. These benefits are estimated at a nominal value of £859m.

Table 8-1 Use case market shares and results of scaling to whole-UK figures

Use case	Geography	Share of UK market	INSPIRe value, base case (£m)	INSPIRe value, whole UK (£m)
Aquaculture	Orkney Archipelago	8%	1.29	16.5
Ship-to-ship	Orkney Archipelago	5%	0	0
Ocean energy	Orkney Archipelago	10%	0.006	0.06
Fisheries	Orkney Archipelago	1.5%	16.8	1,105
Bio-economy	Orkney Archipelago	2.5%	6.2	247
Offshore Windfarms	North Sea defined area	30%	0.24	0.80
Offshore Oil & Gas	North Sea defined area	66%	0.39	0.59
Carbon Capture and Storage	North Sea defined area	20%	0.38	1.96
Marine Investigations	n.a.	100%	5.13	5.13

8.5 Summary

Across the 8 sectors and 13 use cases identified as part of this study, over £2.6bn of potential integrity benefits were identified. Of these, just £30m are estimated to be within scope for INSPIRe and the two scenarios defined as part of this study.

While the vast majority of potential benefits are identified in the oil and gas sector and the carbon capture and storage sector, operations in these sectors are not within scope for INSPIRe due to their stringent user accuracy requirements.

The majority of benefits that are expected to accrue to INSPIRe come from reduced emergencies activities in fisheries and the protection of Marine Protection Areas from bottom-trawlers (contributing a combined £23m of £30m total).

When expanding the use cases considered to a national scale, using appropriate scaling factors that account for the defined scenarios' share of their total UK markets, a total of £2.2bn of potential INSPIRe benefits are estimated over the 20-year period.

Table 8-2 Benefit estimations summary (nominal terms, £m)

Scenario	Use case	Category	Geography	Economic value generated	Potential integrity benefits	Scenario-driven potential INSPIRe benefits
1	Offshore wind	Emergencies	North Sea	£0.6	£0.3	£0.2
1	Offshore oil and gas	Operations	North Sea	£304,137	£28	-
1	Offshore oil and gas	Emergencies	North Sea	£41	£0.5	£0.4
1	Carbon capture and storage	Operations	North Sea	£17,629	£2,526	-
1	Carbon capture and storage	Emergencies	North Sea	£1.9	£0.5	£0.4
2	Ship-to-ship	Operations	Orkney	£19	£14	£-
2	Ocean energy	Emergencies	Orkney	£0.01	£0.01	£0.01
2	Aquaculture	Operations	Orkney	£1,125	£1.4	£1.3
2	Aquaculture	Emergencies	Orkney	£0.1	£0.0	£0.0

Scenario	Use case	Category	Geography	Economic value generated	Potential integrity benefits	Scenario-driven potential INSPIRe benefits
2	Fisheries	Emergencies	Orkney	£35	£18.8	£16.8
2	Bio-economy	Operations	Orkney	£82	£6.7	£6.1
2	Bio-economy	Emergencies	Orkney	£0.2	£0.1	£0.1
2	Marine investigations	Investigations	Both	£12	£6.0	£5.1
	Total			£323,083	£2,603	£30

9 CONSOLIDATED COSTS

9.1 High-level summary

Costs are considered for the 2024-2048 period as this is the expected lifetime of the DFMC Integrity Monitoring service without further CAPEX.

The total costs for the three proposed INSPIRe technologies over this period are a little over £275m. Breaking this down by technology, we have:

- EGNOS Monitor Network: £5.8m
- M(G)RAIM performance prediction tool: £2.7m - £6.1m
- DFMC Integrity Monitoring Service: £265.5m

The average cost per year over a 25 year period from 2024 is slightly over £11m. Excluding the DFMC Integrity Monitoring service this average cost per year falls to £402,000.

The M(G)RAIM performance prediction tool has two possible versions; without a Quality of Service commitment expected OPEX is 5x lower, as less expenditure is anticipated on e.g. a helpdesk.

9.2 Timeline of capital and operational expenditures

The chart below highlights how the DFMC service dominates expected expenditure on development of INSPIRe over the period 2024-2048.

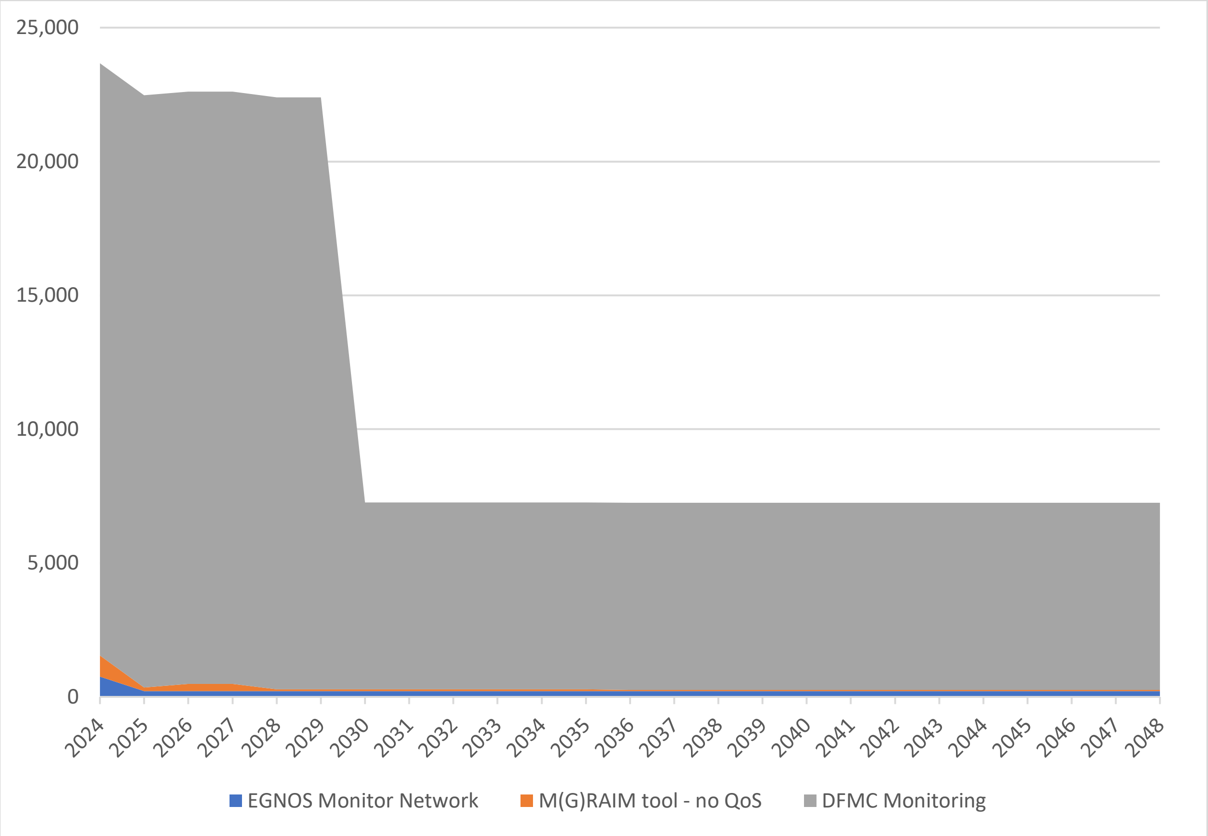

Figure 17 – CAPEX and OPEX schedule, INSPIRe development

Another two charts illustrating the M(G)RAIM tool with and without QoS are included below, with DFMC removed so that the different profiles are more readily visible.

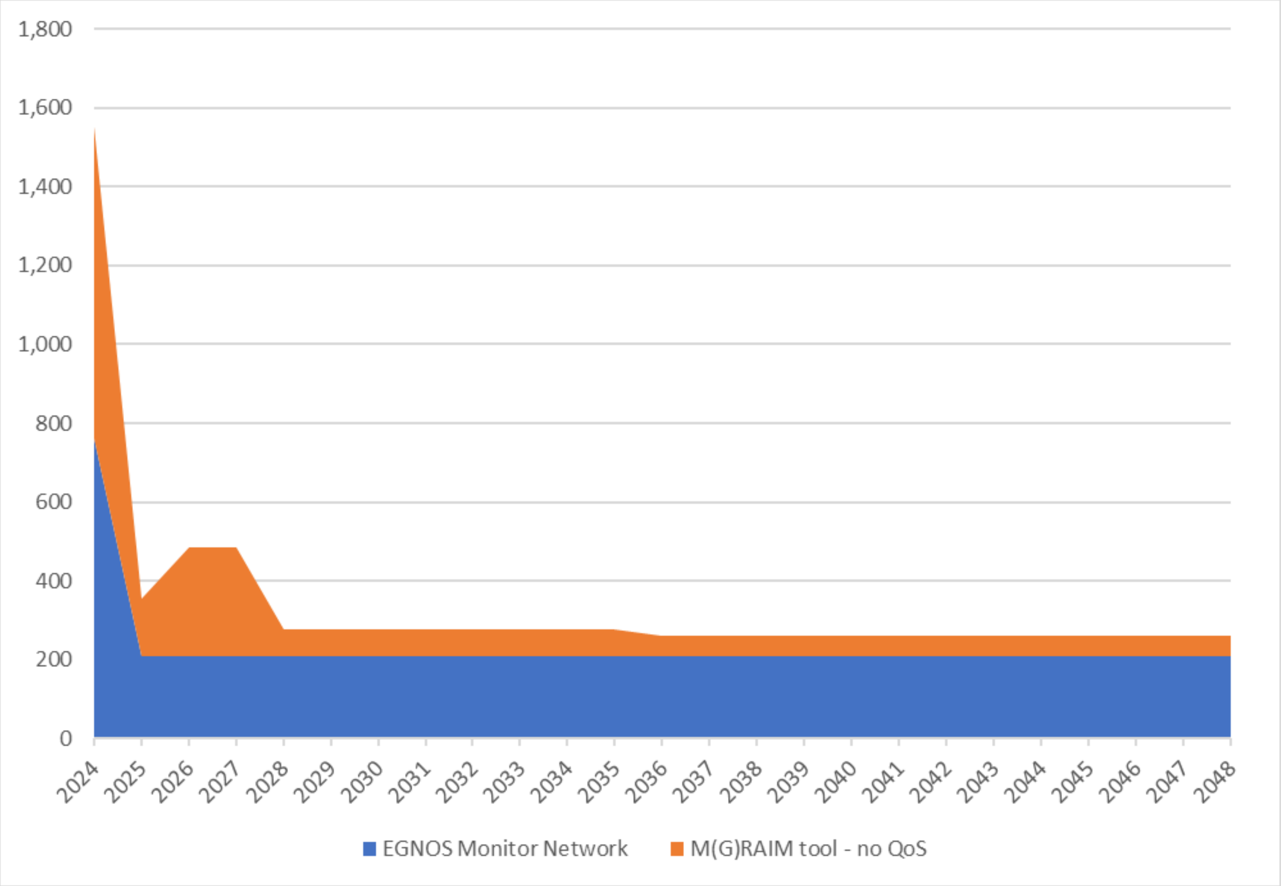

Figure 18 – CAPEX and OPEX schedule, INSPIRe development – excluding DFMC Monitoring Service, no QoS commitment

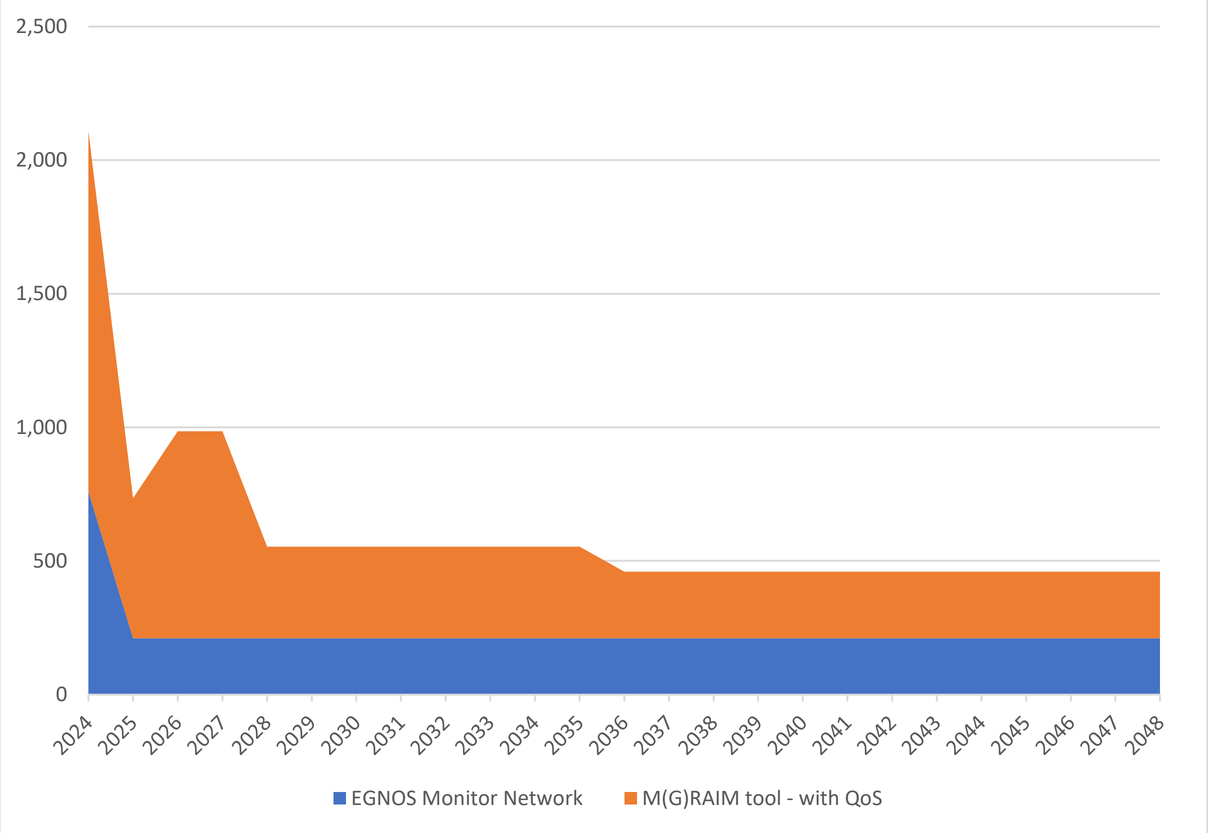

Figure 19 – CAPEX and OPEX schedule, INSPIRe development – excluding DFMC Monitoring Service, with QoS commitment

10 HIGH-LEVEL COST BENEFIT ANALYSIS

To compare the costs and benefits of INSPIRe a Cost Benefit Analysis was conducted. A discount rate of 3.5% per year is used in line with HMG's Green Book, and 2024 is used as the base year.

10.1 Benefits

Across the 20 years 2024-2043, INSPIRe is capable of mitigating a total of £30m of socio-economic losses due to integrity-relevant navigation failure scenarios as detailed in Section 6.

A further case is considered, whereby these benefits are scaled to a national scale. In this national case the estimated INSPIRe mitigation is valued at £2,237m. Marine Autonomous Surface Ships are included in this national-level estimate.

The annualised rate of benefits accrual increases over time as the modelled dependence on integrity increases. A key cause of this is an increase in automation across many sectors.

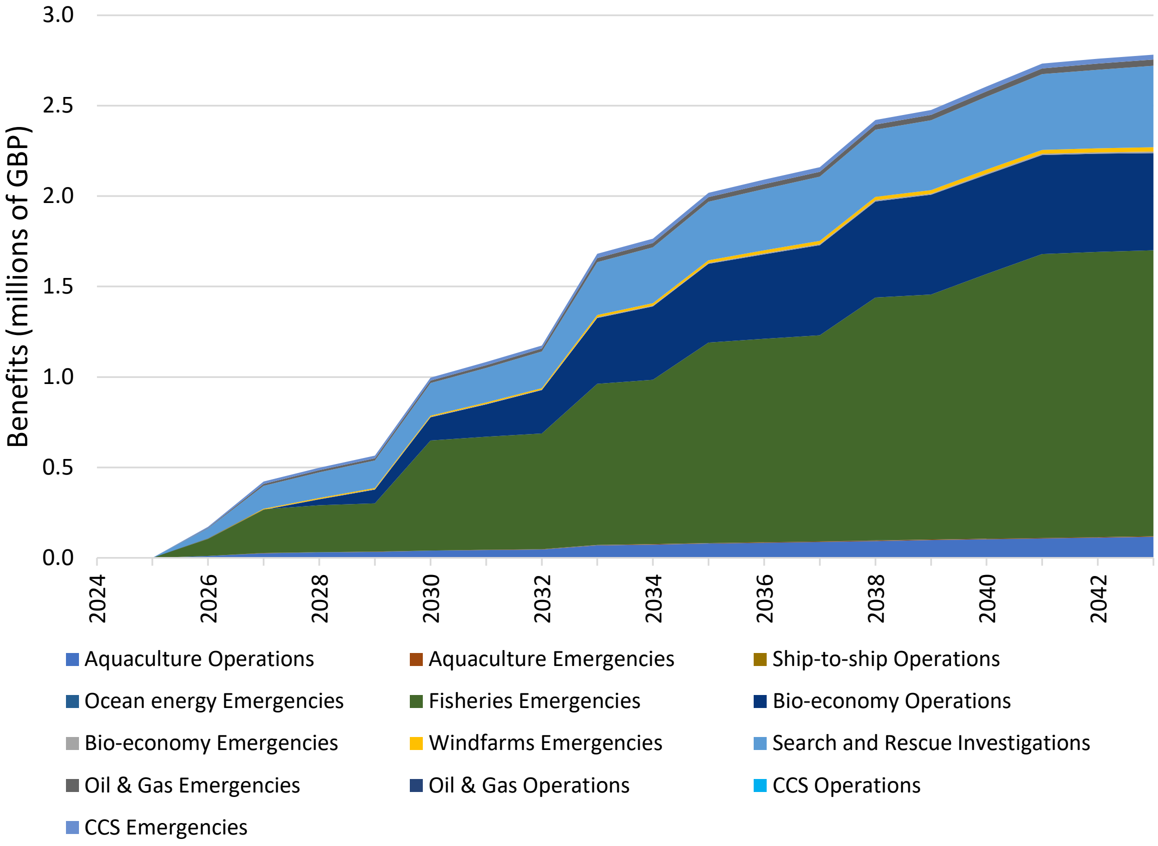

Figure 20 – Annual benefits from INSPIRe mitigation of integrity failure events

In present value terms the benefits are estimated at **£18.9m in the scenario-driven case**, and **£1,371m in the nationally extended case**.

10.2 Costs

The total costs for the three proposed INSPIRe technologies over this period are almost £242.5m when taking the mean value for the M(G)RAIM's two different options. Breaking this down by technology, we have:

- EGNOS Monitor Network: £5.8m
- M(G)RAIM performance prediction tool: £2.7m - £6.1m
- DFMC Integrity Monitoring Service: £265.5m

These costs are greatest early in the development phase, due to CAPEX requirements, and fall over time to a steady level of OPEX-driven costs.

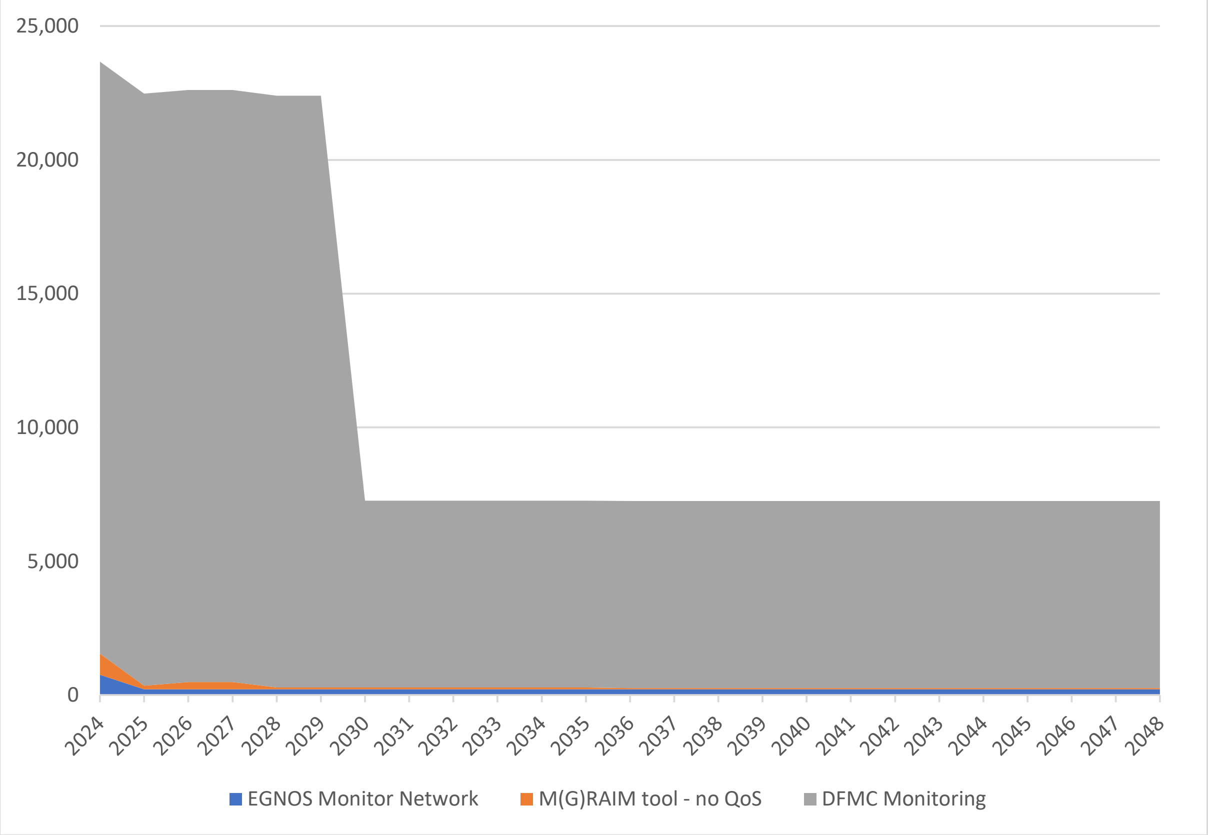

Figure 21 – CAPEX and OPEX schedule, INSPIRe development

In present value terms the **costs are estimated at £194m.**

10.3 Cost Benefit Analysis

The Net Present Value of investment in INSPIRe is below zero for the scenario-driven case (-£175m) but positive for the nationally extended case (£1,177m).

The Benefit:Cost ratio delivered by INSPIRe is 0.10 for the scenario-driven case and 7.06 for the nationally extended case.

These results emphasise the need for a national service rather than a geographically contained solution, as this significantly improves the Net Present Value and cost-benefit ratio due to more of the UK’s marine economy being within scope.

The importance of (not) meeting user accuracy requirements for key marine sectors is clear when considering the vast potential benefits that are not captured in either of the oil and gas or carbon capture and storage sectors.

It is also important to note that the analysis only considered use cases where integrity was considered a high priority – many others were discarded at this stage. Further research could add value to this study by expanding the scope of the study to include these additional use cases.

11 CONCLUSION

This report has synthesised the research conducted as part of the INSPIRe project, including technical, development timeline, and cost information, to develop a Cost Benefit Analysis of the INSPIRe concept.

The report explored 13 distinct use cases across 8 sectors within the UK marine economy, and MASS in addition to this, and how navigation errors in each of them could be impacted by the provision of integrity information. This analysis was centred on the Orkney Archipelago and in the North Sea off the Norfolk coast. The use cases were sourced from Work Package 1, where they were marked as ‘high’ on an integrity information dependence scale.

The costs of developing three different monitoring technologies were collated: an EGNOS monitoring service, a RAIM availability prediction tool, and a Dual Frequency Multi-constellation Integrity Monitoring service.

Key results include that INSPIRe is estimated to have a Benefit:Cost ratio of less than 1 for the scenario-based analysis that focused on two contained geographical areas. The same ratio was, however, above 7 for an extrapolation of these results to the national (UK) level.

One key driver of these results was the selection of only ‘high’ integrity need use-cases for economic analysis. A broader set of use cases may yet reveal significant additional benefits for the INSPIRe service. Another important factor was INSPIRE’s inability to deliver to the required user accuracy for both the ‘oil and gas’ and ‘carbon capture and storage’ sectors; the two largest contributors to UK marine GVA.