Interreg North Sea

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Norsaic REPORT

PARAMETERS AND VISIONS FOR LAND-SEA-INTERACTION - FORECASTING SHIPPING IN THE NORTH SEA TO 2050

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Forecasting Shipping in the North Sea to 2050 - Final Report

UNDERTAKEN ON BEHALF OF

BSH and the NORSAIC project

HH-M22-45819-BSH-NORSAIC

REPORT AMENDMENT RECORD

Rev	Description of Amendment	Author	Checked	Approved	Signed
0	Issue for Client use	Eden Connolly, Gordon Glasgow			
1	Amendments Actioned	Eden Connolly, Gordon Glasgow			
2	Additional explanation in Section 4.2.1	Eden Connolly, Raven Lui			
4	Final version, including rework to include Swedish areas.	Eden Connolly, Raven Lui			
5	Final comments actioned	Eden Connolly			
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Acronym	Description
AIS	Automatic Identification System
CAE	Claims, Arguments, and Evidence
CSOV	Commissioning Service Operation Vessel
CTV	Crew Transfer Vessel
EMSA	European Maritime Safety Agency
EU MSFD	European Union's Marine Strategy Framework Directive
GHG	Greenhouse Gas
ICS	International Chamber of Shipping
IMMA	Important Marine Mammal Area
IMO	International Maritime Organisation
LNG	Liquified Natural Gas
LOA	Length Over All
MPA	Marine Protected Area
MSP	Maritime Spatial Planning
NORSAIC	North Sea Cooperation for Advanced Integrated Maritime Spatial Planning
O&G	Oil and Gas
O&M	Operations and Maintenance
OSPAR II	The North Sea region where this study was conducted.
OWF	Offshore Windfarm
SOV	Service Operation Vessel
SwAM	Swedish Agency for Marine and Water Management
T&I	Transport and Installation
URN	Underwater Radiated Noise

1.0 INTRODUCTION

The future of shipping activity in the North Sea is subject to a complex array of constraints and drivers, including economic, environmental, technological, and regulatory factors. An understanding how these forces will shape traffic patterns, fleet composition, and the spatial distribution of activity over the coming decades is essential for informed marine spatial planning policy development with respect to the Greater North Sea area.

This study contributes to the Interreg project NORSAIC (North Sea Cooperation for Advanced Integrated Maritime Spatial Planning), which aims to strengthen cross-border collaboration in marine spatial planning (MSP) across the North Sea. The project focuses on enhancing governance frameworks, addressing land-sea interactions, assessing cumulative impacts, and promoting the sustainable multi-use of marine space. By supporting innovation and joint planning approaches, NORSAIC plays a key role in fostering a resilient and climate-conscious marine environment (Interreg North Sea Region, 2025).

To support this need, ABL have undertaken a structured and evidence-based analysis to project shipping activity in the North Sea to the year 2050. This analysis has systematically identified, examined, and integrated key factors expected to influence maritime traffic in the region, including:

- Global and regional trade dynamics and their impact on shipping demand.
- Fleet composition and vessel efficiency trends, including anticipated shifts in vessel sizes and operating patterns.
- Expansion of offshore wind energy infrastructure and its implications for vessel operations, routing, and maintenance traffic.
- Environmental protection measures, e.g. the designation of Marine Protected Areas (MPAs) and regulations to mitigate underwater radiated noise (URN).
- Climate change affects operational windows, extreme weather risk, and offshore asset maintenance requirements.
- Fishing activity trends, particularly declining fish biomass and increasing regulatory constraints.
- Oil and gas extraction activity.

The analytical process combined quantitative data (such as trade forecasts, fleet renewal rates, and production trends) with qualitative assessments of policy developments, technological pathways, and spatial constraints. A structured Claims, Arguments, and Evidence (CAE) framework has been developed to ensure that all projections are logically derived, evidence-based and defensible. This can be found within Appendix C: Claims, Arguments, and Evidence (CAE) Framework with the references found after this, which can be applied to raster-based and AIS-derived baseline shipping activity data. The factors reflect anticipated changes in traffic distribution, vessel density, and class composition across the North Sea in 5-year epochs to 2050.

The outcome of this work will be an integrated projection of North Sea shipping activity, reflecting the best available information, transparent analytical methods and an articulation of uncertainty and confidence levels. This projection provides a robust platform for future strategic assessments and spatial analyses in the marine domain. It is also constructed in such a way that alterations to the assumptions that inform the analysis may be changed relatively easily made if these are assessed as warranted.

Following this ‘macro-scale’ analysis of the forecast of shipping traffic in the North Sea, three ‘micro-scale’ case studies were conducted. This enables analysis of specific instances of Offshore Windfarm (OWF) development and their impacts on shipping traffic.

2.0 SCOPE

This analysis addresses a spatial scope that approximately corresponds with the OSPAR II region. It presents the spatiotemporal 'adjustment factors' that are used to construct the analysis of shipping activity in this region across 5-year epochs from 2025 to 2050. These factors are classified according to the following typology:

- General Merchant Shipping Traffic
- Marine Environment Protection
- Climate Change Impacts
- Windfarm Activity
- Fishing Vessel Traffic
- Oil and Gas Activity

A more complete account of the reasoning supporting the adjustment factors offered here is provided in Appendix C: Claims, Arguments, and Evidence (CAE) Framework. Noting that offshore wind activity seems likely to be the single largest driver of changes in North Sea shipping activity, this paper also offers an analysis of the trajectories that this development activity may take.

The scope of this analysis is limited to the North Sea, made up from the OSPAR II Region and a small part of OSPAR III area, so the French OWF sites could be included in this project. This is illustrated in Figure 1; this area is termed 'the study area'. The time period addressed is from 2022, when the AIS data was collected, to 2050, the final forecast epoch used in this study.

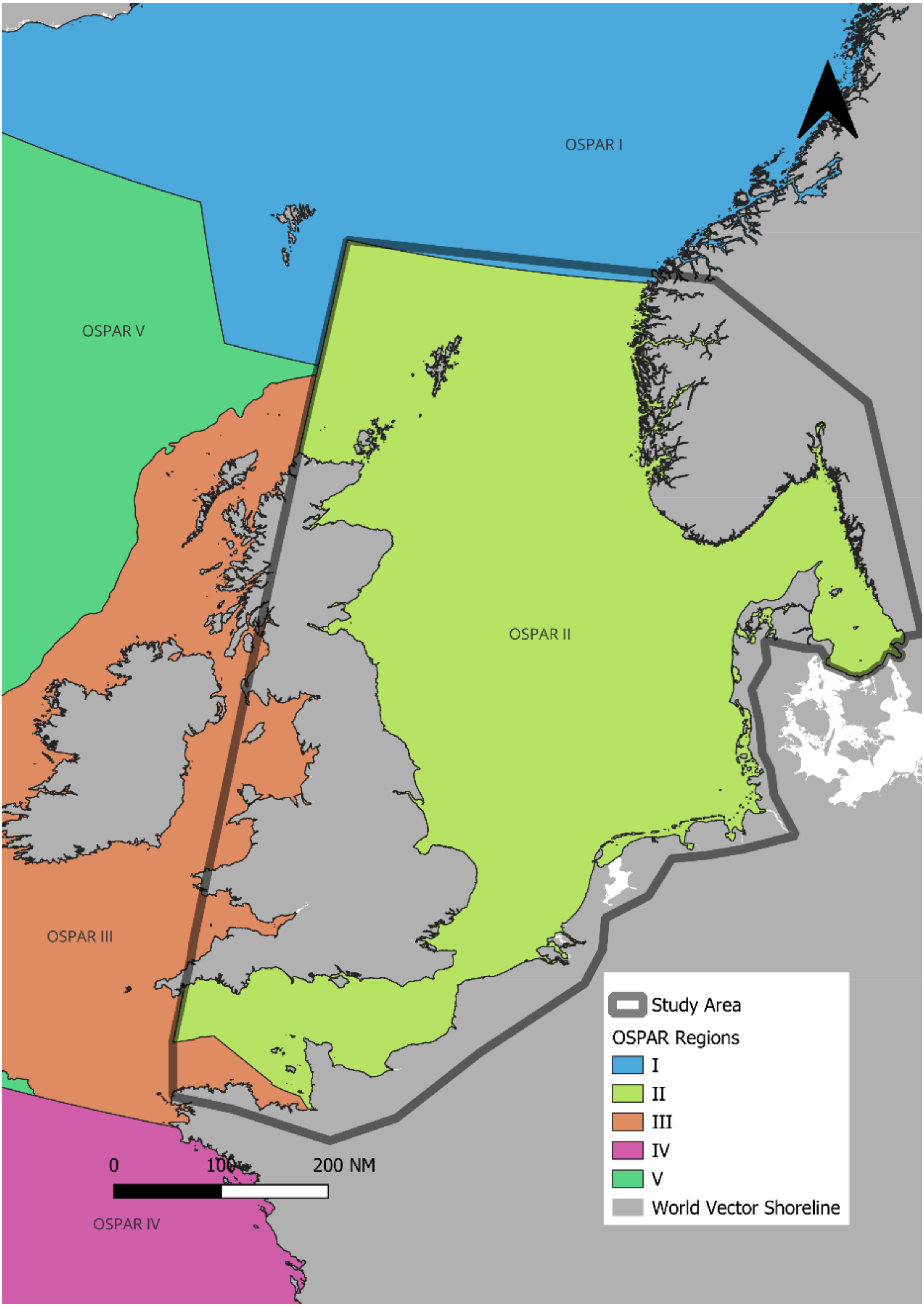

Figure 1: OSPAR Regions (Source: OSPAR website)

Detailed quantitative analysis will include all high-level classes of vessel that are discernible in an AIS dataset covering the study area. Additional detail will be provided for both fishing and service/support vessels. A complementary (qualitative) commentary on the types and classes of vessel that may not be discernible in this dataset will be provided. It is anticipated that analyses will address the following main classes of vessel:

- Bulk Carriers
- Chemical Tankers
- Crude Oil Tankers
- Container Ships
- Fast Ferries
- Gas Carriers
- General Cargo Ships
- Oil Product Tankers
- Other Ships
- Passenger Ships
- Pleasure Boats (see: Appendix B: Exclusion of Pleasure Boats)
- Ro/Ro Cargo Ships
- Offshore Support/Service Ships

The AIS dataset used for this study consists of 12 consecutive months (1 calendar year) of AIS positional data messages with a temporal extent of January 2022 to December 2022 inclusive. The data used has a spatial extent with 100% coverage of the study area shown in Figure 1.An example of this AIS data is shown below (1 calendar month, for a limited spatial extent). This AIS data contains points for vessel locations every 6 minutes. While this study focuses solely on 2022, it is worth noting that maritime traffic patterns during this period may reflect ongoing recovery from the disruptions caused by the COVID-19 pandemic and global supply chain issues in 2020 and 2021. It is also acknowledged that maritime traffic in 2022 may have been influenced by ongoing geopolitical developments, including the war in Ukraine, which could have affected international shipping and trade, particularly for certain vessel types such as passenger and pleasure craft. However, it is assumed that this dataset can be trusted for use as a reliable dataset to conduct this study on.

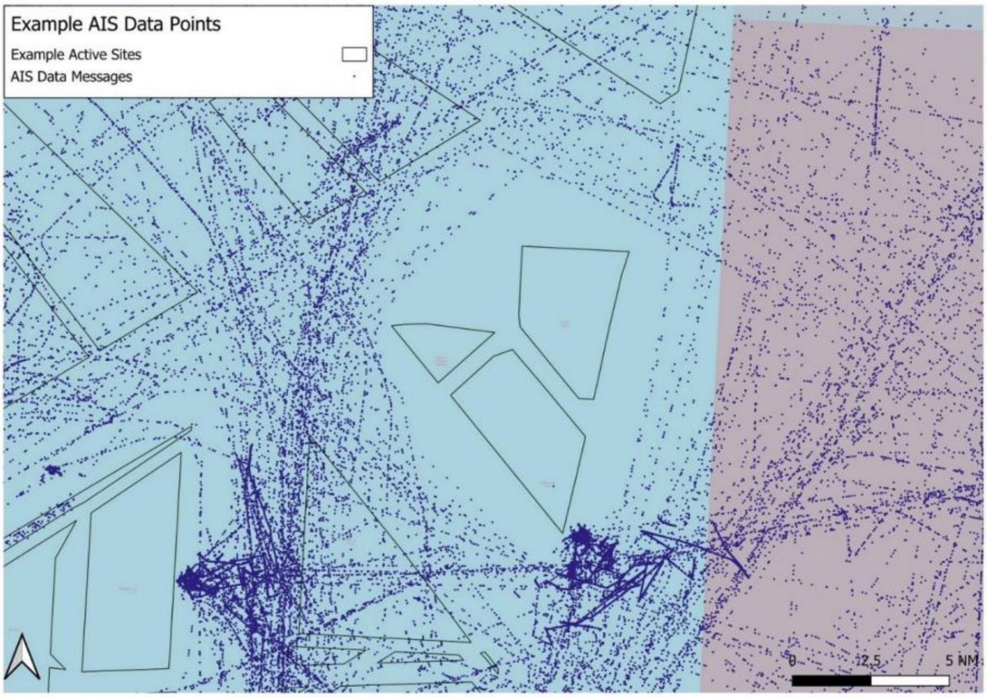

Figure 2: Example AIS Data Points

The data is sourced from the European Maritime Safety Agency (EMSA). Much of the analysis in this report is made based on an annualised assessment of shipping activity change or at the epoch intervals supplied by the Client. These epochs cover 5-year steps from 2025 to 2050 (inclusive): 2025, 2030, 2035, 2040, 2045, and 2050. Where the data availability precludes making projections with a useful level of confidence, we have averaged the forecasting predictions from multiple sources to find an acceptable value. Where necessary we have chosen more conservative values. All results are made under the list of assumptions and limitations in the report. The patterns of shipping activity over time and the factors that affect this is complex. This report aims to provide a view of shipping activity to 2050 based on the resources available.

3.0 METHODOLOGY

3.1 OBJECTIVES

The objectives of this project are twofold: first, to provide insight into the current characteristics of shipping traffic in the North Sea region and second to develop forecasts of the likely future characteristics of this shipping traffic. This is then be used to forecast shipping traffic changes through six epochs to 2050 by vessel class further unpacking the implications of the factor analyses to derive recommendations for maritime spatial planning. This is done by:

- Providing 'macro-scale' evaluations of current shipping logistics concepts.
- Providing 'micro-scale' case study evaluations of shipping traffic activity at three windfarm sites.

3.2 OVERVIEW OF METHOD

The overall methodological approach to this task is as follows:

1. Undertake a baseline assessment of shipping traffic characteristics in the study area.
2. Assess the factors affecting change in the shipping characteristics (constraints and drivers), these to address the following set of five focus areas:
    - Environmental protection requirements
    - Climate change effects
    - Windfarm service traffic considerations
    - Fishing vessel traffic considerations
    - The wider commercial context
3. All assessments of constraints and drivers' factors will have regard to the findings of previous, relevant assessments, which have been provided by the Client.
4. Adjust the baseline assessment in the light of the findings of the factor analyses to obtain forecasts of the likely future characteristics of shipping traffic. Depending on the factor analyses, these forecasts may include scenario-based assessments in combination with causal forecasts (explanatory models).
5. Analyse these results within the areas of three micro-scale case studies.

The following sections detail the specific methods to be employed under this general approach.

3.3 ASSUMPTIONS AND LIMITATIONS

While this assessment offers a structured and evidence-based projection of shipping activity in the North Sea to 2050, several limitations should be acknowledged in relation to data scope, analytical assumptions, and external uncertainties:

3.3.1 Simplified Economic and Technological Assumptions

The analysis applies aggregate adjustment factors to represent trade growth, fleet renewal, and efficiency improvements. These factors are derived from authoritative forecasts and historical trends but do not account for short-term economic shocks, geopolitical disruptions, or breakthrough technological developments (e.g. autonomous vessels, radical fuel innovations) that may affect shipping patterns in ways not presently foreseeable.

3.3.2 Spatial Simplifications

The projection does not incorporate a full Origin-Destination analysis of vessel movements, nor does it explicitly differentiate traffic linked to specific port pairs. Instead, the model applies generalised spatial adjustment factors to redistribute traffic density patterns over time. While analytically defensible, this approach may smooth over fine-grained routing decisions, particularly in congested or environmentally sensitive areas.

In addition, the outputs of this are in a raster format, which show the total number of vessel tracks predicted to pass through each cell/grid square (total tracks per km^2 per year). This does not show the path of travel, although traffic patterns can be identified from this.

3.3.3 Uncertainty in Policy Implementation

The projection assumes the introduction of certain regulatory measures, including underwater radiated noise (URN) mitigation zones and marine protected areas (MPAs). However, the timing, enforcement, and spatial extent of such measures remain uncertain, and actual outcomes may differ from the assumptions applied in this analysis. This study provides one such possible introduction. Further study should include variant scenarios of policy implementation and timelines.

3.3.4 Fishing Activity Data Limitations

The fishing vessel traffic component of the projection is based solely on AIS-derived data. Given that many small-scale and inshore fishing vessels are not required to carry AIS transponders, this approach likely under-represents small-vessel activity, particularly in coastal areas and ecological zones. Furthermore, the AIS dataset does not distinguish between active fishing and transiting behaviour, requiring behavioural inference that may introduce classification error.

Notwithstanding the limitations identified above, this assessment provides a robust, transparent, and analytically defensible projection of North Sea shipping activity through to 2050. The structured approach adopted ensures that all assumptions, data sources, and causal linkages underpinning the analysis are explicitly documented. This provides a solid foundation for informed decision-making, spatial planning, and risk assessment.

While certain dimensions of maritime activity, notably small-scale fishing traffic, are not fully resolved within this analysis, the core drivers of structural change, including trade demand, fleet efficiency, offshore infrastructure growth, and environmental regulation, are incorporated and evidenced. The assessment is therefore considered to offer a credible baseline projection of large-scale, long-term patterns in shipping activity across the North Sea.

3.4 BASELINE TRAFFIC ASSESSMENT

This section details the methods to be used to assess traffic for each of the three main vessel activity classes addressed by this study: service vessels, fishing vessels and commercial vessels.

All offshore wind developments within the OSPAR II region have been categorised as under investigation where the predicted commission date is after 2025, under construction where the commission date is between 2022 and 2025, , and operational where the commission date is before 2022. This information was sourced from the Client, internal expertise, and publicly available Maritime Spatial Planning (MSP) and Site Development Planning datasets.

For each offshore wind farm, the periods of time for which it was “under investigation,” “under construction,” and “operational” will be ascertained for the time-horizon for which AIS data is available (i.e., January 2022 to December 2022 inclusive).

The vessel traffic that interacts with identified OWFs has been identified by extracting the AIS observations broadcast to create the Long List (ABL, 2025), as shown in Figure 3. This details the vessel tracks per OWF site. Additionally, summary statistics of all traffic data information has been analysed in Section 4.1. These tracks are made from joining the AIS points together in chronological order.

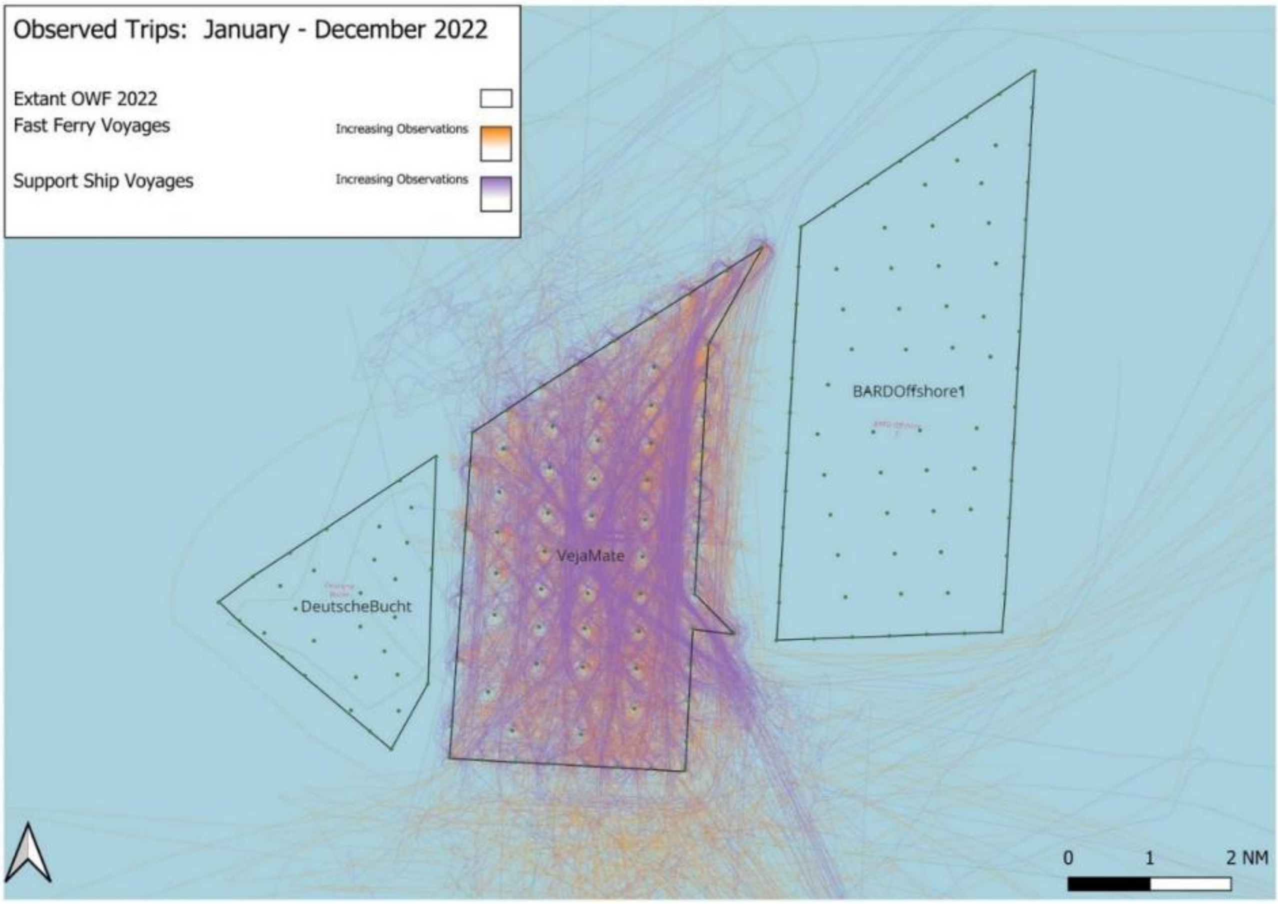

Figure 3: Depiction of Service Vessel Trips as Derived from AIS Data

3.5 FACTOR ANALYSIS

This section summarises the factor analyses on environmental protection, climate change effects, windfarm service traffic, fishing vessel traffic, and the wider commercial context and how they will impact shipping traffic to 2050. For the sources of this analysis, see Appendix C: Claims, Arguments, and Evidence (CAE) Framework.

3.5.1 Factor Analysis 1: Environmental Protection

International and regional efforts to reduce underwater noise pollution and increase protection of environmentally important areas are increasing. These initiatives aim to reduce the negative impacts on marine biodiversity, particularly marine mammals, by introducing new zoning measures, noise thresholds, and operational guidelines.

The key policies in the North Sea are:

- Important Marine Mammal Areas (IMMAs): There were 33 new IMMAs designated in the Northeast Atlantic and Baltic Sea in 2024. These zones do not, currently, have any legal binding but aim to influence future conservation measures and route planning to avoid disturbance to sensitive marine mammal habitats (MMPATF, n.d.).
- IMO Revised Guidelines on Underwater Radiated Noise (URN) of 2023 encourages (IMO, 2023):
    - Minimisation of cavitation-induced noise through a reduction in speed and adjustments to propellers.
    - Avoiding routes through protected and sensitive areas.
    - The current adoption of these guidelines is voluntary throughout the trial phase of 2023 to 2026.
- Redirecting shipping lanes away from MPAs and migratory routes to lower noise exposure. This could increase voyage distances, fuel use, and costs for operators, especially near high-traffic zones like the Mediterranean and Baltic Seas (IMO, 2023) (Borsani, et al., 2023).
- EU Marine Strategy Framework Directive (MSFD) (Borsani, et al., 2023) establishes limits on underwater noise exposure:
    - No more than 20% of marine areas should be exposed to continuous noise annually.
    - No more than 20% (daily) or 10% (annually) should be exposed to impulsive noise.
    - These thresholds will impact marine spatial planning and could lead to partial closures or rerouting in busy maritime zones.
- OSPAR 2030 Strategy commits to a regional noise reduction plan by 2025 (OSPAR, 2021), including:
    - Developing the best available environmental techniques and practices for shipping noise, including conducting risk assessments and impact evaluations.
    - Expanding monitoring across all regions.
    - This may result in new regulations requiring route changes or operational restrictions.
- National Policy Examples
    - Netherlands: Advocates stronger implementation of IMO guidelines (Kinneging, 2023) (Ministry of Infrastructure and Water Management, Netherlands, 2022).
    - Denmark: Encourages noise reduction through fuel efficiency improvements (Porst & Mogensen, 2024).
- Industry and Technological Innovation:
    - The SATURN project and initiatives by BIMCO and the International Chamber of Shipping (ICS) promote quieter ship design.
    - Tracking adoption of IMO guidelines, which could lead to mandatory requirements if there is a failure of voluntary uptake (BIMCO & ICS, 2024).

The foreseen environmental protections that affect the North Sea will affect the shipping traffic by encouraging, or possibly enforcing, navigational changes around protected or sensitive areas may lengthen voyages, increase fuel costs, and increase route planning complexity. Shipowners may need to adjust propeller types, manage speed profiles, or adopt quiet ship designs to comply with noise reduction policies and guidance, especially if mandatory international regulations could be imposed post-2026. However, many noise-reduction measures overlap with fuel-saving and emissions reduction initiatives.

3.5.2 Factor Analysis 2: Climate Change Effects

Climate change is expected to impact shipping traffic in the North Sea through extreme weather events, sea level rise and coastal erosion, impacts on fishing, maintenance of OWFs, changes in international shipping routes, and regulatory changes.

1. Extreme Weather Events: While waves and wind patterns in the North Sea are not projected to change significantly, climate change is expected to bring more intense and more frequent rainfall. This can lead to disruptions in berthing and cargo handling due to reduced visibility and increased delays. The rise in extreme weather events may also pose safety risks.
2. Sea Level Rise and Coastal Erosion: Rising sea levels contribute to greater agitation in ports and harbours, increasing coastal erosion, and more frequent severe floods. These conditions heighten the risk of damage to coastal infrastructure, affect mooring and berthing operations, and require costly adaptation measures for port authorities.
3. Disruptions to Fishing Traffic: Changes in sea temperatures and storm intensity can impact fishing vessel performance, vessel stability, and gear effectiveness. Fishing is reduced in severe weather as many fishers stay in port to avoid equipment loss and excessive fuel consumption. Furthermore, the projected decline in marine biomass due to climate change threatens fish catch potential, affecting income, food security, and market stability.
4. OWF Maintenance Challenges: Offshore wind farms in the North Sea face increased maintenance needs due to climate change-related impacts, which add to operational costs and make wind power generation more challenging:
    a. Heatwaves cause turbine shutdowns.
    b. Frost, ice, and drifting ice can damage turbine foundations.
    c. Extreme winds, lightning, and hail events accelerate blade erosion.
5. Changes in International Shipping Routes:
    a. Melting Arctic ice presents the possibility of new shipping routes between Northern Europe and East Asia. However, the high costs, icebergs, limited infrastructure, and insurance concerns could hinder their impact on shipping.
    b. Climate-induced droughts in the Panama Canal reduce vessel transits which has been increasingly impacting global trade flows.
6. Regulatory Changes: Stricter protections for marine species and ecosystems could implemented. New policies to reduce greenhouse gas (GHG) emissions may encourage transition away from fossil fuels, increase cold ironing, and impose restrictions on activities within ports.

Overall, climate change introduces challenges for shipping traffic in the North Sea, affecting infrastructure, operations, trade routes, and regulatory landscapes. This will certainly change the shipping traffic composition and volume in the North Sea.

3.5.3 Factor Analysis 3: Windfarm Service Traffic

The vessel activity associated with windfarm developments can be grouped into three main classes: transport and installation (T&I) activity, operations, and maintenance (O&M) activity, and decommissioning activity. The traffic characteristics associated with offshore wind development areas varies with the attributes of a development and with its lifecycle status.

Although vessel-based service traffic remains the primary mode of access for offshore windfarm operations, helicopters may offer a supplementary option, particularly during the O&M phase. Their ability to operate in otherwise inaccessible sea states and provide rapid transport for technicians makes them valuable for urgent maintenance or inspections. However, helicopters are unlikely to see widespread use due to their significantly higher operational costs compared to vessels. Factors such as limited payload capacity, the need for specialized infrastructure (e.g. winching systems or helipads), and long-term contractual commitments further constrain their practicality. As such, helicopter access is generally reserved for specific scenarios where vessel access is impractical or time-critical (Energy Institute, London, 2021) (Li, Bijvoet, Wu, Jiang, & Negenborn, 2024).

3.5.4 Factor Analysis 4: Fishing Vessel Traffic

Fishing traffic in the North Sea is heavily influenced by changing regulatory measures and environmental conservation. Strict fishing regulations have been implemented in the North Sea which aim to protect marine ecosystems by limiting where and how fishing operations take place.

1. Regulatory Restrictions on Fishing Activities: Several MPAs impose significant limitations on bottom trawling and other disruptive fishing techniques. The United Kingdom introduced an MPA fisheries byelaw in March 2024, banning bottom trawling in key conservation zones (UK Government, 2024). Belgium's marine spatial plan (MSP) for 2020–2026 restricts several fishing techniques that disturb the seabed, including bottom trawling, gillnetting, and longlining (Belgian Government, 2020). In Germany and the Netherlands, new regulations prohibit mobile bottom-contacting fishing gear in Natura 2000 sites to protect sensitive habitats and reduce bycatch (European Commission, 2022). Norway has implemented additional protections for coral reefs to limit fishing-related damage (Norwegian Fisheries Directorate, 2023). In addition, the Swedish government has announced a general ban on bottom trawling in marine protected areas within the trawl limit, set to take effect from 2026 (Svensson, Johansen, & Westerberg, 2019).
2. Implications for Shipping Traffic: These restrictions influence shipping patterns in multiple ways. Reduced fishing activity in regulated areas may lead to lower vessel density in conservation zones, potentially easing congestion for commercial shipping routes. However, displaced fishing traffic may relocate to unregulated areas, altering traditional maritime traffic flows. Furthermore, changes in port activity due to fishing restrictions can shift logistical demands for shipping support services.
3. Forecasting Long-Term Trends: Given increasing regulatory pressures, fishing traffic in the North Sea is expected to decline in certain restricted areas while intensifying elsewhere. This reallocation of fishing operations could influence shipping navigation strategies, requiring adaptive planning for commercial shipping corridors.

3.5.5 Factor Analysis 5: Wider Commercial Context

In the North Sea, shipping demand is unlikely to rise significantly. While oil tanker cargo volumes are expected to decline, increases in container and LNG shipments may offset the reduction. To accommodate this change, vessels are expected to increase in size which will ensure efficient transport without a surge in total shipping activity.

Larger vessels could necessitate port infrastructure upgrades, such as deeper berths, improved handling capabilities, and wider zones around OWFs and other obstacles for safer navigation. The decline in oil tanker volumes reflects changing energy consumption patterns, while LNG growth aligns with the demand for cleaner fuels. Although this may also be a consequence of the geopolitical situation regarding the war in Ukraine.

Trade agreements, regulations, and technological advancements will shape these trends. Stakeholders must adapt to evolving market conditions.

These dynamics are further explored in the project model diary, where implications for infrastructure and logistics are examined in greater detail.

3.5.5.1 SLOW STEAMING

Slow steaming is the practice of operating vessels at reduced speeds. It is widely recognised as a cost-effective and practical strategy to lower GHG emissions (AirClim, 2012) and is seen as a global best practice. Additionally, slower speeds reduce underwater noise pollution, mitigating disturbances to marine wildlife (Powell, 2025).

However, slow steaming also presents challenges as longer transit times can raise operational costs, reducing the profitability of shipping (Cariou, 2011). Adoption is strongly linked to economic conditions, with stronger markets favouring quicker speeds and weaker markets encouraging slower operations to cut costs. Furthermore, the IMO may introduce speed limits, enforcing slow steaming, in certain areas to enhance maritime safety and reduce environmental impact (AirClim, 2012).

While slow steaming can improve schedule reliability and reduce the need for additional ocean carriers, its effectiveness depends on comprehensive adoption (Maloni, Paul, & Gligor, 2013). Despite its environmental advantages, studies predict that slow steaming will not significantly affect shipping traffic volume in the North Sea before 2050 (Shin, 2024).

The reviewed shipping and port development literature will be weighted for plausibility and for applicability to the study area and to the forecast period. Composite activity adjustment factors for shipping traffic will then be derived in the light of the findings of the literature review and of the baseline traffic assessment. These factors will be used to adjust the forecast of expected future shipping across each of the classes of vessel activity addressed. The bases by which these adjustment factors are derived will be recorded in the project model diary.

3.6 FORECASTING

3.6.1 Generation of Traffic Forecasts

Drawing on the adjustment factors and insights obtained from the Factor Analysis (Section 3.5) that explored the constraints and drivers across five categories of shipping traffic and in Appendix C: Claims, Arguments, and Evidence (CAE) Framework.

The project team has collectively reviewed this to determine the expected sum effect of all factors on the classes of shipping traffic activity reviewed across the forecast period. Empirical data was used if available, and traffic adjustments were supported by qualitative inference where data is sparse, or developments are novel. Here, assumptions have been recorded that have been used in the model to reduce the unknown uncertainty with the outputs of the model.

The forecasting of the AIS data applied the changes found in Table 1and the analysis done to calculate the impact of OWF sites on shipping traffic and applied them to the 2022 AIS data.

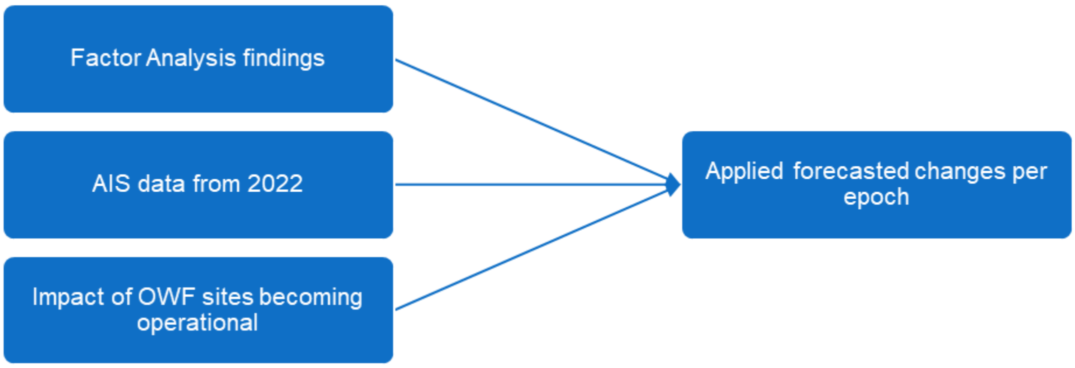

Figure 4: Flow Chart of Forecasting Method

Table 1 lists the summary of the adjustment factors applied in this study. The source of these adjustment factors can be found in the Factor Analysis (Section 3.5) and in Appendix C: Claims, Arguments, and Evidence (CAE) Framework. These adjustment factors were applied compound, i.e. the adjustment factor was applied to the 2022 data to create the 2025 output, which was then in turn applied the adjustment factor for 2030 to calculate the 2030 output. Pleasure boats have been excluded from this study, as explored in Appendix B: Exclusion of Pleasure Boats.

Table 1: Summary of Adjustment Factors (percentage change)

<table>
<tr><th colspan="2">Vessel Class</th><th>Explanation</th><th>2025</th><th>2030</th><th>2035</th><th>2040</th><th>2045</th><th>2050</th></tr>
<tr><td colspan="2">Bulk Carriers</td><td>Reduced demand for bulk commodities due to shifts in industrial production.</td><td>1</td><td>0.98</td><td>0.98</td><td>0.98</td><td>0.98</td><td>0.98</td></tr>
<tr><td colspan="2">Chemical Tanker</td><td>Decline driven by greener industrial processes.</td><td>0.9</td><td>0.98</td><td>0.84</td><td>0.75</td><td>0.81</td><td>0.73</td></tr>
<tr><td colspan="2">Container Ship</td><td>Slight decline due to regionalised supply chains and improved logistics.</td><td>1</td><td>0.98</td><td>0.98</td><td>0.98</td><td>0.98</td><td>0.98</td></tr>
<tr><td colspan="2">Crude Oil Tanker</td><td>Sharp drop due to global transition away from fossil fuels.</td><td>0.76</td><td>0.75</td><td>1.06</td><td>1.06</td><td>0.74</td><td>0.55</td></tr>
<tr><td colspan="2">Fast Ferry</td><td>Decrease due to alternative transport and lower tourism traffic.</td><td>0.93</td><td>0.89</td><td>0.89</td><td>0.89</td><td>0.89</td><td>0.89</td></tr>
<tr><td colspan="2">Fishing Ships in the English Channel and south North Sea</td><td>Decline in fish stocks and stricter environmental regulations.</td><td>0.98</td><td>0.96</td><td>0.96</td><td>0.96</td><td>0.96</td><td>0.96</td></tr>
<tr><td colspan="2">Fishing Ships elsewhere in the study area</td><td>Moderate decline due to sustainable fishing practices and quotas.</td><td>1</td><td>0.98</td><td>0.98</td><td>0.98</td><td>0.98</td><td>0.98</td></tr>
<tr><td colspan="2">Gas Carrier</td><td>Reduced LNG transport as renewable energy replaces fossil fuels.</td><td>0.9</td><td>0.98</td><td>0.84</td><td>0.75</td><td>0.81</td><td>0.73</td></tr>
<tr><td colspan="2">General Cargo Ship</td><td>Slight decline due to more efficient cargo consolidation and routeing.</td><td>1</td><td>0.98</td><td>0.98</td><td>0.98</td><td>0.98</td><td>0.98</td></tr>
<tr><td colspan="2">Oil Products Tanker</td><td>Long-term decline from decarbonisation, with a temporary rise around 2040 due to transitional energy demands.</td><td>0.76</td><td>0.75</td><td>1.06</td><td>1.06</td><td>0.74</td><td>0.55</td></tr>
<tr><td colspan="2">Other Ship</td><td>General reduction in miscellaneous maritime activity.</td><td>0.90</td><td>0.81</td><td>0.87</td><td>0.84</td><td>0.79</td><td>0.66</td></tr>
<tr><td colspan="2">Passenger Ship</td><td>Lower demand due to changing travel habits and environmental concerns.</td><td>0.93</td><td>0.89</td><td>0.89</td><td>0.89</td><td>0.89</td><td>0.89</td></tr>
<tr><td colspan="2">Ro/Ro Cargo Ship</td><td>Slight decline due to improved land transport and logistics.</td><td>1</td><td>0.98</td><td>0.98</td><td>0.98</td><td>0.98</td><td>0.98</td></tr>
<tr><td rowspan="6">Support Vessels for Oil & Gas</td><td>UK</td><td rowspan="6">Phased out as offshore fossil fuel extraction is decommissioned.
The Support Vessel traffic for OWF is calculated separately, as described in Section 3.6.2.</td><td>0.9</td><td>0.62</td><td>0.79</td><td>0.74</td><td>0.65</td><td>0.47</td></tr>
<tr><td>Norway</td><td>1</td><td>0.95</td><td>0.88</td><td>0.86</td><td>0.84</td><td>0.81</td></tr>
<tr><td>The Netherlands</td><td>0.92</td><td>0.42</td><td>0.75</td><td>0.67</td><td>0.5</td><td>0</td></tr>
<tr><td>Denmark</td><td>1.14</td><td>0.61</td><td>0.75</td><td>0.67</td><td>0.5</td><td>0</td></tr>
<tr><td>Germany</td><td>1</td><td>0.67</td><td>1</td><td>1</td><td>1</td><td>0</td></tr>
<tr><td>Elsewhere in the Study Area</td><td>0.86</td><td>0.7</td><td>0.82</td><td>0.8</td><td>0.76</td><td>0.7</td></tr>
<tr><td colspan="2">IMMA (Designated areas with Marine Mammals as features) and Marine Protected Areas (MPAs)</td><td>Slight reduction due to stricter conservation measures limiting vessel access.</td><td>1</td><td>0.95</td><td>0.95</td><td>1</td><td>1</td><td>1</td></tr>
</table>

The adjustment factors for the impacts of IMMA and OSPAR II MPAs were applied in addition to the other adjustment factors.

For further information on these numbers, please see the Factor Analysis (Section 3.5) and in Appendix C: Claims, Arguments, and Evidence (CAE) Framework.

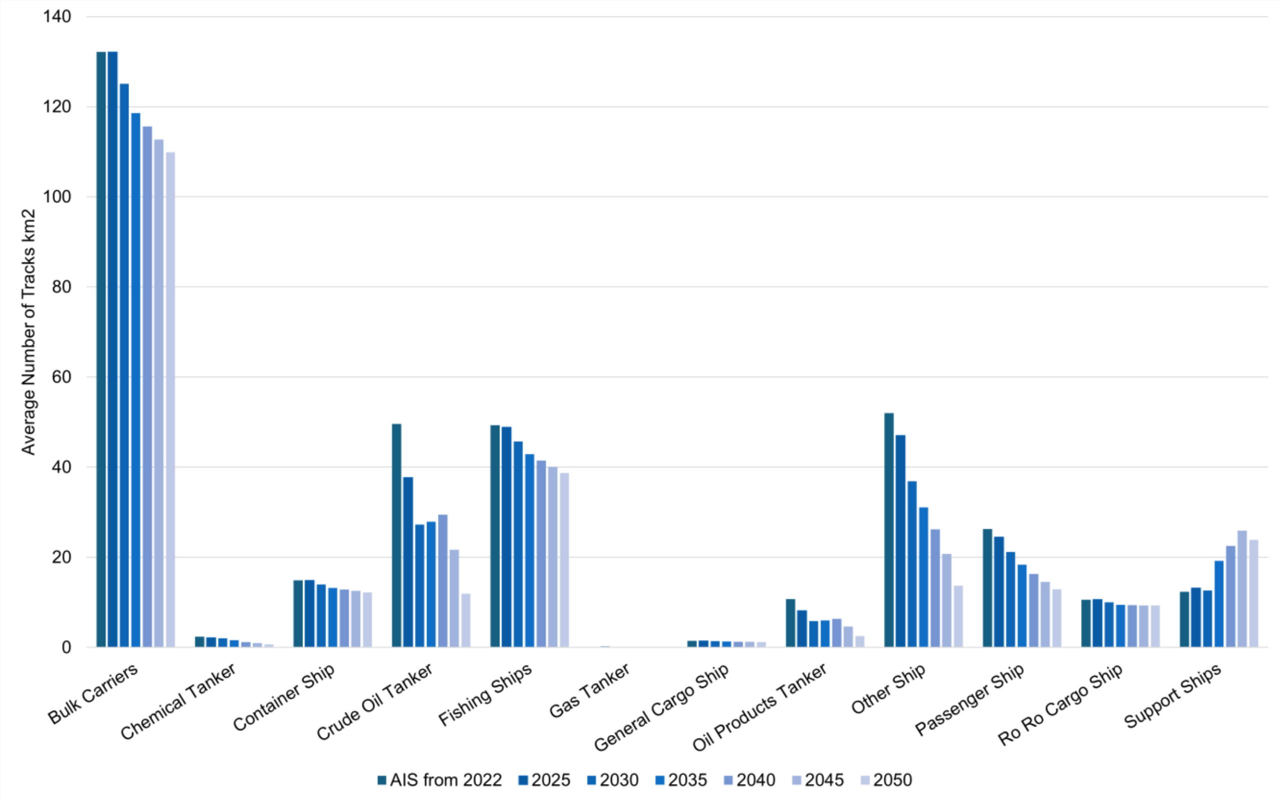

Figure 5: Average Number of Tracks per km² per year

Due to the classifications used in the AIS data, it is difficult to separate the oil and gas support traffic and the traffic supporting OWFs, thus the average traffic is variable. The patterns of forecasted support traffic are clearer in maps of this data (found in Appendix E: GeoPDFs of Track Volumes per Vessel Class per Epoch).

Figure 5 shows the average number of tracks per km^2 per year by vessel class through the six epochs (2025, 2030, 2035, 2040, 2045, and 2050) and from the AIS data from 2022. This shows how to the adjustment factors and change values, shown in Table 1 and Table 2, have been applied to the AIS data from 2022 to forecast the traffic volume across the epochs.

As explored in Section 3.6, the factors affecting the future of shipping in the North Sea are varied and complex. The overall trend for shipping traffic in the North Sea is for it to decrease slightly. A factor in this decrease might be an expected increase in environmental regulations.

Based on the assumptions, the greatest declines in traffic are forecast to occur in bulk carriers and crude oil tankers. Passenger voyages will also decline significantly as more people may choose alternative modes of transport as operational and fuel costs make these routes more expensive.

Support vessels include ships servicing both oil and gas and OWFs. Thus, the overall trend of traffic is variable, as there is a decline in oil and gas service traffic, down to zero in some areas, which is most noticeable in the change between 2025 and 2030 and 2045 to 2050. While there is an increase in service traffic for OWF as more are built and become operational to 2050.

3.6.2 aOWF sites

The impacts of OWF site were calculated from the 2022 AIS data. This has limitations, due to only being from one year and thus this would impact all following results.

This study only considered the OWFs planned in the North Sea until 2045. This may be subject to change over the next 20 years as new technologies could change support traffic patterns, extant OWFs are decommissioned, or specific of planned OWFs adjust to accommodate future need.

The forecasted change shown in Table 2 is applied across the areas of influence. In the results, the extant OWFs shows the traffic is heaviest closer to the centre of the OWF site and lessens towards the outer edges. Thus, the makes the extant OWF traffic look higher than the forecasted OWF traffic.

Table 2: Absolute Change Values for OWF Sites and Transit Areas (total tracks per km^2 per year).

Type	Average Change for OWF Sites	Average Change for OWF Transit Areas
Bulk Carrier	-48.7	-50.5
Chemical Tanker	-35.1	0.0
Container Ship	-115.3	-6.8
Crude Oil Tanker	-28.5	-19.9
Fishing Ship	-55.9	+21.6
Gas Tanker	-3.5	-8.8
General Cargo Ship	-97.6	+4.5
Oil Product Tanker	-10.1	-38.0
Other Ship	+55.6	+42.9
Passenger Ship	+2.2	-13.3
Ro/Ro Cargo Ship	-66.4	-3.5
Support Ship	+385.5	+137.0

Table 2 shows the absolute change values calculated from the extant OWF sites in tracks per km^2 per year. These were calculated from the difference in the number of tracks in the operational OWF area versus a 2NM buffer around them. The 2NM buffer was assessed as the balance between a buffer wide enough to average the traffic in the immediate area but narrow to avoid traffic that is influenced by other OWFs. The difference between the traffic in the operational OWF site and the 2NM buffer around it was compared pairwise and these difference where then averaged to calculate the values in Table 2. There are many factors that impact the change in traffic once an OWF becomes operational which would be very complex to model. Here, this was simplified to an average of the impact of current OWFs. These change values match our expectations as the positive changes are in Fast Ferry, Other Ship, Passenger Ship, and Support Ship, which are all vessel classes we identified as supporting OWFs from the 2022 AIS data. The rest of the vessel classes have negative change values as, once an OWF becomes operational, most vessels will actively avoid the OWF site, due to risk mitigation measures in place or for their own navigational needs.

3.6.2.1 REVIEW OF PHASES OF LIFE OF OWFS

The change values listed in Table 2 are applied for the epoch calculation following the commissioning of the OWF site, i.e. when it becomes operational. There is no change applied in the other three phases of life of a windfarm identified in this study:

- Under investigation: between the site being proposed and construction starting. In this study, OWFs under investigation have a predicted commission date after 2025.
- Under construction: while the OWF site is being built, between construction date and commission date. In this study, OWFs under construction have a commission date between 2022 and 2025.
- Operational: time after the commission date, before the predicted decommission date. In this study, operational OWFs have a commission date before 2022 and exist in the AIS data.
- Decommissioned: time after decommissioning date. This is not taken into account in this study's model and is qualitatively assessed below.

The change values stated in Table 2 will be applied in the epoch following the OWF becoming operational. The values are direct changes in traffic, rather than percentage changes as described in Section 3.6.1.

This project involves predicting the water space traffic until 2050 in the North Sea. To increase the reliability of these results, the impact of an OWF at the end of its life span would have to be assessed.

Currently, the expected life span of OFW is 20-25 years (Phillips, 2025) (Memija, 2025) (Baumgartner, 2021). However, more recent OWF developments have used progress in research and development efforts to extend the life of OWF (Sheppard, 2025) (TWI, 2025). Current project developers are suggesting life spans of 30 years minimum (Environmental Protection Information Center, 2024), but an aim of 35 years with robust O&M practices (Bills, 2021). To ensure that the traffic volume is not underrepresented, this study would suggest a life span of 35 years.

However, this value does not consider other end of life options than decommissioning (RenewableUK, 2025) (Spyroudi, 2021). For example, repowering old sites (i.e. replacing the WTGs with newer, usually more powerful models on top of the existing infrastructure) (Environmental Protection Information Center, 2024). Additionally, this study does not take into consideration policy, for example, the rights to the seabed under the site may expire during the life span of the OWF, curtailing the life prematurely (Buljan, 2023).

In conclusion, the decommissioning of OWF sites will have an impact on shipping traffic in that area, but that is dependent on the life span of the OWF, which is likely between 25 to 35 years, and the end-of-life action take, which can vary from dismantling and scrapping the OWF to repowering the site. As such, decommissioning was not taken into the calculations for the forecasted shipping traffic to 2050 as it is too complex for this scale. The traffic associated with these OWF is kept at predicted levels throughout the results.

For the AIS data used in the study, the traffic volumes were studied for the different phases of life of the OWFs. To analyse the impacts of the change in phase of life of an OWF on the traffic volumes, there were only five OWF sites that changed phase of life in the 2022 dataset: Calvados, Dogger Bank A, Kaskasi, Hornsea Project 2, and Triton Knoll. These are shown in Figure 6.

Alternative scenarios, such as exclusive decommissioning, reuse with increased maritime traffic, or slowed OWF development due to political or economic factors, are acknowledged as relevant considerations. However, they fall outside the scope of this analysis. This report focuses on the baseline and planned development trajectories supported by current data and stakeholder input. A detailed assessment of these alternative pathways would require additional modelling and assumptions beyond the remit of this study but may be appropriate for future targeted investigations.

To explore how OWF sites change when transitioning between the phases identified (under investigation, under construction, and operational), this study identified the five OWF sites that changed phase within the 2022 AIS data from EMSA. These were Calvados, Hornsea Project 2, Dogger Bank A, Kaskasi, and Triton Knoll.

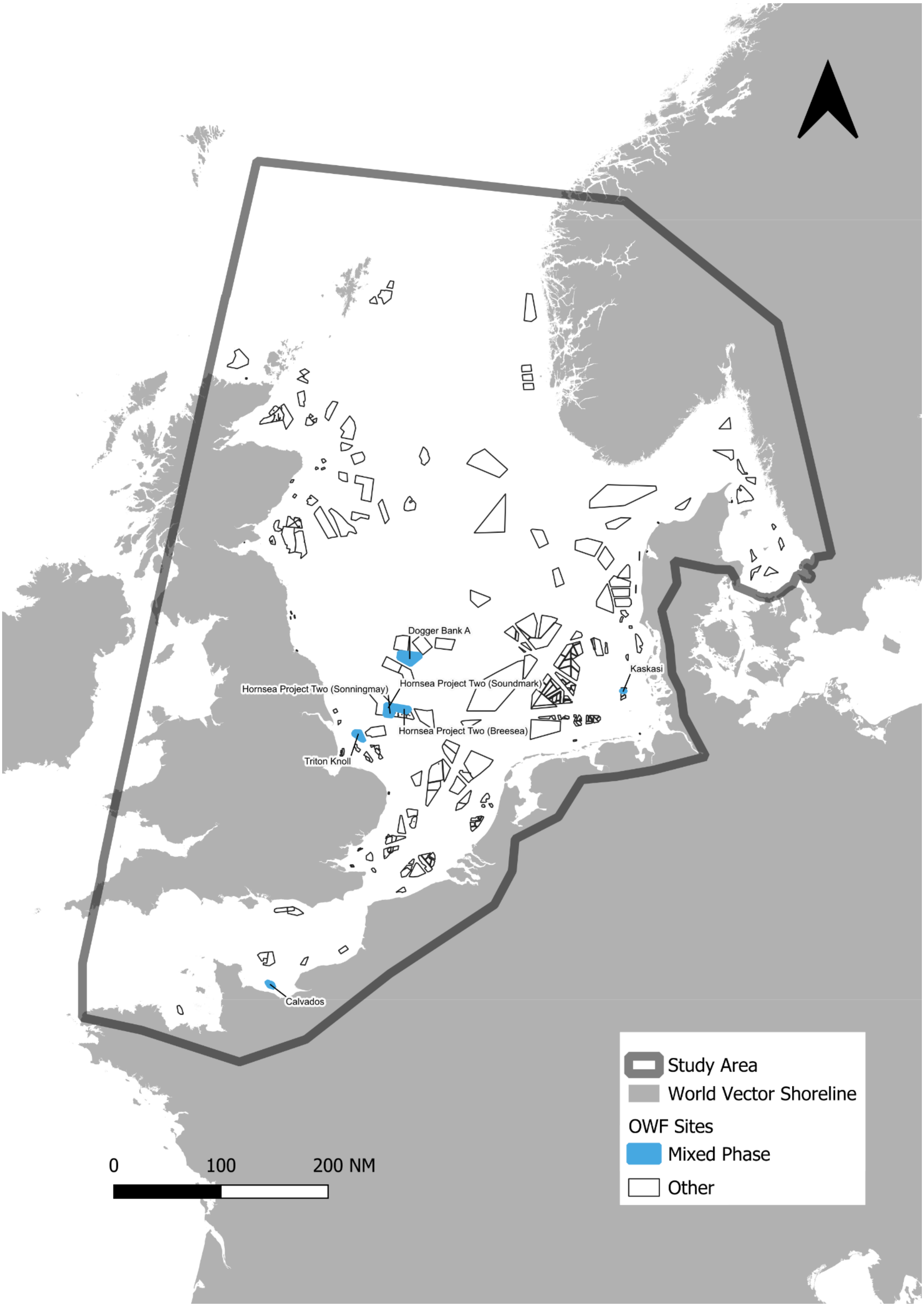

Figure 6: Map of the five OWF sites that change Phase of Life in 2022

Figure 7 shows the number of tracks per month within Calvados OWF. This is split by vessel type: fishing, non-OWF, other, passenger, pleasure, support. Fishing includes all vessel identified as fishing in the AIS data, however, this number is likely underrepresented along with the other smaller boat categories, as they are not all required to have AIS onboard and thus, would not be present in the dataset. Non-OWF traffic includes the vessel traffic classes that are not included in the other categories (Bulk Carriers, Chemical Tankers, Crude Oil Tankers, Container Ships, Gas Carriers, General Cargo Ships, Oil Product Tankers, and Ro/Ro Cargo Ships). These are grouped in this analysis as this section of the report focuses on the traffic within the OWF site. This is unlikely to contain many commercial shipping vessels due to the elevated navigational risk. Other vessels are those which did not include a vessel class within the static information included in the AIS data. Passenger vessels are any vessels that carry people made up of the passenger ships and fast ferry vessel categories. Pleasure boats are discussed in Appendix B: Exclusion of Pleasure Boats. These include vessel like yachts. Support vessels are made up of any vessels providing support to O&G or OWF sites. These vessel classes are further described in Table 4. Calvados shifts phase within 2022 from under investigation to under construction in May. There is a distinct lack of fishing traffic from April to September due to the change in season and the patterns of life of fish (Rijnsdorp, Daan, & Dekker, 2006). There are no changes in vessel traffic which can be attributed to the change in OWF phase.

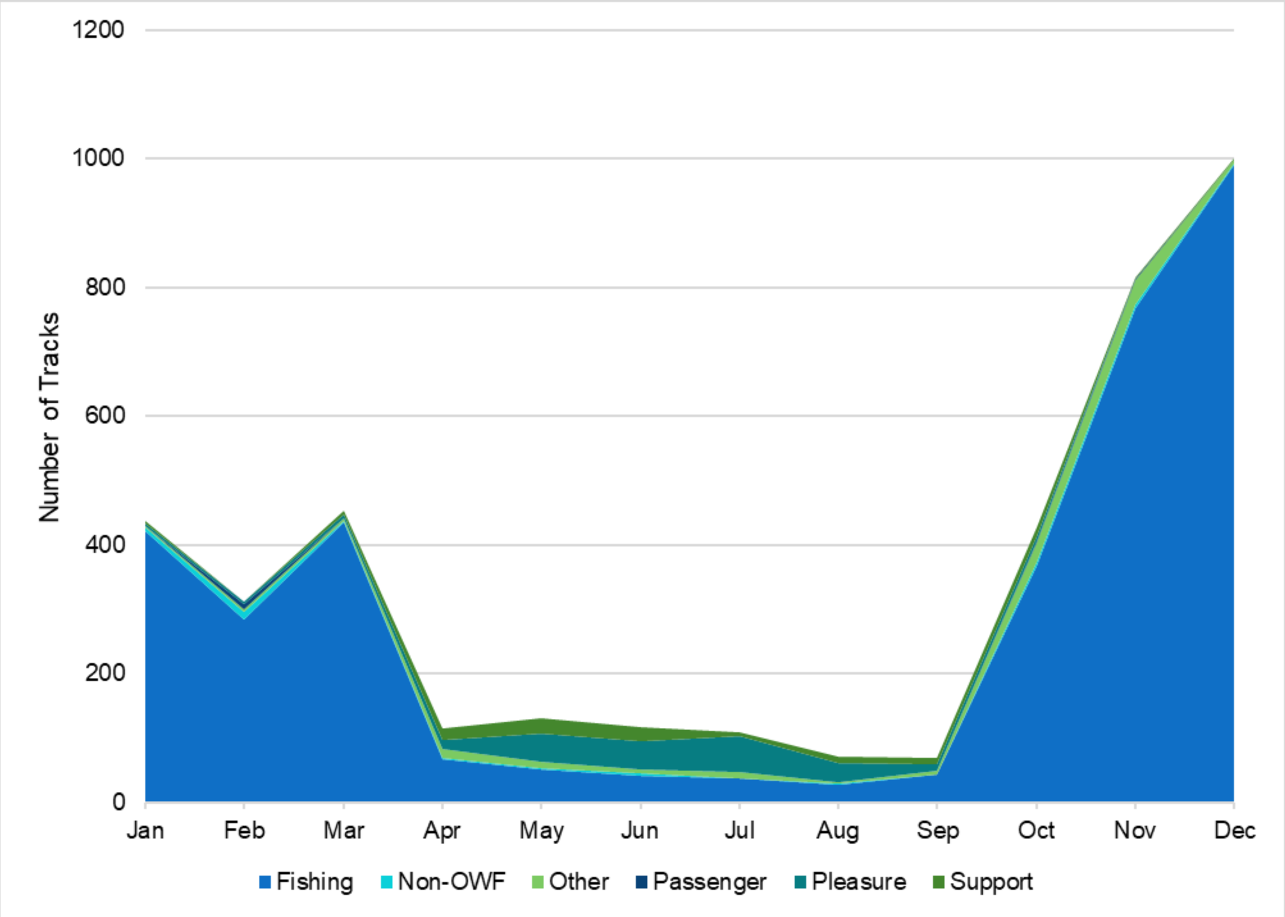

Figure 7: Traffic Volumes for Calvados OWF

Figure 8 shows the number of tracks per month within Dogger Bank A OWF. This is split by vessel type: fishing, non-OWF, other, and support as described above. There are no passenger or pleasure vessels detected within the Dogger Bank A site. Dogger Bank A shifts phase within 2022 from under investigation to under construction in March. Although there is no immediate change in traffic, the amount of support vessel tracks in the area increases to 28 in June, months after the start of construction. There is also an increase about the same time in other vessel traffic. This could also be attributed to the change in phase. The increase in fishing traffic is expected, due to the summer fishing season. There is also a decrease in non-OWF traffic, which is expected if construction has begun.

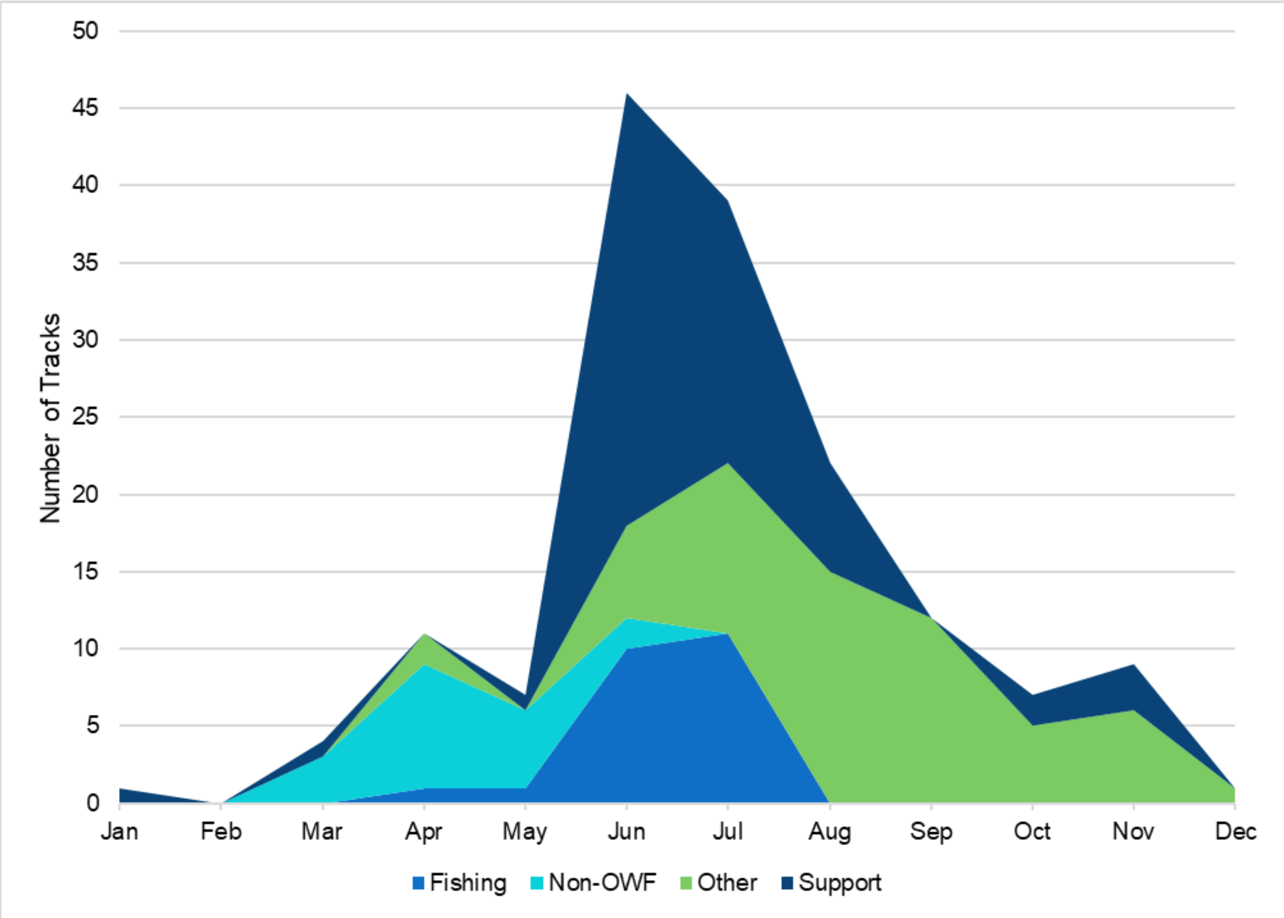

Figure 8: Traffic Volumes for Dogger Bank A OWF

Figure 9 shows the number of tracks per month within Kaskasi OWF. This is split by vessel type: fishing, other, passenger, and support as described above. There is no pleasure or non-OWF traffic detected within the Kaskasi OWF site. Kaskasi shifts phase within 2022 from under investigation to under construction in March. The increase in support vessels from February is clear in this graph. However, the location of Kaskasi must be considered; Kaskasi is in a cluster of four windfarms, the other three which have been operational since 2014-2015. Due to the proximity of the other OWFs, the changes seen may also be a result of increased maintenance work on the other windfarms in proximity during the summer when the weather is more pleasant. These factors together likely explain the changes in traffic seen.

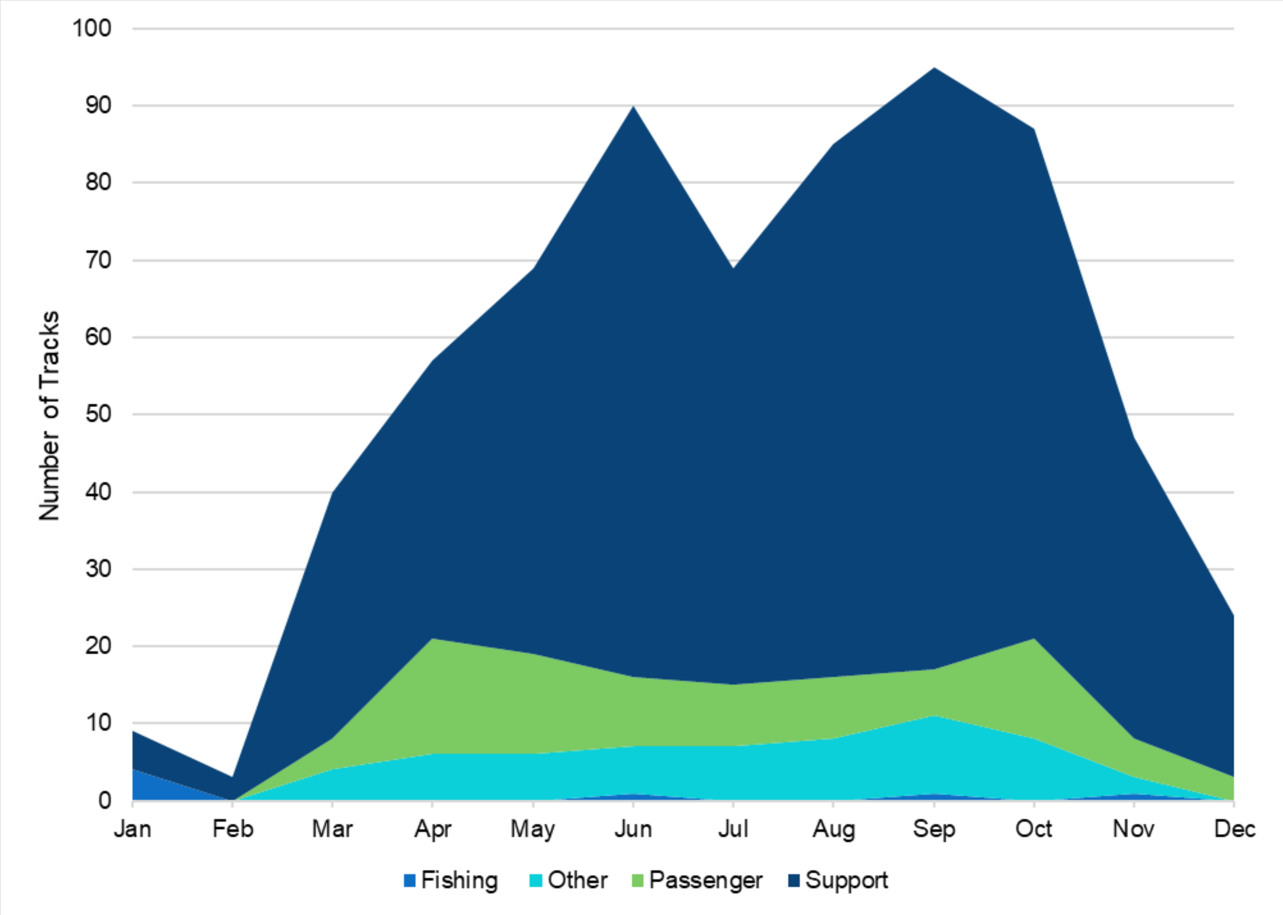

Figure 9: Traffic Volumes for Kaskasi OWF

Figure 10 shows the number of tracks per month within Triton Knoll OWF. This is split by vessel type: passenger, pleasure, and support as described above. There is no fishing, non-OWF, or other traffic detected at the Triton Knoll OWF site. Triton Knoll shifts phase within 2022 from under construction to operational in April. Due to the low volume of traffic in the area, this graph has a 'spikier' appearance than the others in the series. This is especially true for the support ship vessel class. There is no change in vessel traffic here that could be caused by the change in phase of the OWF.

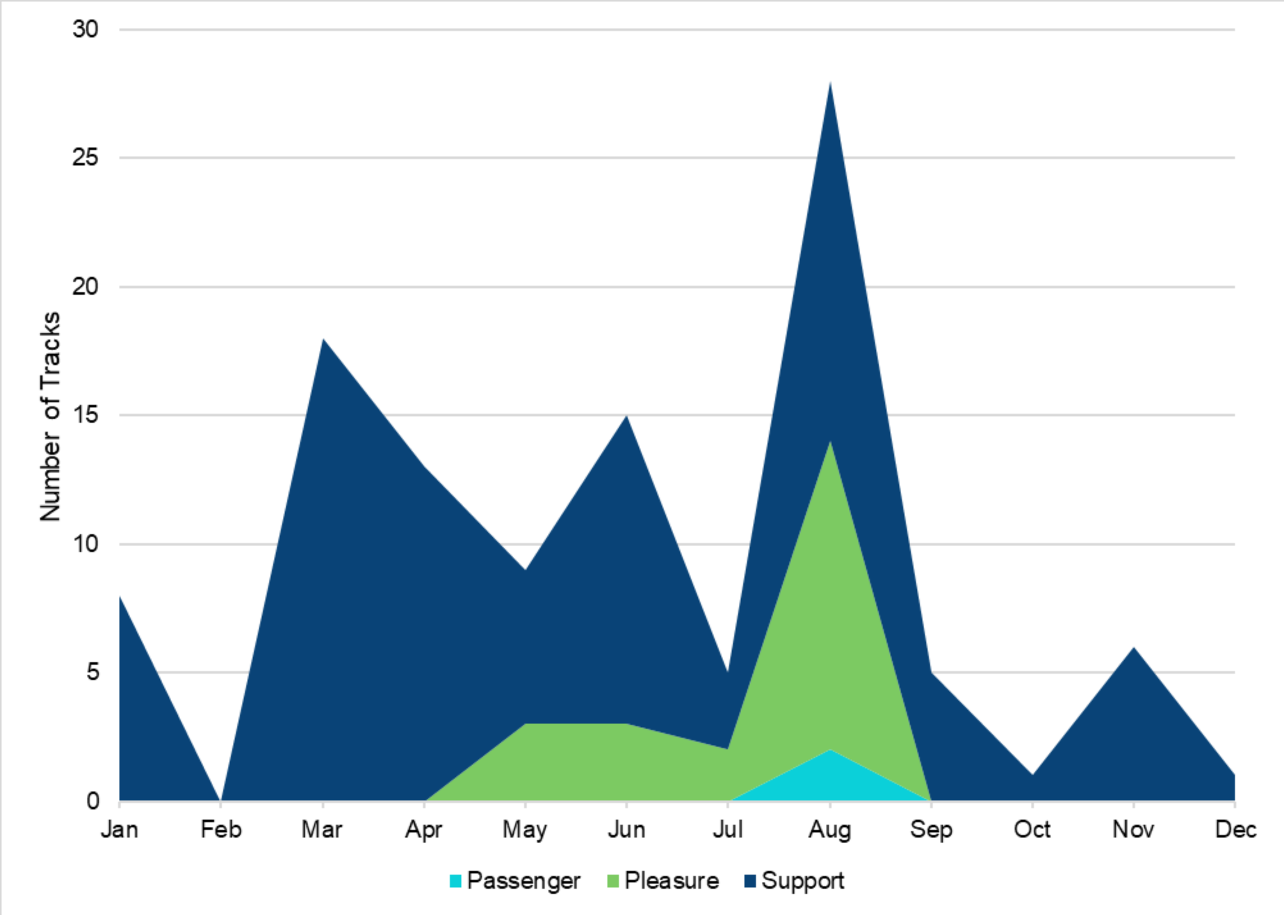

Figure 10: Traffic Volume for Triton Knoll OWF

Figure 11 shows the number of tracks per month within Hornsea Project 2 OWF. This is split by vessel type: fishing, non-OWF, other, and support as described above. There is no passenger or pleasure traffic detected at this site. Hornsea Project 2 shifts phase within 2022 from under construction to operational in August. The general trend of this graph shows a decline in vessel traffic over the year, most of which is support vessel traffic. This decrease may be due to the end of the construction phase of this windfarm's lifecycle. The peak in April may be caused by an increase in traffic associated with the final stages in construction. The decrease in traffic after August may also be caused by the worsening weather in the winter months meaning planned maintenance can wait for Spring.

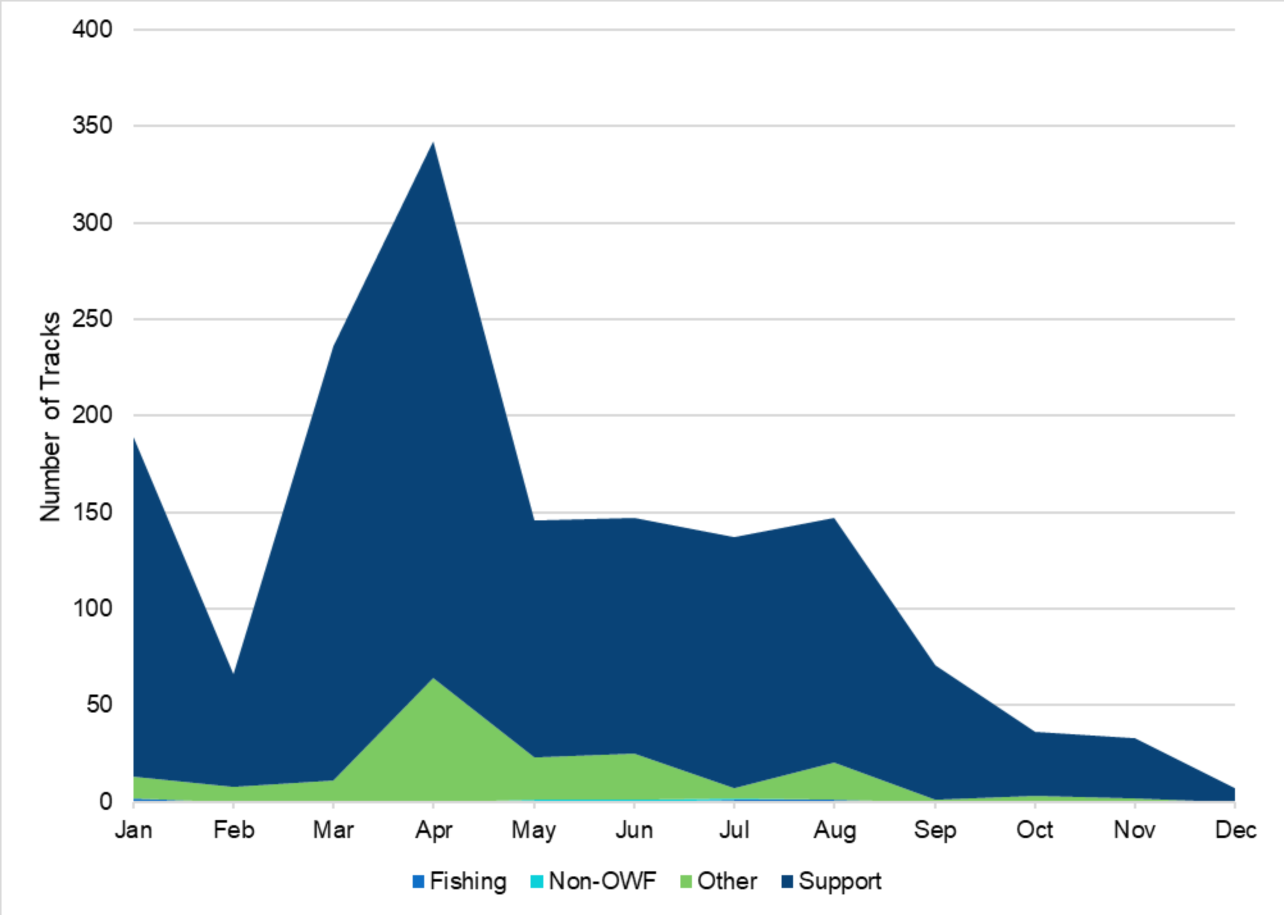

Figure 11: Traffic Volume for Hornsea Project 2 OWF

As there is no clear pattern or trend in changes between phases, the forecasting of changes in AIS traffic is only going to consider the change from before commission date to operational to decommission. The lack of trend in this series of graphs is likely due to several factors, such as:

1. Small subset of OWFs that have a change of phase in the year for which we have AIS data (2022).
2. Short temporal range: the construction of OWFs takes years, so analysing the changes in traffic a few months either side of the change in phase is less likely to show a change in traffic patterns than a longer study of many years before and after the change.
3. Other factors affecting shipping traffic: shipping traffic forecasting is complex as there are innumerate factors that impact the volume of shipping traffic in an area; environmental, seasonal, socio-economic, and political include some of the factors affecting traffic. As such, there is always going to be noise and variation within the patterns predicted that we are unable to consider.

3.6.3 Calculation of Buffer Size

OWFs affect the traffic not just in the site area but also in a buffer around them and in the transit paths to and from the OWFs. Thus, to forecast the change more reliably in shipping volume the size the buffer around OWF and to/from the OWF needed to be analysed.

This buffer can be clearly seen in Figure 12. This shows the volume of traffic from support vessels in and around the OWF site. Here, the traffic servicing the OWF can be seen to extend well beyond the extent of the OWF site. This increase in area of influence of the OWF must be considered for the future OWFs in the North Sea. Although this is not a uniform increase across the site, the analysis in this section will determine how to best calculate the size of the area of influence for future OWFs.

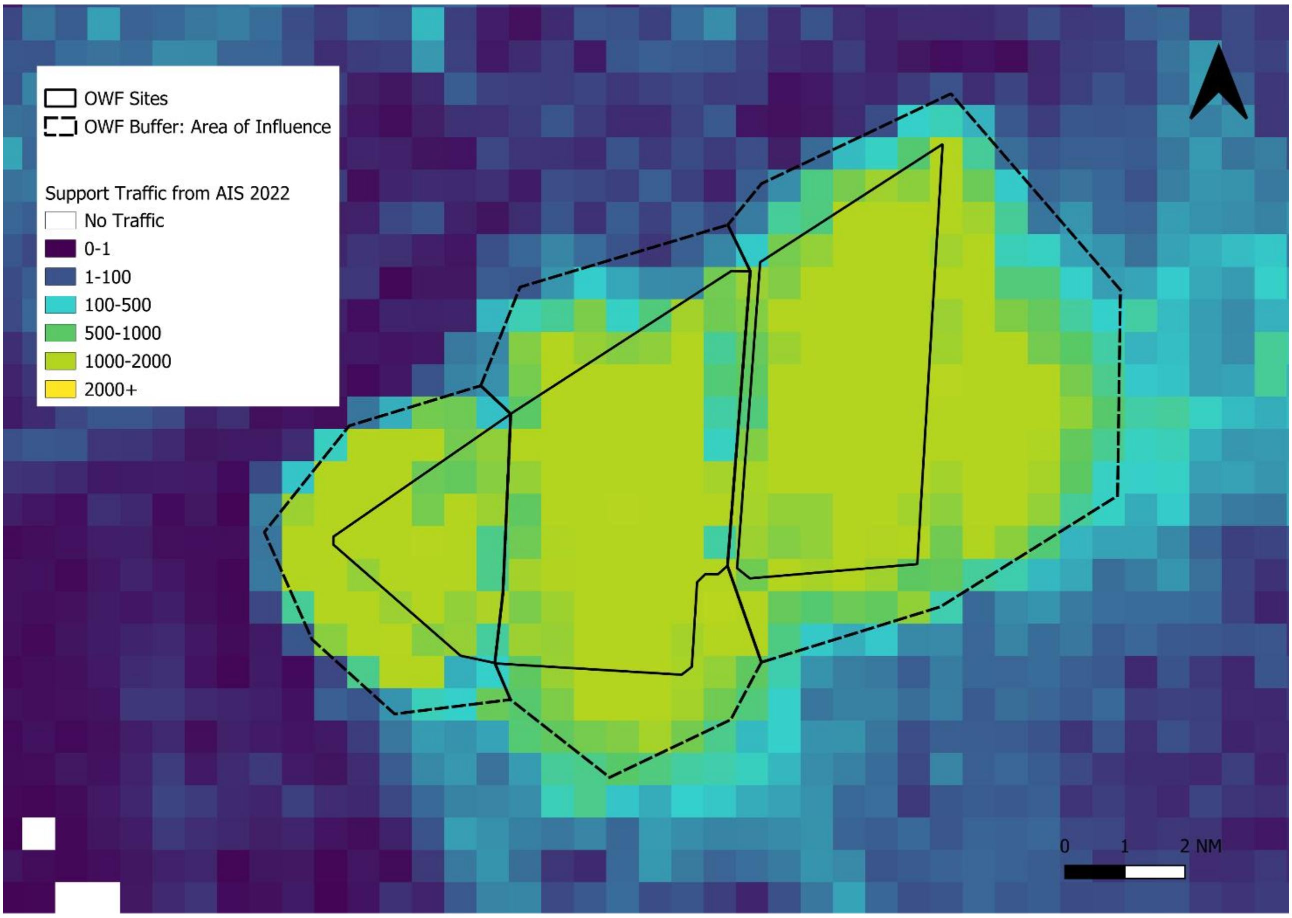

Figure 12: Diagram of the Area of Influence of an Extant OWF

3.6.3.1 OWF AREAS

First, the areas of influence around extant OWF were identified manually. The areas of influence were identified from the EMSA 2022 AIS data. The heat maps of the AIS data for the classes of ship likely to support OWFs were analysed: support, other, and passenger. Polygons were manually drawn around the extant OWFs to include the traffic supporting the OWF based on the density maps by vessel class generated by this study. As support traffic does not stay inside the bounds of the OWFs as shared in the OWF dataset, it was important to ensure the analysis in this report included the traffic in the area of influence around the OWF, i.e. the area in which the OWF has influence the traffic greatly as the support traffic is the majority of the vessels found in the area. This method of manually drawing the areas of influence around OWFs could not be replicated for the future OWFs, as they were not yet built, and thus did not have the area of influence on the traffic to identify. Thus, the data was extracted from the areas of influence identified from the extant OWFs to produce the following analysis to determine the leading cause of the size of the buffer, i.e. How big is this area of influence around an OWF? What factor is this most dependent on?

The next section of the report shows different factors that were hypothesised could have an impact on the size of the buffer for each OWF site. These are presented as ratios of the size of the OWF site versus the size of the identified buffer on existing OWFs (commission date before or in 2022). As both of these values have the same unit (km^2), the ratios displayed are unitless.

In Figure 13, the distance to shore was analysed. This distance to shore was calculated as the shortest straight line distance to the nearest coastline. The size of the area of influence was calculated as a ratio of the size of the OWF size and the size of the buffer drawn around it.

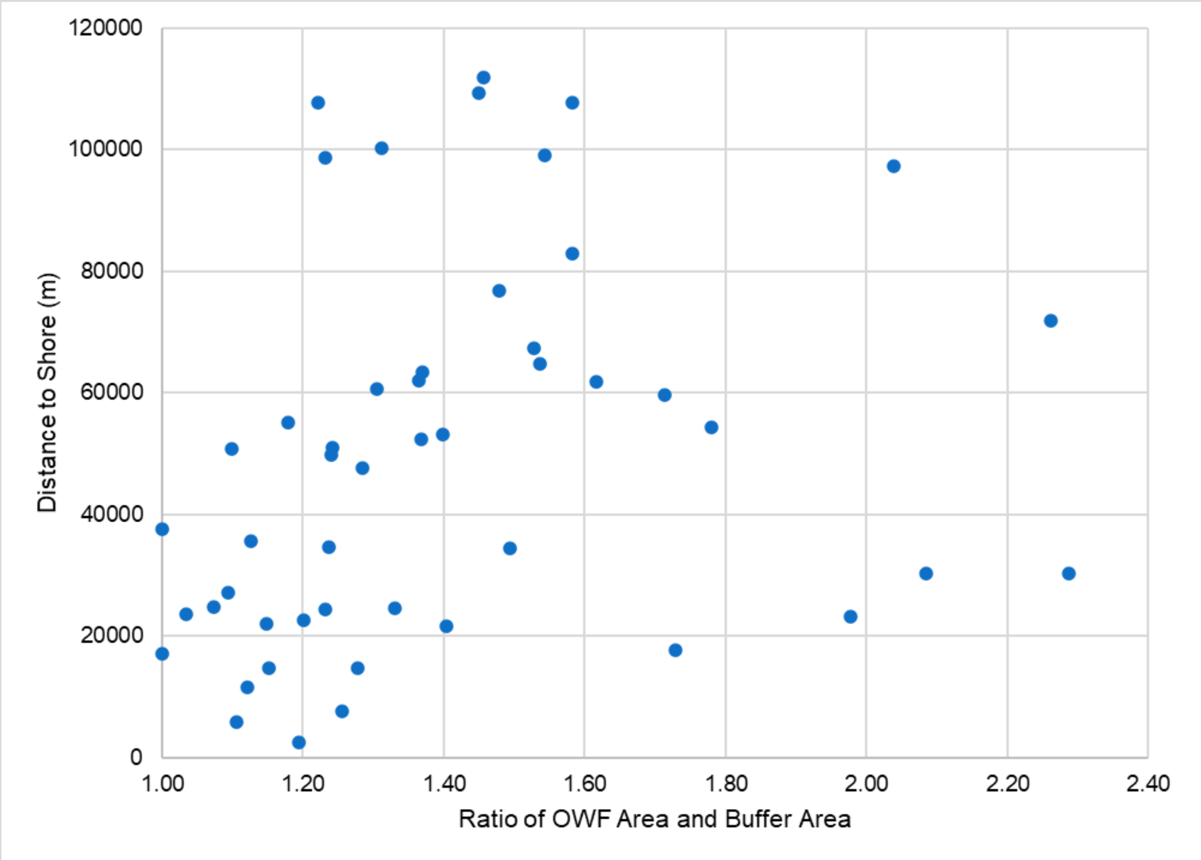

Figure 13: Distance to Shore and the Size of the Area of Influence of OWF on Traffic Volumes

Figure 13 shows there is little to no correlation between the distance to shore and the size of the buffer around OWF sites. This was discounted for the calculation of buffer size in future OWFs.

Figure 14 shows box and whisker diagrams of the size of the area of influence of the extant OWFs across the three main service vessel types for operations and maintenance. Although a Commissioning Service Operation Vessel (CSOV) has a larger buffer size compared to a Crew Transfer Vessel (CTV) and Service Operation Vessel (SOV), this may be due to only three OWF sites with CSOV type. As such, the operations and maintenance type was not taken into consideration due to the lack of information on the operation and maintenance type.

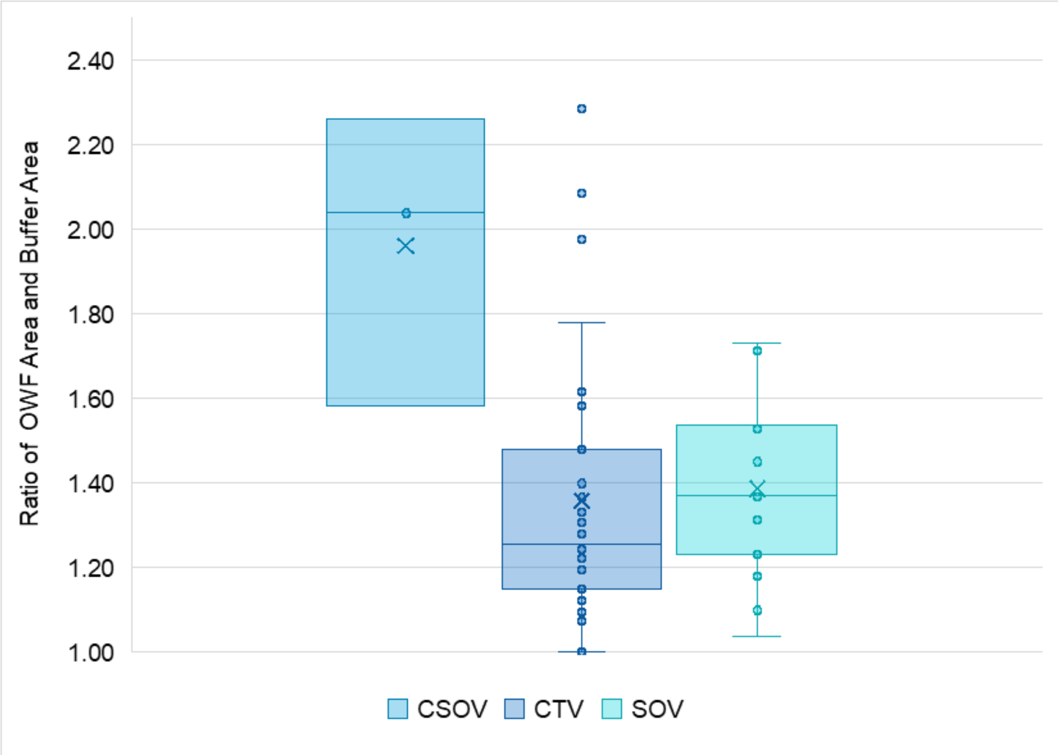

Figure 14: Operations and Maintenance Type and Area of Influence of OWF on Traffic Volumes

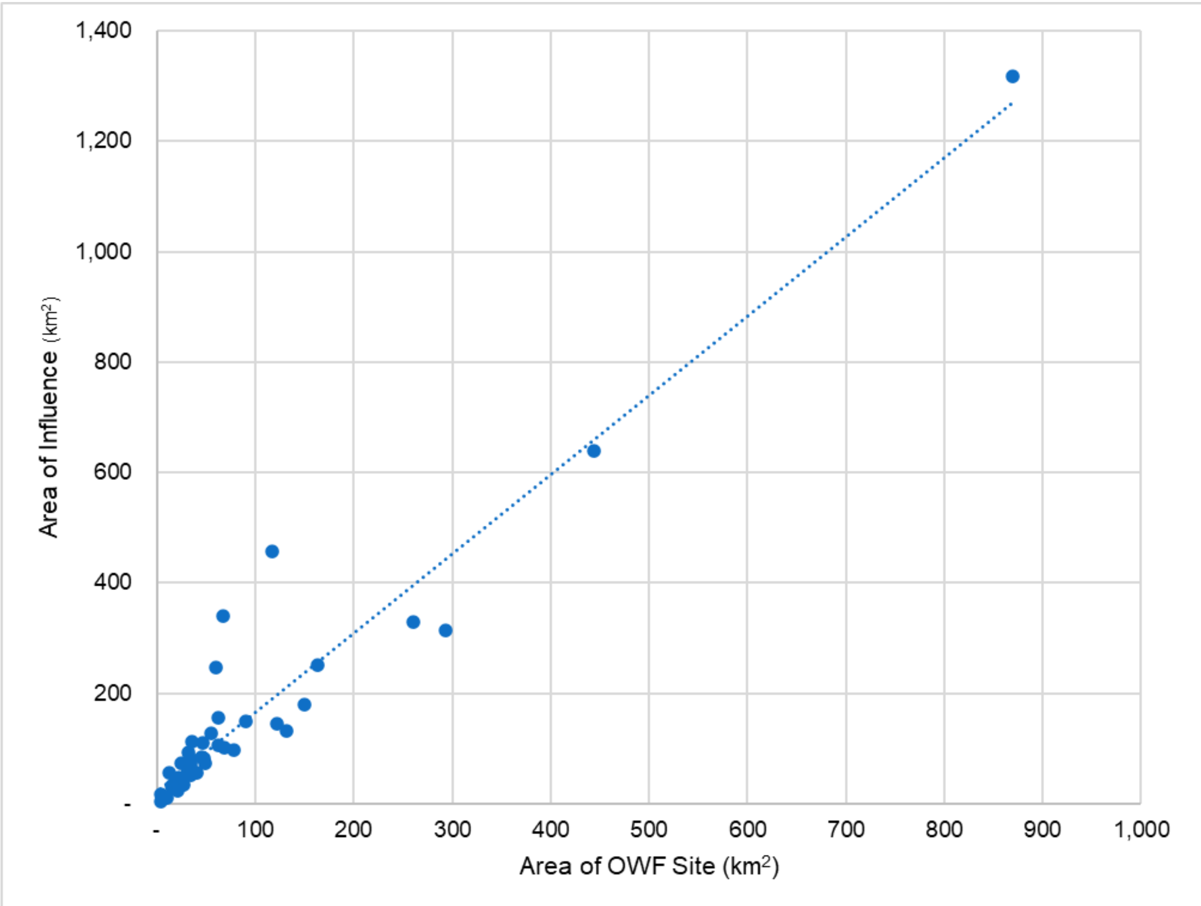

Figure 15: Area of OWF Site and Area of Influence

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Figure 15 shows the size of the OWF site and the size of the area of influence, which is the area around the OWF site for which the traffic directly services the OWF. This graph shows the strongest correlation is the size of the OWF site, with an R^2 value of 0.91, more than the results of comparing the size of the area of influence to the operations and maintenance type or the distance to shore.

The O&M type has some correlation: the CSOV seems to have a larger buffer. However, the spread of buffer size for CTV is large so this is not conclusive. The distance to nearest port does not seem to have any correlation to buffer size.

From this, for the level of precision we are using, we should determine that the only factor we will take into consideration when calculating the size of the buffer of affected traffic is the area of the OWF site.

However, there are a few assumptions for this calculation:

- There is a relationship/causation between the area of the OWF site, and the area of traffic affected, not just correlation.
- That OWF are square for the purpose of the analysis' calculations.
- For a perfect fit, the gradient of the trendline would be one showing that as the actual area of B changes, so does the calculated area at the same rate. Due to the irregular shape of the OWF sites, this would not happen. However, the gradient of the square method is 0.91, which acceptable.

3.6.3.2 OWF TRANSIT PATHS

The paths to/from the future OWFs must also be forecast. From the operational OWFs, there was some variance in the width of these transit paths. Thus, we then conducted a similar analysis on what factors impacted the width of the transit paths or the transit area buffer size.

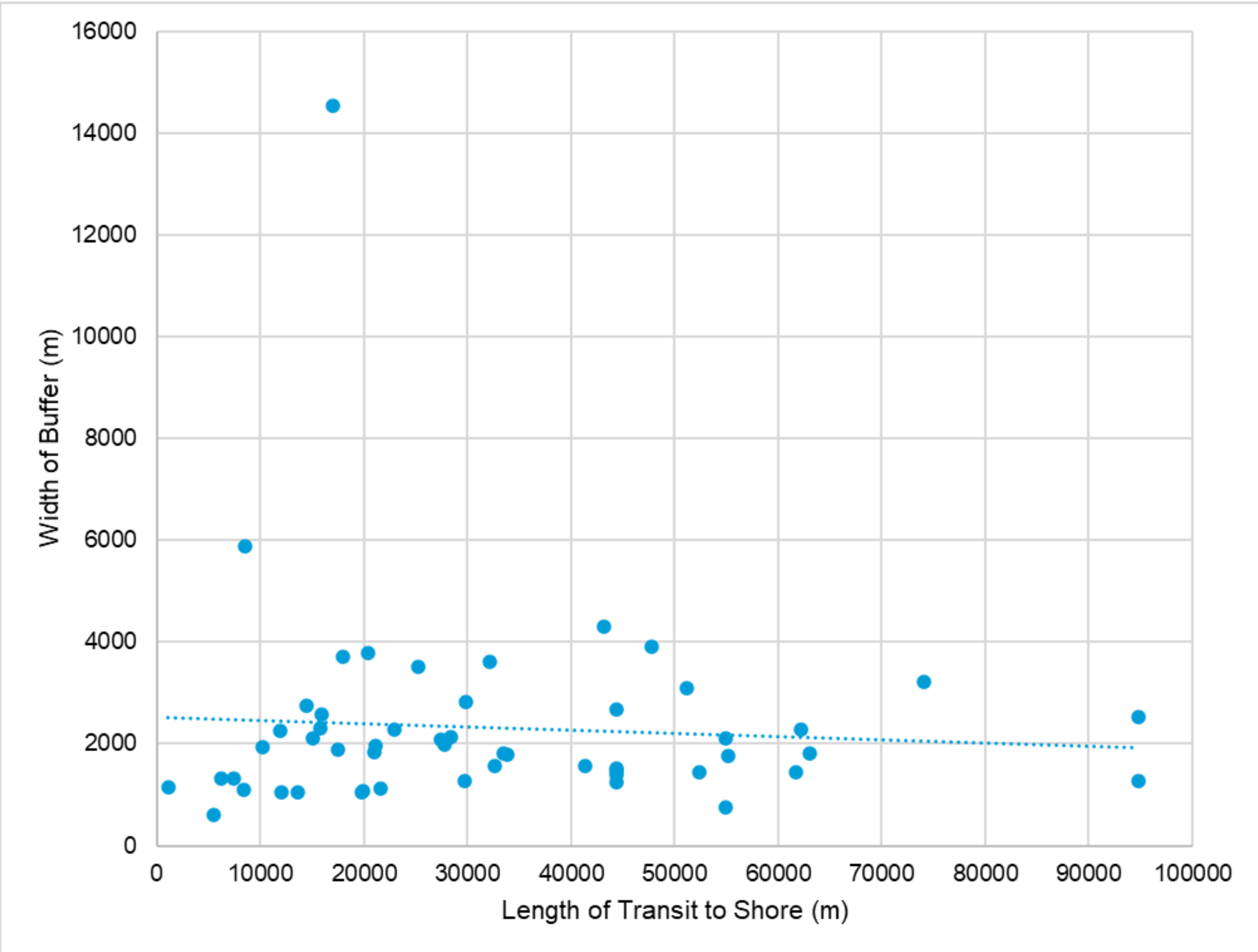

Figure 16: Width of Transit Buffer and Length of Transit to Shore

As the trend line for the width of the transit path width is flat, a static value for size of the transit path width is a better fit. From this, the average of these values, 2322m, can be used for the width of all transit areas for future OWF. Although there are areas with much wider transit path widths, these would be difficult to predict for the future. Using the mean of extant OWF as a 'best fit' value is most appropriate here.

The paths of travel for support vessels to future OWF sites was calculated by drawing the shortest line from the OWF site to the nearest port. This was manually reviewed to ensure the quality of results., i.e. that the resulting paths did not pass through obvious obstacles, like coastal islands. The buffer width, as calculated above at 2322m, was then drawn around them. No additional environmental or regulatory constraints, such as nature reserves or speed restrictions, were incorporated into the routing or travel time estimates.

3.7 MACRO-SCALE ANALYSIS: BASELINE TRAFFIC ASSESSMENT

As part of the wider NORSAIC project, a review of current North Sea shipping behaviours has been undertaken, which has been documented in the Factor Analysis (Section 3.5) and Appendix C: Claims, Arguments, and Evidence (CAE) Framework.

The outputs of this assessment have been combined with assumptions about future development of the North Sea region, to yield an assessment of potential future shipping patterns (logistic concepts), under different assumptions. These logistic concepts have been codified in the form of a series of future traffic adjustment factors for the different high-level types of vessels considered in the study. The identified factors have been used to construct study-area wide traffic density maps, as provided in Appendix E: GeoPDFs of Track Volumes per Vessel Class per Epoch.

3.8 MICRO-SCALE CASE STUDIES

The outputs of the forecasted shipping traffic will be studied more in-depth for the three OWF case studies chosen. This includes GIS maps showing the forecast traffic volume and an assessment of this output. This assessment identifies the explanatory factors (constraints on and drivers of activity) assessed as carrying the most significance for each case study.

This study required three OWF sites to be chosen for further study. From the client, the requirements were to include windfarms from multiple countries and to cover all the phases of life of a windfarm, as described by the client:

- Under Investigation: This was categorised as the time between an OWF site being proposed and its construction date. In this study, the predicted commission date is after 2025.
- Under Construction: This was categorised as the time between the construction date of an OWF and the commission date. In this study, the predicted commission date is between 2022 and 2025.
- Operational: This was categorised as the time after the commission date. In this study, the predicted commission date is before 2022.
- Decommissioned: There were no decommissioned OWF identified in the 2022 AIS dataset, nor were these modelled in the forecast epochs.

Of the OWF sites included in this study from the OSPAR II area, most of the sites are under investigation during 2022 for which we have the AIS data available. To be able to analyse the data of all phases of life of the OWFs, the micro-scale Case Study areas will have to be selected from the other areas. Mixed phase OWFs include the five OWFs studied in Section 3.6.2.1 where the OWFs change phase within the 2022 dataset.

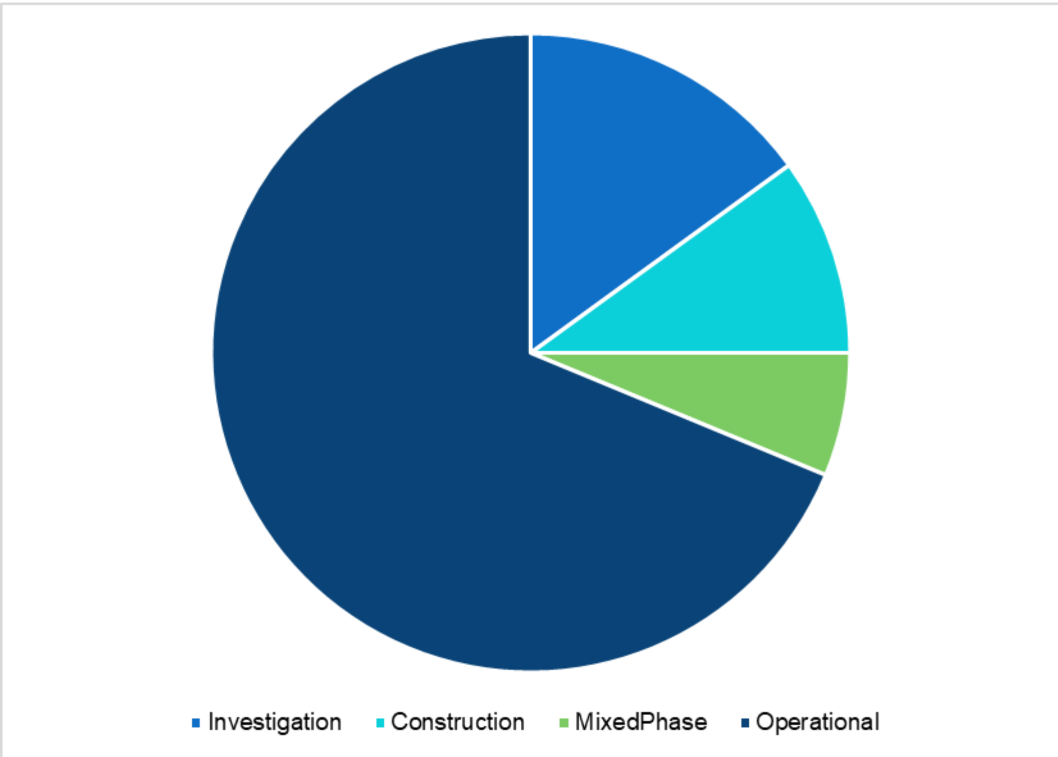

Figure 17: OWF sites by Phase of Life

From this, the following areas were selected with approval from the client.

Table 3 lists the three sites chosen for a 'micro-scale' case study. The aim of these case studies is to:

- Analyse all phases of the lifecycle of an OWF.
- Include sites from multiple countries involved in the NORSAIC project.

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- Study varied sizes and types of OWF to get the most complete analysis of the OWF in the North Sea.

Table 3: Micro-Scale Case Study OWF sites

OWF name	Country	Size (Total km^2)	Phases of Life	O&M Type
Nordsee B and Nordsee One (2)	DE	127	1 Under Investigation, 1 Operational	CTV
Hollandse Kust Zuid I to III (3)	NL	350	Under Construction	CTV
Saint-Brieuc	FR	100	Under Construction	SOV
* Nordsee Cluster B (OWFs NC3 and NC4), in the analysis abbreviated to Nordsee B				

The Nordsee One offshore wind farm is a 332 MW project located 40 to 45 km off the German coast, comprising 54 turbines. It has been fully operational since 2017, benefiting from strong wind conditions and water depths of 26 to 29 metres (Nordsee One GmbH, 2025). Nordsee B, part of the broader Nordsee cluster, is a planned extension aiming to further expand offshore wind capacity in the region, supporting Germany's renewable energy targets and the EU's climate goals (RWE AG, 2025).

This area includes the Nordsee Cluster B, made up of NC3 (N-3.5) and NC4 (N-3.6), and Nordsee One and is in German waters. These OWFs receive their support traffic from Eemshaven, or other ports on the River Ems. NordSee Clusters A & B are under investigation throughout 2022, and NordSee One is operational, having been commissioned in 2017. The operations and maintenance type of these three sites is CTV.

The Hollandse Kust Zuid I & II offshore wind farms are part of the world's first subsidy-free offshore wind project, located 18–36 km off the Dutch coast. Developed by Vattenfall in partnership with BASF and Allianz, the wind farm consists of 139 turbines with a total capacity of 1.5 GW, supplying fossil-free electricity to approximately 1.5 million households (Vattenfall, 2025).

Hollandse Kust Zuid III & IV are the second phase of the same project, also developed by Vattenfall. Together with I & II, they form a single 1.5 GW wind farm, making it one of the largest in the world and a key contributor to the Netherlands' renewable energy goals (Vattenfall, 2025).

Hollandse Kust is made up of five OWF sites, which makes this a much larger site at 350km^2. All the OWFs are under construction in 2022, with I and II to be commissioned in 2023 and III and IV to be commissioned in 2024. The O&M type here is also CTV. These OWFs receive their support traffic from Ijmuiden, or other ports along the Noordzeekanal up to Amsterdam.

The Saint-Brieuc offshore wind farm, located 16.3 km off the coast of Brittany, France, is Iberdrola's first large-scale offshore project in the country. Commissioned in 2024, it features 62 Siemens Gamesa turbines with a total capacity of 496 MW, generating enough electricity to power around 835,000 people annually (Iberdrola, 2024).

Saint Brieuc is a OWF in French waters, with a SOV O&M type. It has also been under construction for 2022 to be commissioned in 2024. This OWF receives its support traffic from Treguier, Le Legue, or Saint Helier Harbour. This OWF is very isolated from other sites, and other major traffic routes. This will allow analysis of the OWF in isolation from some of the factors affecting the volume and distribution of vessel traffic.

4.0 RESULTS

4.1 BASELINE TRAFFIC ASSESSMENT

The following figures are from analysis conducted on the AIS data included in the 'Long List' (ABL, 2025).

4.1.1 Average Vessel Movements

The average vessel movement have been analysed to produce the following graphs (Figure 18 to Figure 29). These volumes of tracks have been analysed within the vessel classification outlined in the Long List: Table 4: IWRAP types and vessel types presented in the results

IWRAP Ship Type	Presentation in analysis	Description
Crude Oil Tanker	Non-OWF	This includes any other class of vessel not included in the other classes.
Oil Products Tanker		
Chemical Tanker		
Gas Tanker		
Container Ship		
General Cargo Ship		
Bulk Carrier		
Ro-Ro Cargo Ship		
Passenger Ship	Passenger	Passenger vessels as classed by the AIS data; this could also include vessels taking personnel to/from the OWF sites.
Fast Ferry		
Support Ship	Support Vessels	Support vessels can be for both OWF and O&G, as classed by AIS.
Fishing Ship	Fishing	Fishing vessels as classed by AIS.
Other Ship	Other	Other ships as classed by AIS.
Pleasure Boat	Pleasure	Pleasure and leisure vessels, such as yachts, as classed by AIS.

The volume of tracks by vessel class has been analysed by OWF site, phase of life, megawatt generated, turbine, O&M type, and the size of the OWF site.

Although the OWF traffic is not contained into a class of its own; by studying the AIS data and its relation to the extant OWFs, it is easy to identify the traffic that is supporting the OWFs through the patterns of vessel volume.

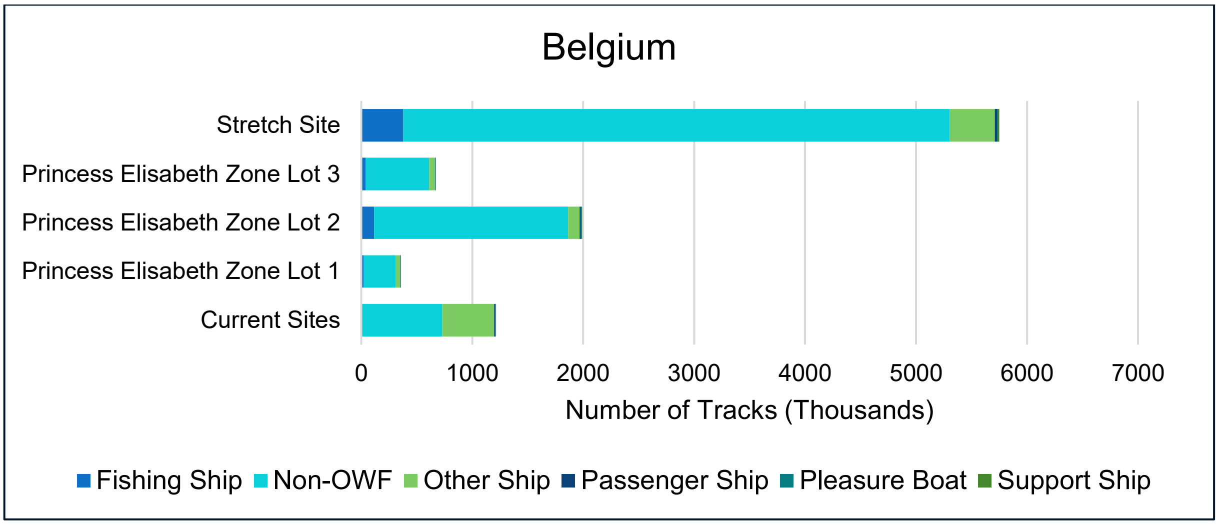

Figure 18: Total Tracks by Vessel Class for OWFs in Belgium

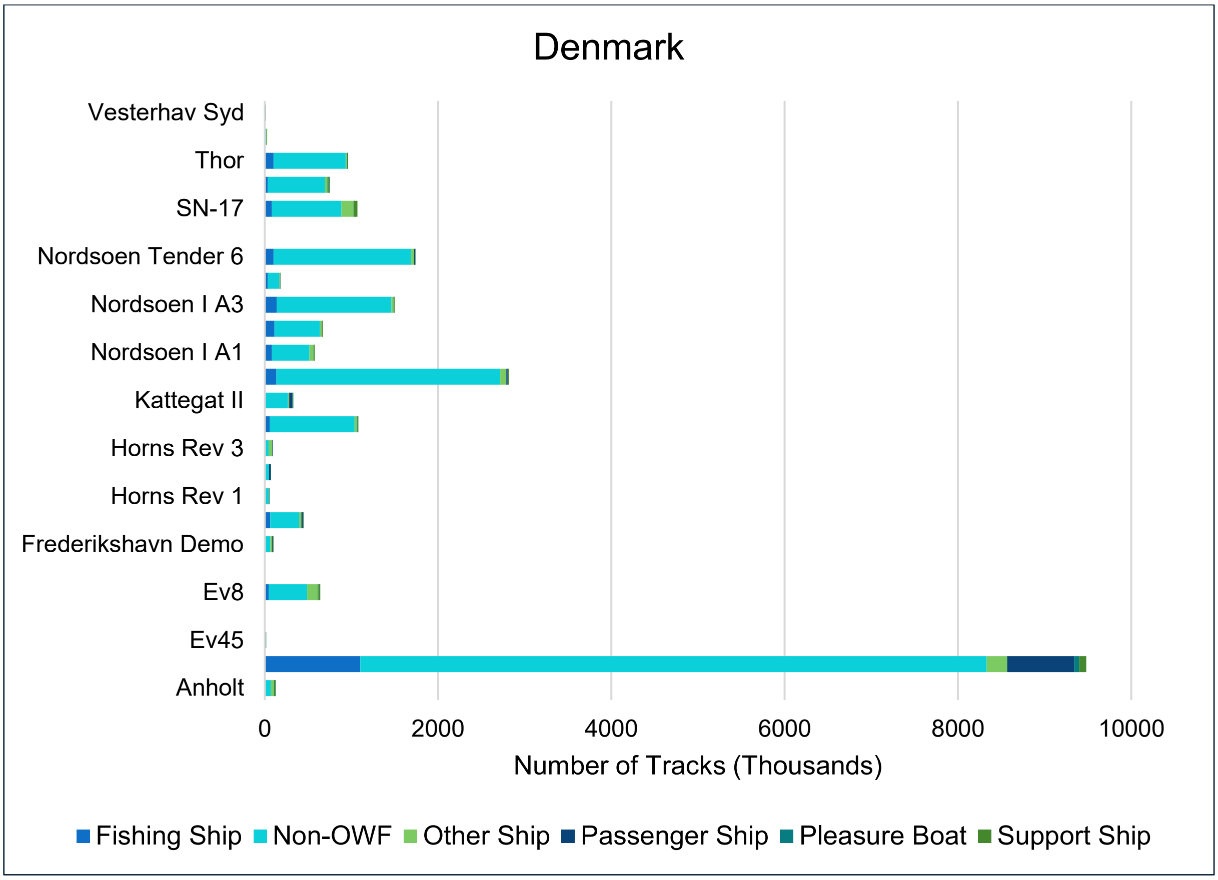

Figure 19: Total Tracks by Vessel Class for OWFs in Denmark

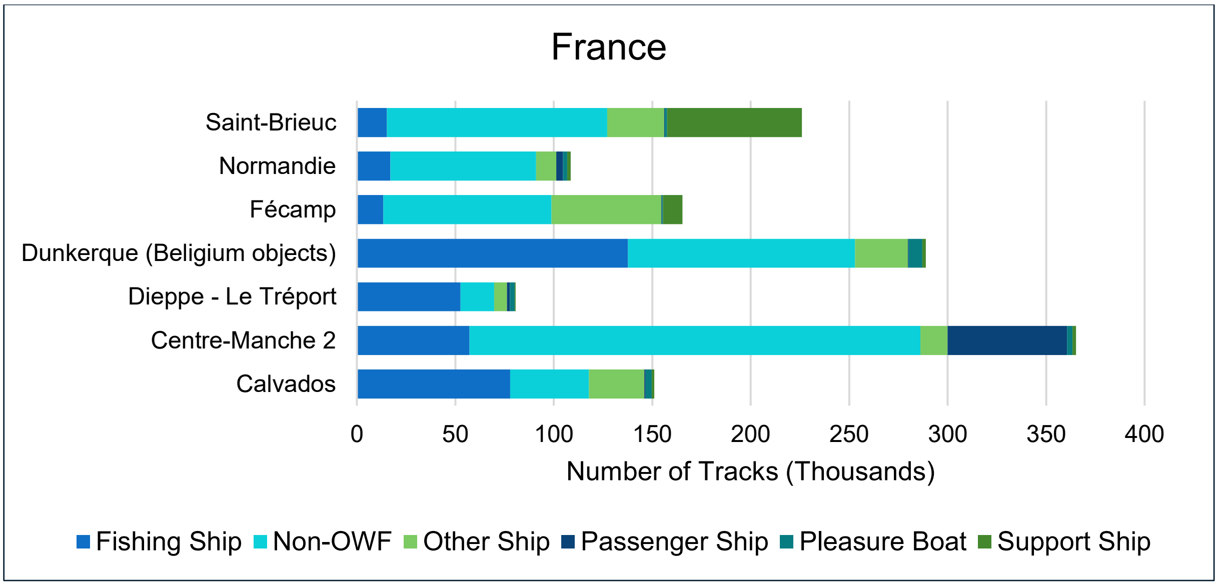

Figure 20: Total Tracks by Vessel Class for OWFs in France

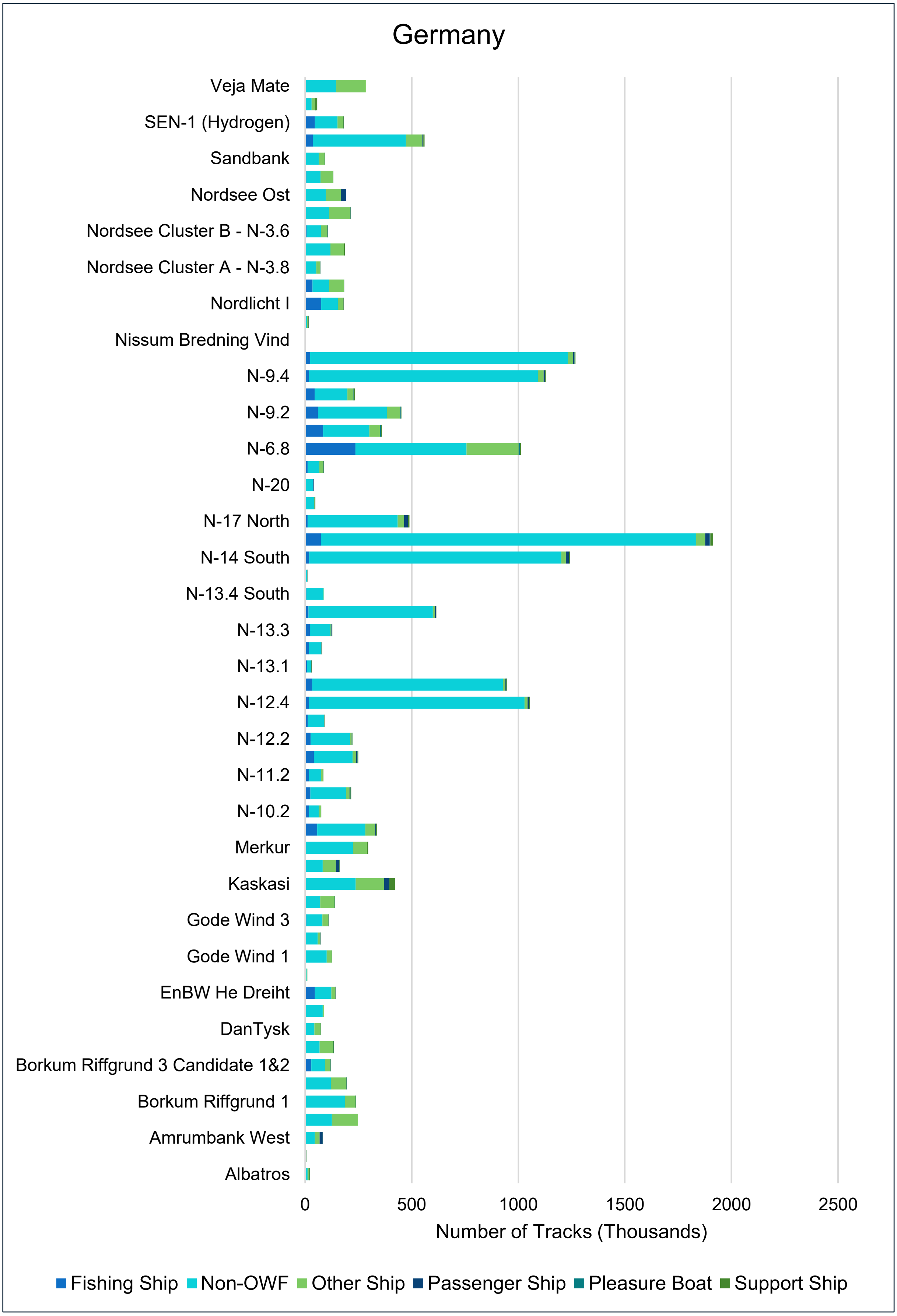

Figure 21: Total Tracks by Vessel Class for OWFs in Germany

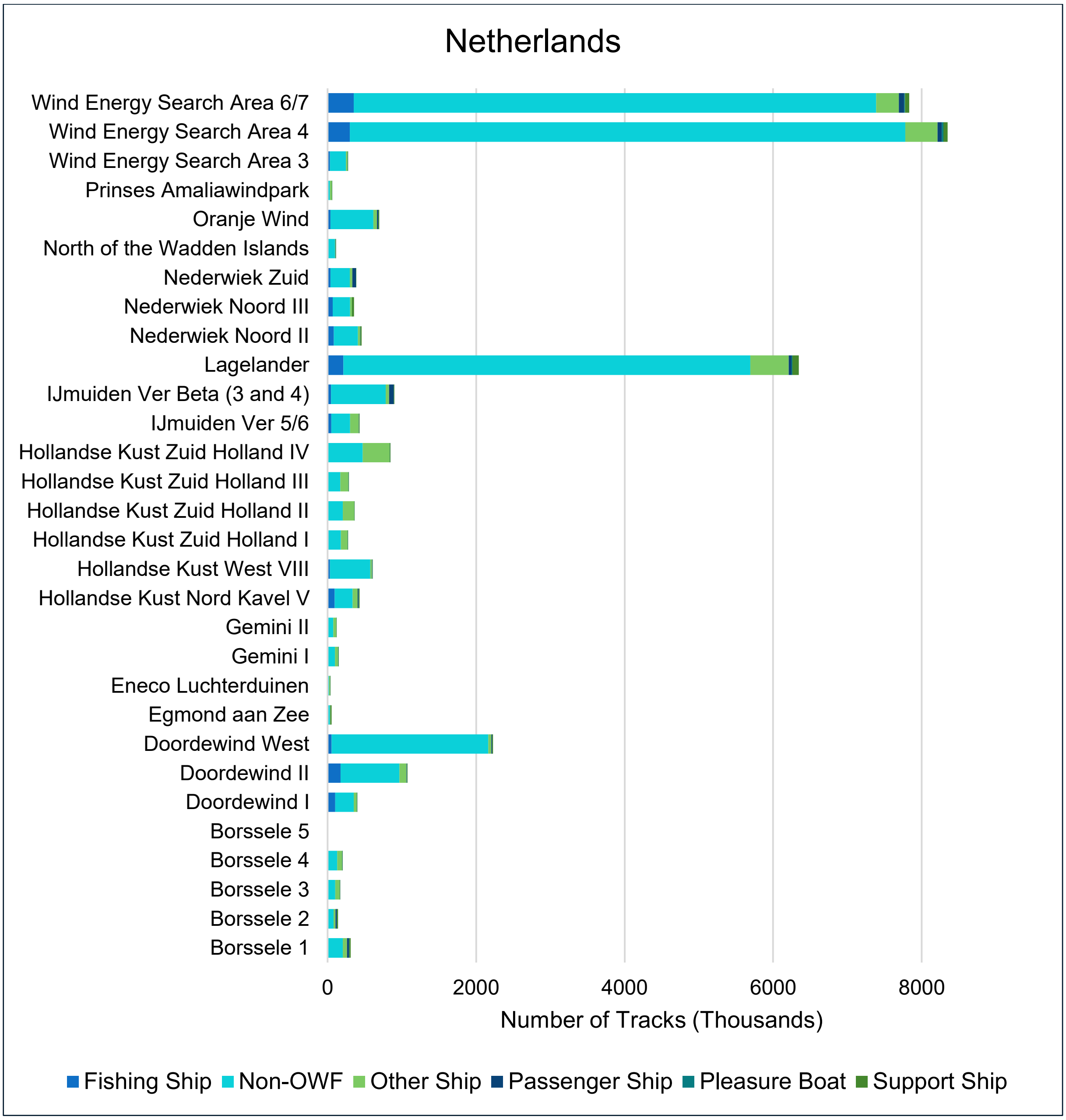

Figure 22: Total Tracks by Vessel Class for OWFs in the Netherlands

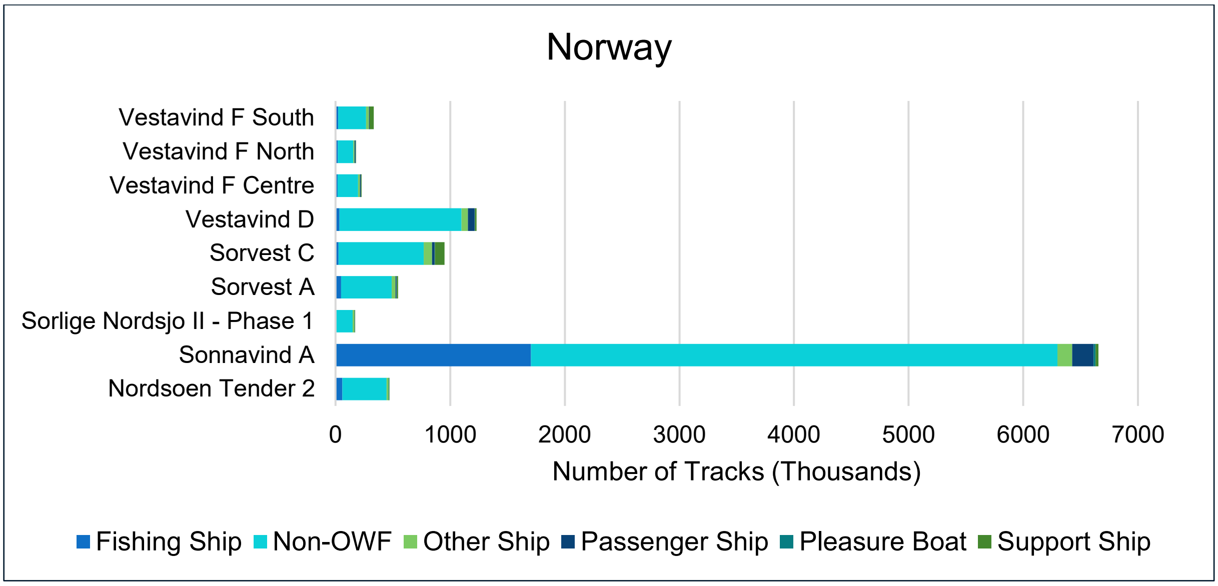

Figure 23: Total Tracks by Vessel Class for OWFs in Norway

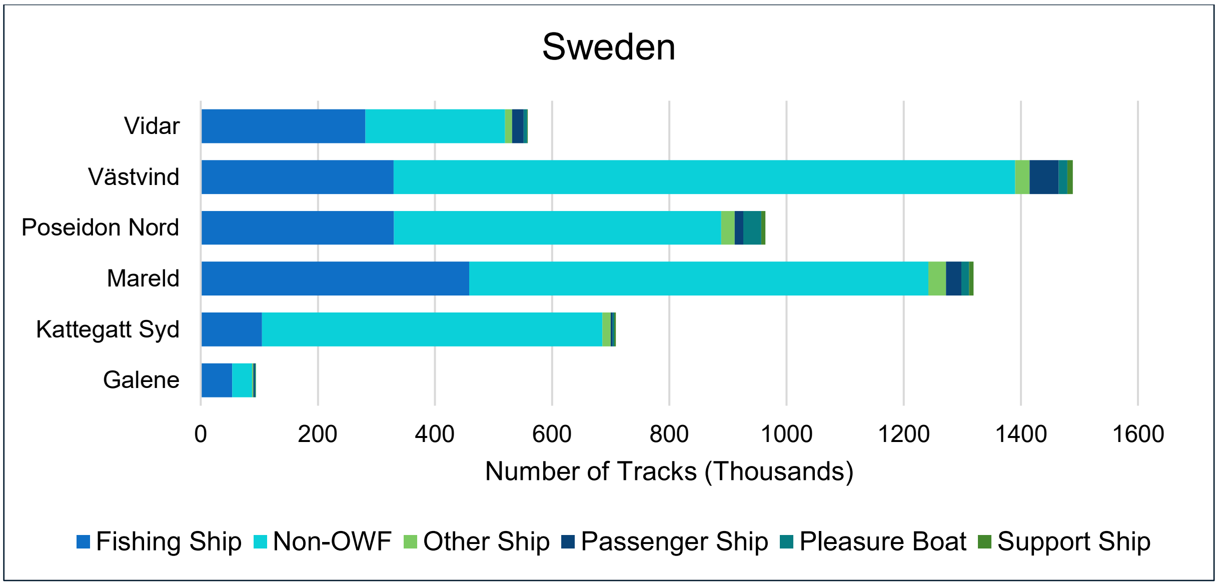

Figure 24: Total Tracks by Vessel Class for OWFs in Sweden

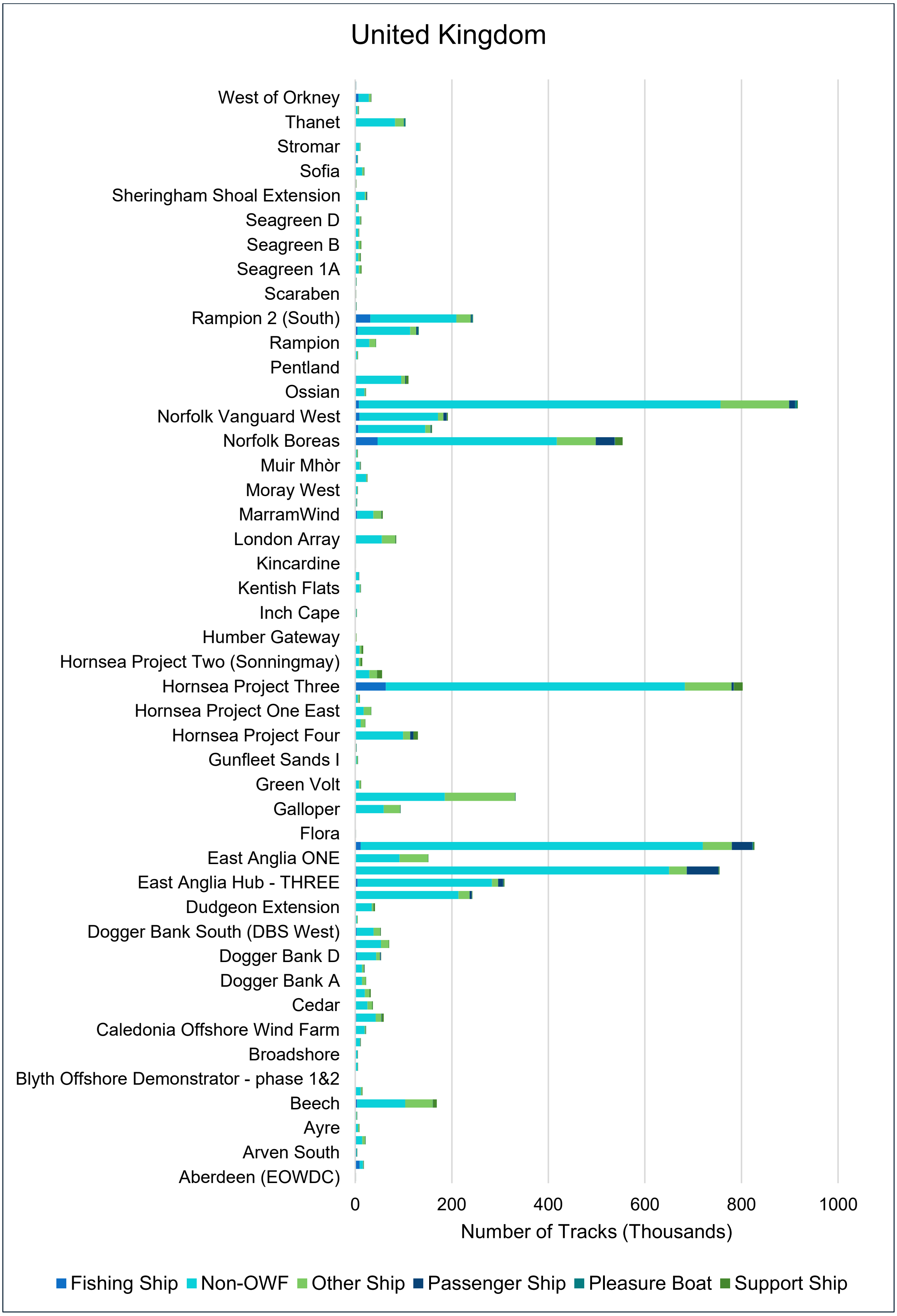

Figure 25: Total Tracks by Vessel Class for OWFs in the United Kingdom

Figure 18 to Figure 25 shows that there is no clear pattern in the distribution of the different traffic classes as they range dramatically from 0% to 98% of the tracks at each site. These figures also show how the amount of traffic also varies, from 14 tracks (Westermost Rough) to 4,056 tracks (Calvados). This is mainly due to the location of the OWF, rather than a quality of the OWF themselves. For example, the traffic around Calvados OWF is made up of 87% fishing traffic, due to the high fishing activity in the area.

However, 50 of the 233 OWF sites included in this analysis have most of the traffic in the areas of the OWFs sites from support traffic, with an average distribution of support vessel traffic of 1.1%, as shown in Figure 26. Although it may be expected that most of the traffic around an OWF is supporting the site, other traffic frequently passes through OWF sites or near their borders. This especially true where the OWF sites are close to busy shipping lanes. Some of this traffic may also be supporting offshore oil and gas sites and transit to/from these sites passes through the buffer around the OWF included in this study.

The least amount of traffic comes from pleasure boats, at an average of 13.2 tracks per site in 2022. This could be due to most pleasure craft are typically smaller and therefore less likely to carry AIS transponders. This would mean their tracks would not show in our dataset.

This shows that each individual OWF site has its own make up of traffic volumes and distribution. Despite patterns in distribution, forecasting traffic in future OWFs is complex with many variables affecting the resulting volumes and distribution.

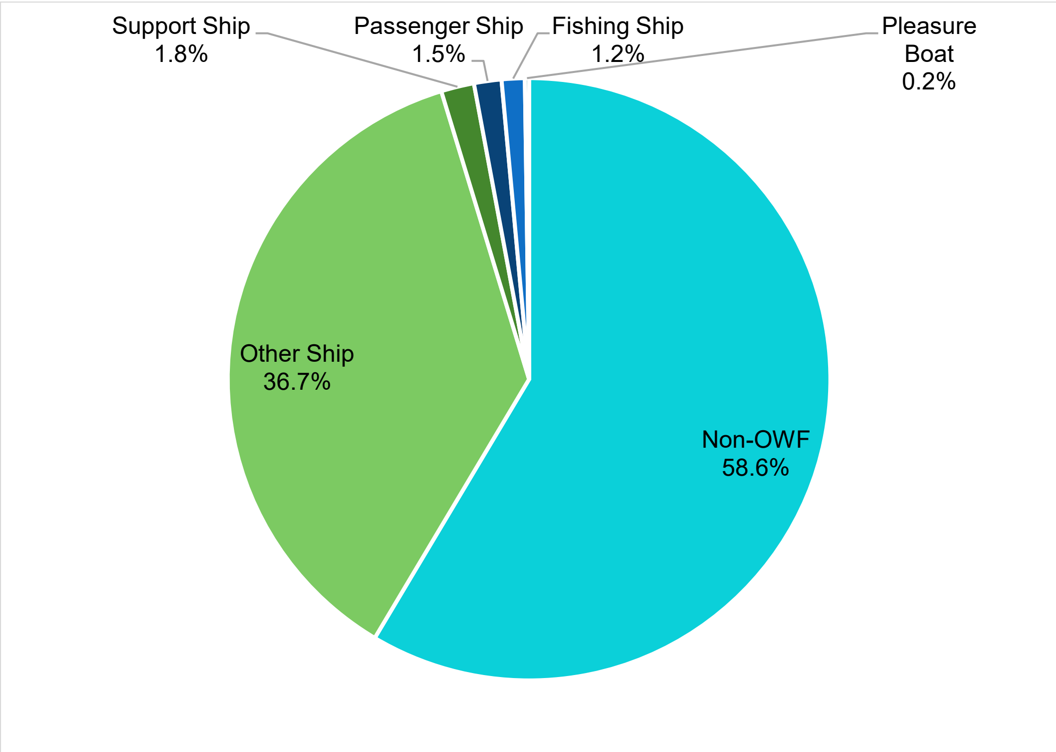

Figure 26: Average Distribution of Vessel Class in percentage of Tracks per Operational OWF Site

In addition to showing that most traffic in OWF sites is from non-OWF traffic at 58.6%. This is likely due to the proximity of the OWF sites to major shipping lanes. The rest of the traffic is other ships (36.7%) with small contributions from fishing, pleasure boats, support ships, and passenger vessels. This highlights the limitations inherent in AIS vessel classification. Due to the limited classes in AIS records, it is not clear which vessel are working directly with the OWF site, and which are passing through.

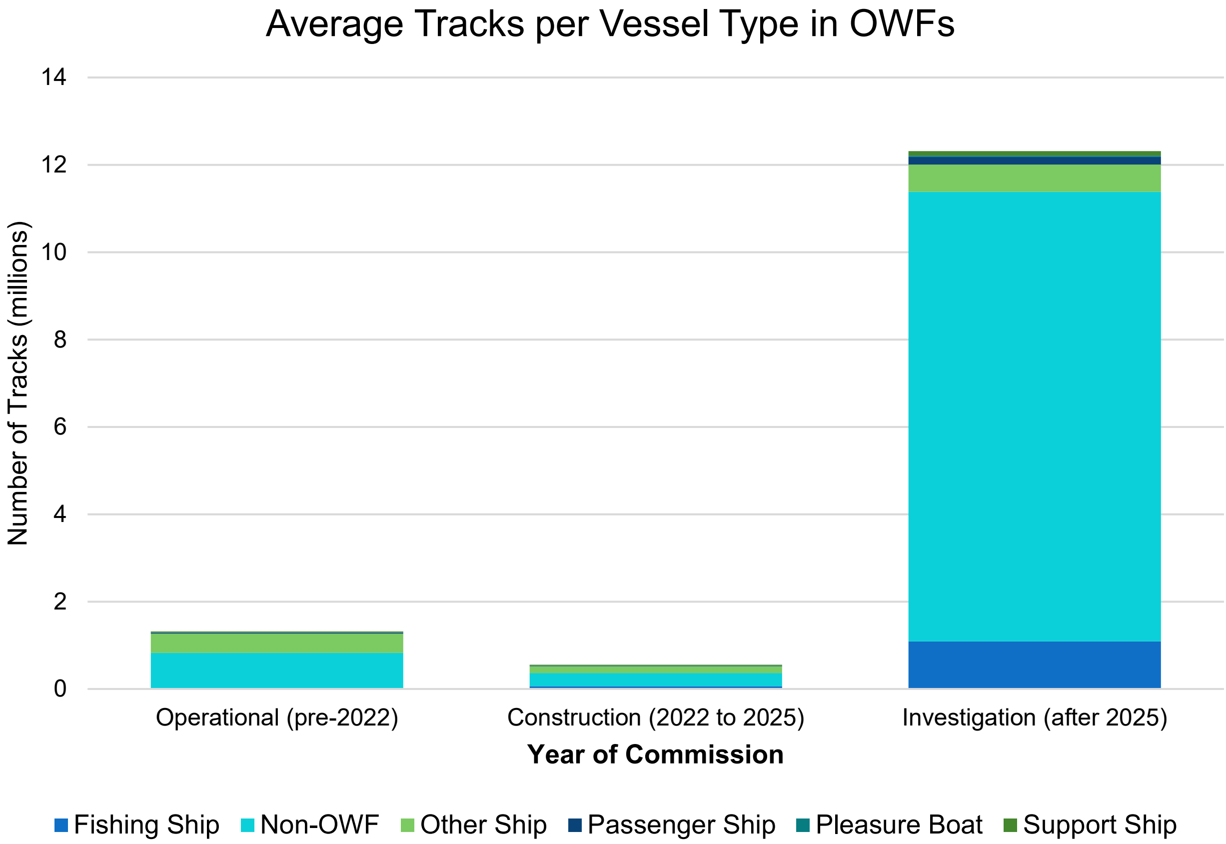

Figure 27: Average Number of Tracks per OWF by Phase of Life

Figure 27 shows the average number of tracks found in a OWF area. This all traffic within the area broken into the following classes: fishing, non-OWF, other, passenger, pleasure, and support. This does not only include the traffic supporting the OWFs, but all the traffic in the area. This is separated by the phase of the OWF: operational, construction, and investigation (the OWF has been identified but construction has not started).

The offshore windfarms (OWFs) in this analysis have been categorised according to their commissioning status relative to the AIS dataset year (2022). Sites classified as *operational* were commissioned before or during 2022, those under construction have expected commissioning dates between 2022 and 2025, and investigation sites are those with commissioning dates beyond 2025. The average total number of AIS tracks observed within each category is 1,318,859 for operational sites, 552,073 for construction sites, and 12,314,469 for investigation sites.

Although it might be expected that construction-phase OWFs would exhibit higher vessel activity than operational ones, the data suggests otherwise. One explanation may be that construction zones are subject to stricter exclusion policies, which limit incidental or transit traffic. Additionally, construction activity is not continuous; it typically occurs in short, intense phases, and if 2022 did not coincide with peak installation periods, the average track count may underrepresent actual construction-related traffic. The relatively small number of OWFs classified as under construction, 24 OWFs, compared to operational (73 OWFs) and investigation (133 OWFs) sites may also influence the average values, as a smaller sample size can amplify variability and reduce representativeness.

It is also important to consider that many small vessels used during the construction phase for rapid deployment and turnaround may not broadcast AIS signals, making them effectively invisible in the dataset. Rather than being related to operational sensitivity, this is more likely due to vessel size and regulatory exemptions. Fishing activity is the only vessel type that shows a notable increase during the construction phase. This may be attributed to ecological factors, as fish tend to congregate around turbine structures for shelter and feeding, which in turn attracts fishing vessels. Moreover, the lingering effects of the COVID-19 pandemic in 2022 may have contributed to increased recreational fishing, as it provided a socially distanced outdoor activity during a period of restricted travel and limited leisure options.

The high average track count observed in investigation-phase sites is likely due to their larger spatial extent and overlap with existing marine traffic routes, rather than activity directly related to windfarm development.

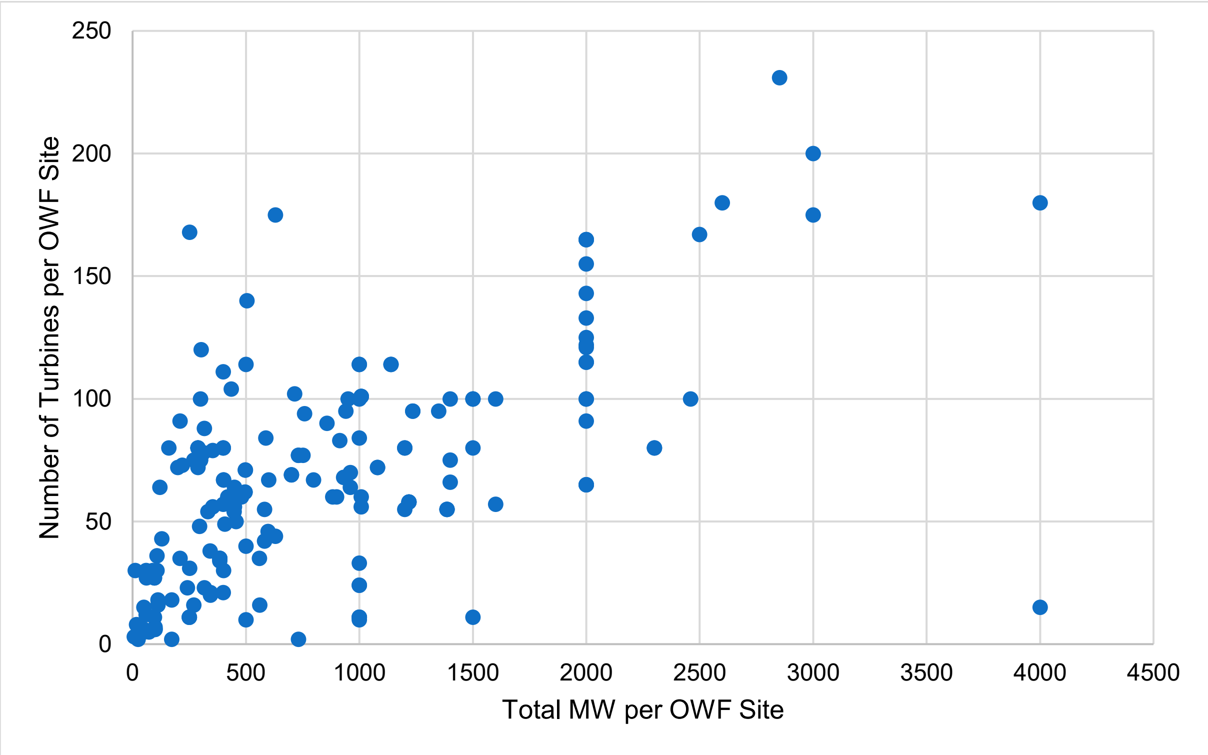

Figure 28: Number of Turbine and Megawatt (MW) per OWF Site

Figure 28 shows that the number of turbines in an OWF site and total Megawatt are very closely linked. This is expected as many of the turbines have a similar power rating, with an average of 13MW per turbine. The number of turbines and Megawatt values of each OWF were sourced from news articles, OWF development websites, and 4C Offshore (TGS, 2025).

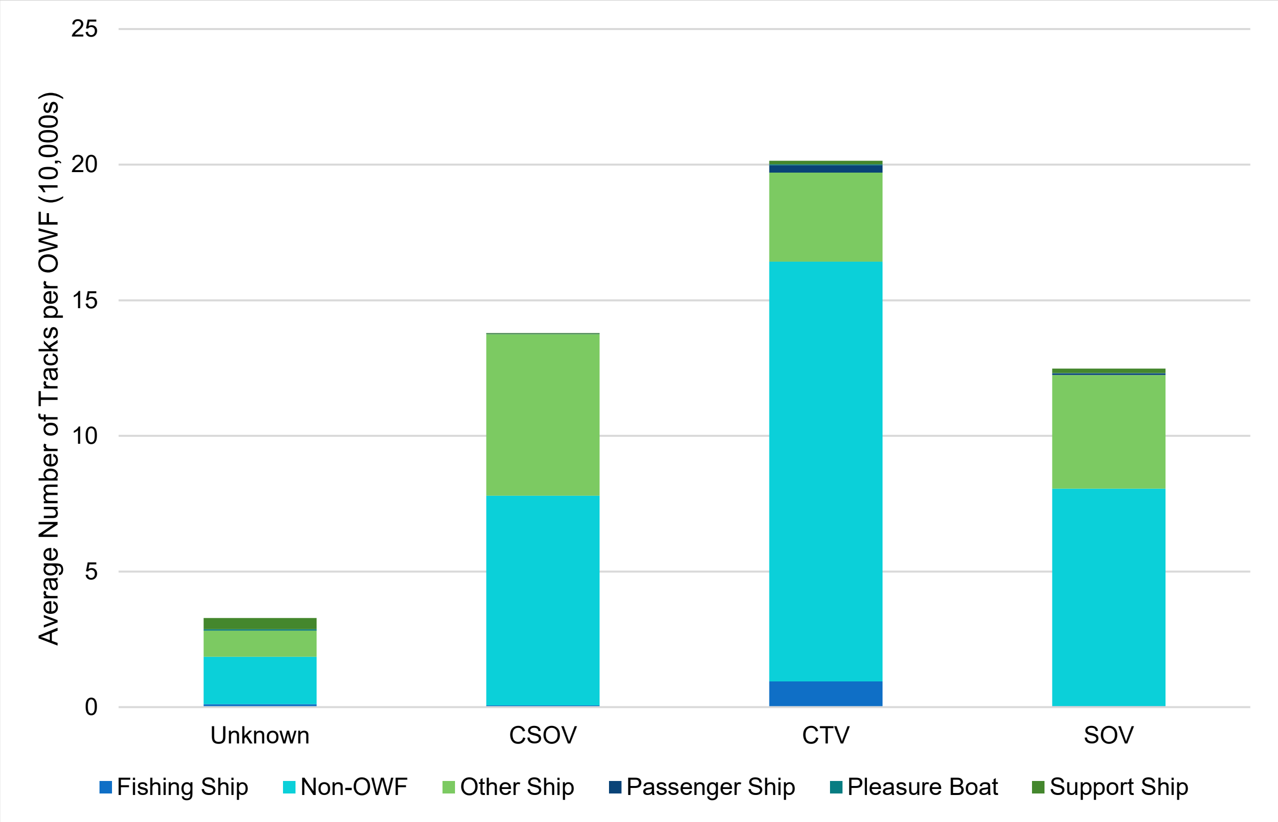

Figure 29: Average Number of Tracks per Operational OWF by O&M Type

Figure 29 presents the average number of vessel tracks per OWF split by the main type of operations and maintenance (&M): 3 OWFs with CSOV (Commissioning Service Operation Vessel), 42 OWFs with CTV (Crew Transfer Vessel), 25 OWFs with SOV (Service Operation Vessel), and 4 OWFs with an unknown O&M type. These bars are then broken down by type of vessel recorded in the OWF area: fishing, non-OWF, other, passenger, pleasure, and support.

Across CSOV, CTV, and SOV vessel categories, non-OWF and other ships dominate activity. In CSOV, non-OWF vessels account for 56%, and other ships 43%, with support vessels and passenger ships each below 0.2%. CTV traffic is led by non-OWF vessels (77%), followed by other ships (16%) and fishing vessels (5%), while support and pleasure boats remain under 1%. SOV shows a similar pattern, with non-OWF vessels at 64% and other ships at 34%. Passenger and support vessels contribute less than 2%, and fishing and pleasure boats are negligible. These figures highlight the limited AIS-recorded presence of support vessels relative to broader marine traffic.

4.1.2 Vessel length Distributions

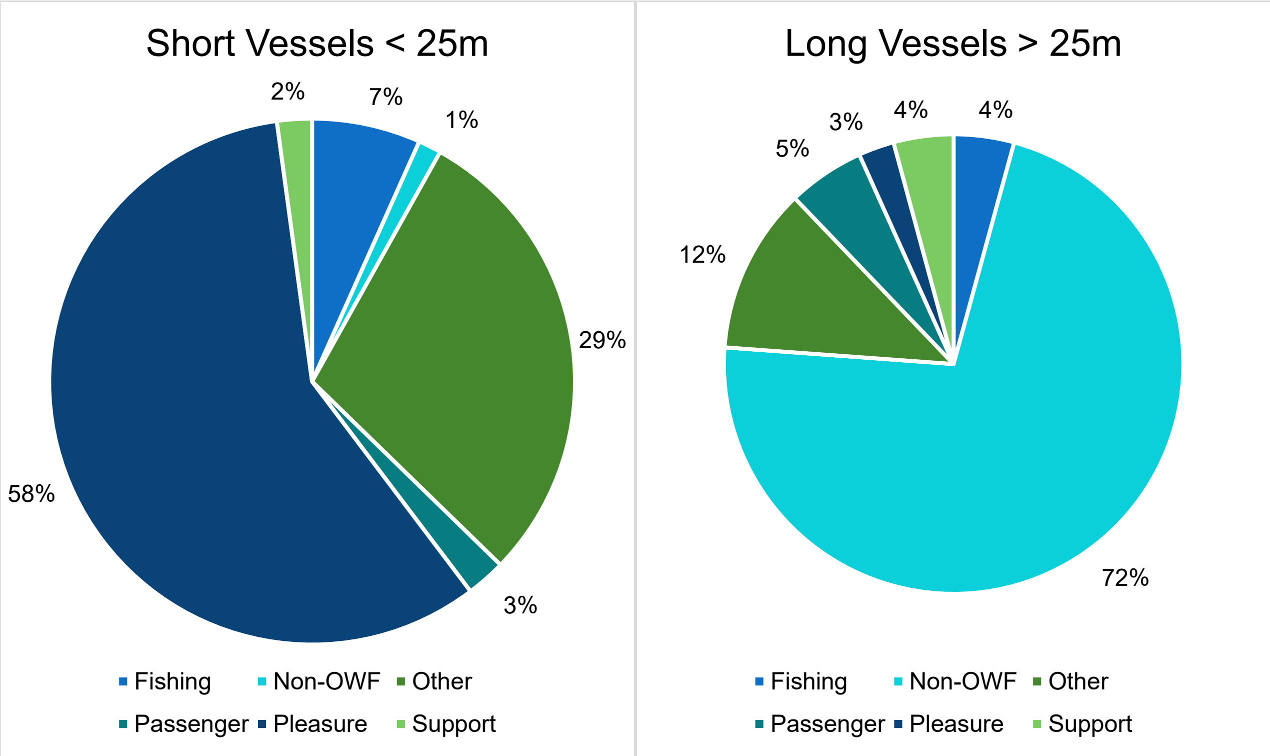

Figure 30: Distribution of Vessels by Length (Short <25m LOA, Long >25m LOA)

Figure 30 shows that 2% of the short vessels are support ships; the majority of the short vessels are pleasure boats (58%) and Other (29%). The long vessels have a clearer majority of Non-OWF vessels at 72%. The rest of the tracks have a somewhat even distribution between the rest of the vessel classes.

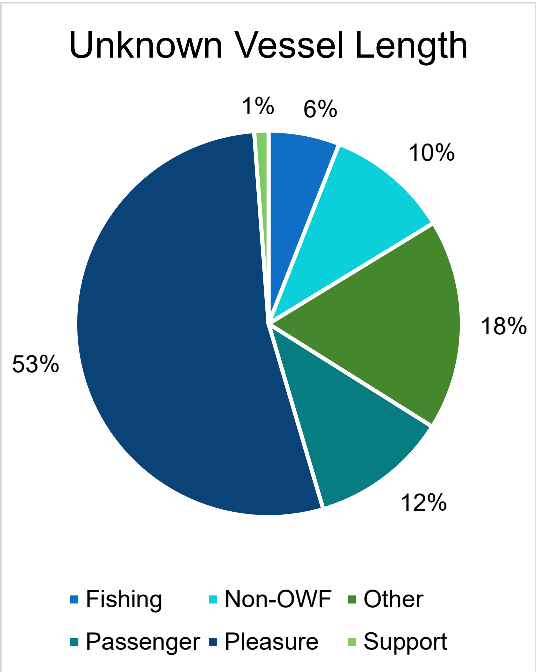

Figure 31: Distribution of Vessels by Length (Unknown LOA)

Figure 31 shows a distribution of vessel types among those with unknown length that closely resembles the short vessel category, suggesting that smaller vessels are both more prevalent in these groups and less likely to complete static AIS information such as length overall.

4.2 FORECAST RESULTS

These forecasts take into account all of the factor analysis research explained in section 3.5 and the results of the baseline traffic assessment in section 4.1. Please find the attached GeoPDFs in Appendix E:GeoPDFs of Track Volumes per Vessel Class per Epoch. There is also a short ‘How to use a GeoPDF’ provided if you are unfamiliar with them.

Figure 32 shows the OWF sites considered in this study. They are colour coded based on the epoch year their (predicted) traffic has been added to the analysis. These 5 epochs are detailed in the scope.This is calculated as the epoch after they become operational. For example, if a OWF became operational in 2022 or prior to 2022, it would be Extant/Operational (blue), if the OWF becomes operational in 2030, the predicted traffic changes would be implemented to the analysis in 2030 (yellow), and if an OWF become operational in 2032, the predicted traffic changes would be implemented to the analysis in 2035 (orange).

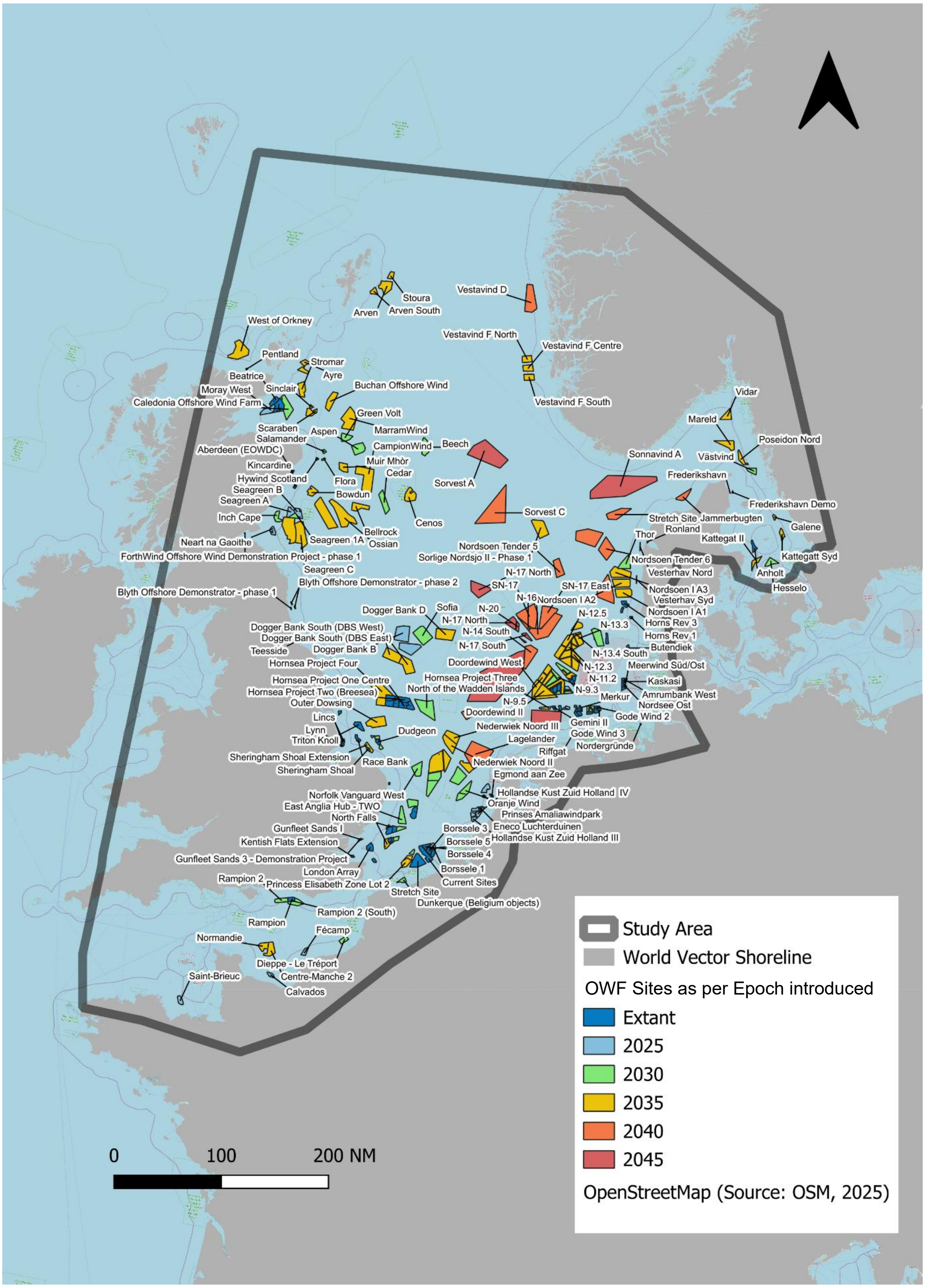

Figure 32: Overview Map of OWFs symbolised by the Epoch they are introduced to the model

4.2.1 Change in Support Vessels from 2022 to 2050

Figure 33 and Figure 34 show the forecasted support ship traffic in 2022 and 2050, respectively. There are two main changes between the forecasted traffic of 2025 and 2050. First, the projected decrease in oil and gas support traffic, most clearly seen in the north of the North Sea as oil and gas sites are decommissioned in the move towards more sustainable energy sources. Secondly, the predicted increase in service traffic where OWFs are predicted to come operational. The impact of new operational OWFs will be inputted into the model when they become operational. Figure 32 shows the epoch in which each OWF will be applied to the model. Extant OWFs will have no additional change in OWF traffic, as this is presumed to be stable.

Although, the decrease in traffic due to oil and gas decommissioning will decrease the risk climate for vessels in this area, the increase in OWF support traffic is predicted to be concentrated in the southern North Sea, near key routes at the entrance through the English Channel. OWF sites are chosen mindfully to not increase the risk of collisions and allisions unduly, but the increased volume of traffic to and from OWF sites is predicted to increase the risk of the area if no suitable risk mitigation methodologies are implemented.

Figure 33 and Figure 34 show the support traffic forecasted by our model for 2025 and 2050, respectively. These images show the changes that are predicted to happen in the North Sea. The yellow cells show greater volumes of traffic, whereas purple shows very few tracks in that cell. It is worth noting that this is all service traffic, which includes service vessels for both oil and gas sites and OWF.

One of the starkest differences in these two images is the lack of service traffic outside the OWF sites and predicted transit paths in the EEZs of the Netherlands, Denmark, and Germany. These countries have projected no oil and gas production in their waters by 2050. The "No Traffic" value in Figure 34 refers specifically to the absence of forecasted support traffic for oil and gas activities, as these fall outside the OWF sites. For the Netherlands, Denmark, and Germany, this assumption is based on published national strategies and policy commitments aiming to end oil and gas activities in their seas by 2050, thus, forecasting no oil and gas support traffic. In the Netherlands, the government aims to reduce its CO_2 footprint by decommissioning half of its oil and gas infrastructure by 2030, which implies there will be no oil and gas support traffic in Dutch waters in 2050 (Nexstep, 2021). Denmark has similarly committed to ending oil and gas extraction in the North Sea by 2050. This follows a parliamentary decision in 2020 which aligned with its broader climate neutrality goals (European Parliamentary Research Service, 2024). Germany is actively phasing out its gas infrastructure as part of a comprehensive fossil fuel transition strategy (Oeko-Institut, 2025). This is reinforced by international commitments such as the IMO's net-zero target for 2050, which supports the elimination of fossil fuel-related maritime operations (UNCTAD, 2023) (International Maritime Organization, 2023). Specific national actions, such as the planned end of oil extraction in the Wadden Sea by 2041 (Wehrmann, 2024) and the decommissioning of fields like Nordsee A6/B4 (Offshore Technology, 2022), further support this projection. However, it is unlikely that oil and gas support traffic will cease entirely without anomalies or transitional activity, especially given the complexity of maritime operations. This estimate represents the most accurate forecast possible at the current scale and resolution. As noted in the report, all modelling and forecasting carry inherent uncertainties, particularly when projecting over a 25+ year horizon based on a single year of data.

The general reduction in oil and gas traffic can be seen in other parts of the North Sea, especially in the central north of the map. In 2025, there are bright spots of traffic at the locations of the oil and gas sites. The tracks have been predicted to decrease by 2050, as can be seen in Figure 34.

The increase of forecasted OWF sites can also be seen in these figures. This model predicts about 100 to 1000 tracks per km^2 per year within an operational OWF based on the averages of the extant OWF in the North Sea. This does not consider any decrease in OWF traffic due to advancements in turbines, operations and maintenance methodology, and efficiencies in multi-OWF visits that may reduce the need or frequency of transits to and from the OWF.

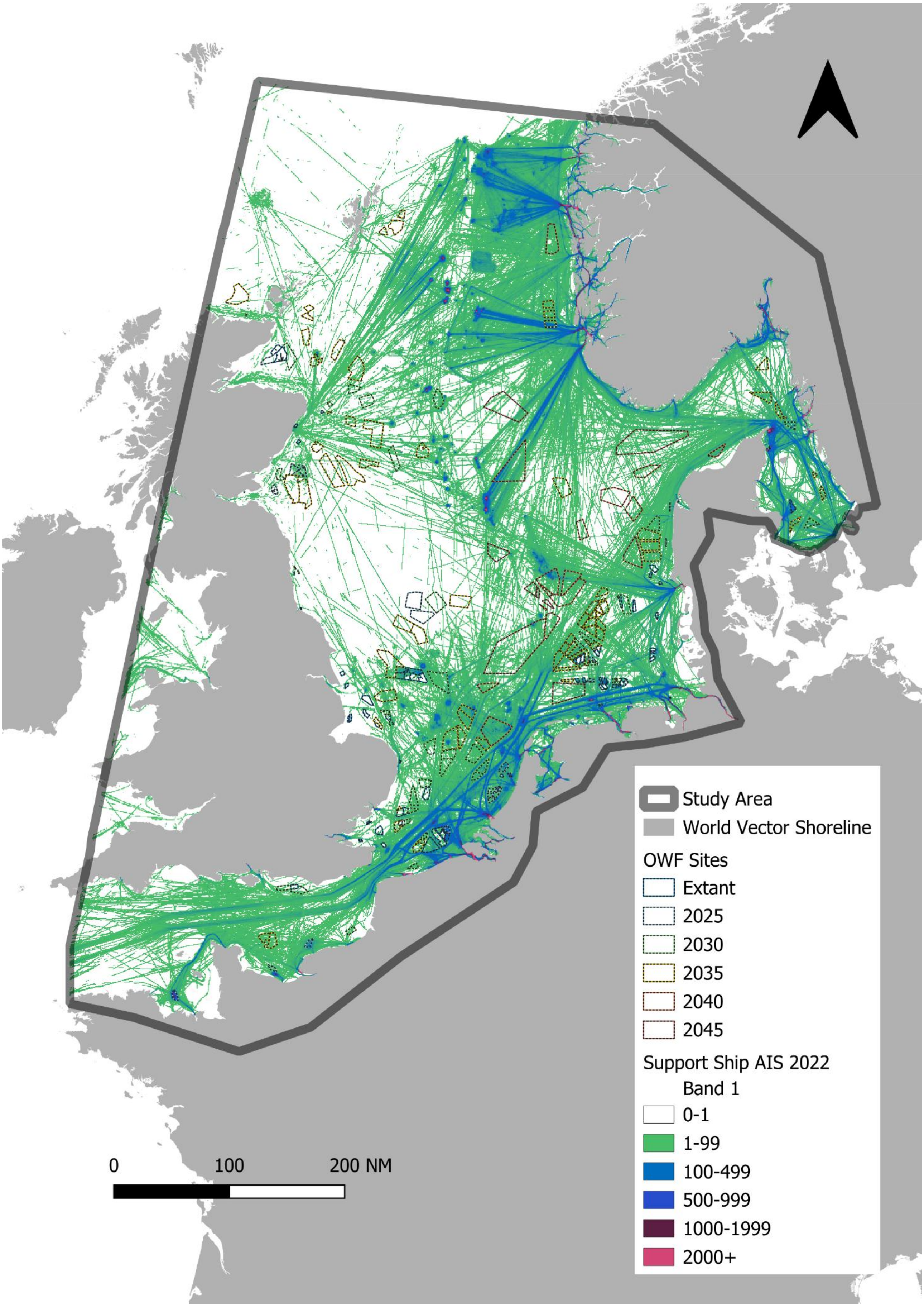

Figure 33: GIS image of Forecasted Support Vessel Traffic in 2022

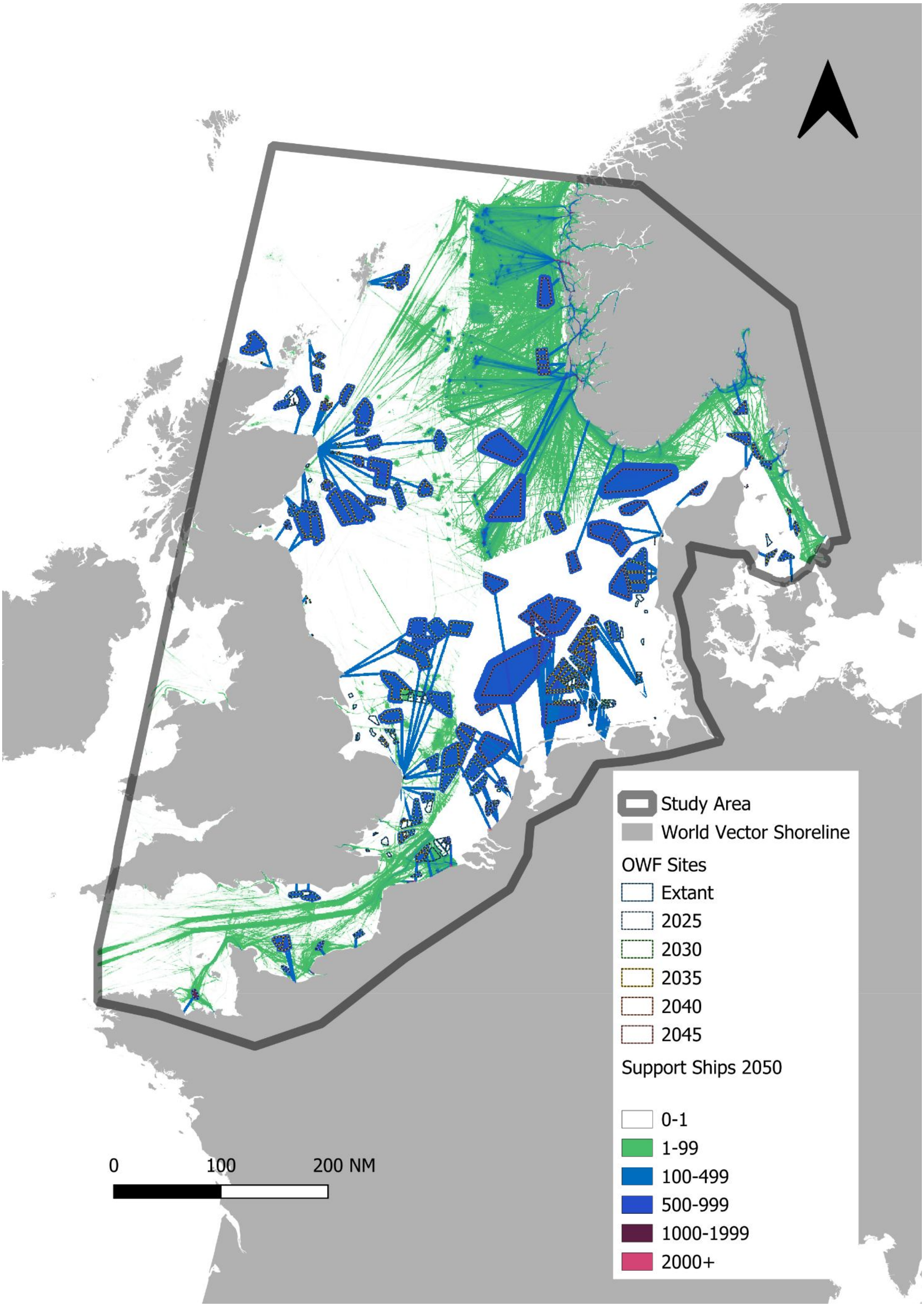

Figure 34: GIS image of Forecasted Support Vessel Traffic in 2050

Figure 35 shows the change in support traffic between the EMSA 2022 AIS dataset and the result of the analysis in this study forecasted to 2050. The more clearly shows the changes between Figure 33 and Figure 34, with green showing the increases in traffic forecasted and, in red, the decrease in traffic. The yellow shows the areas where the traffic is not predicted to change meaningfully.

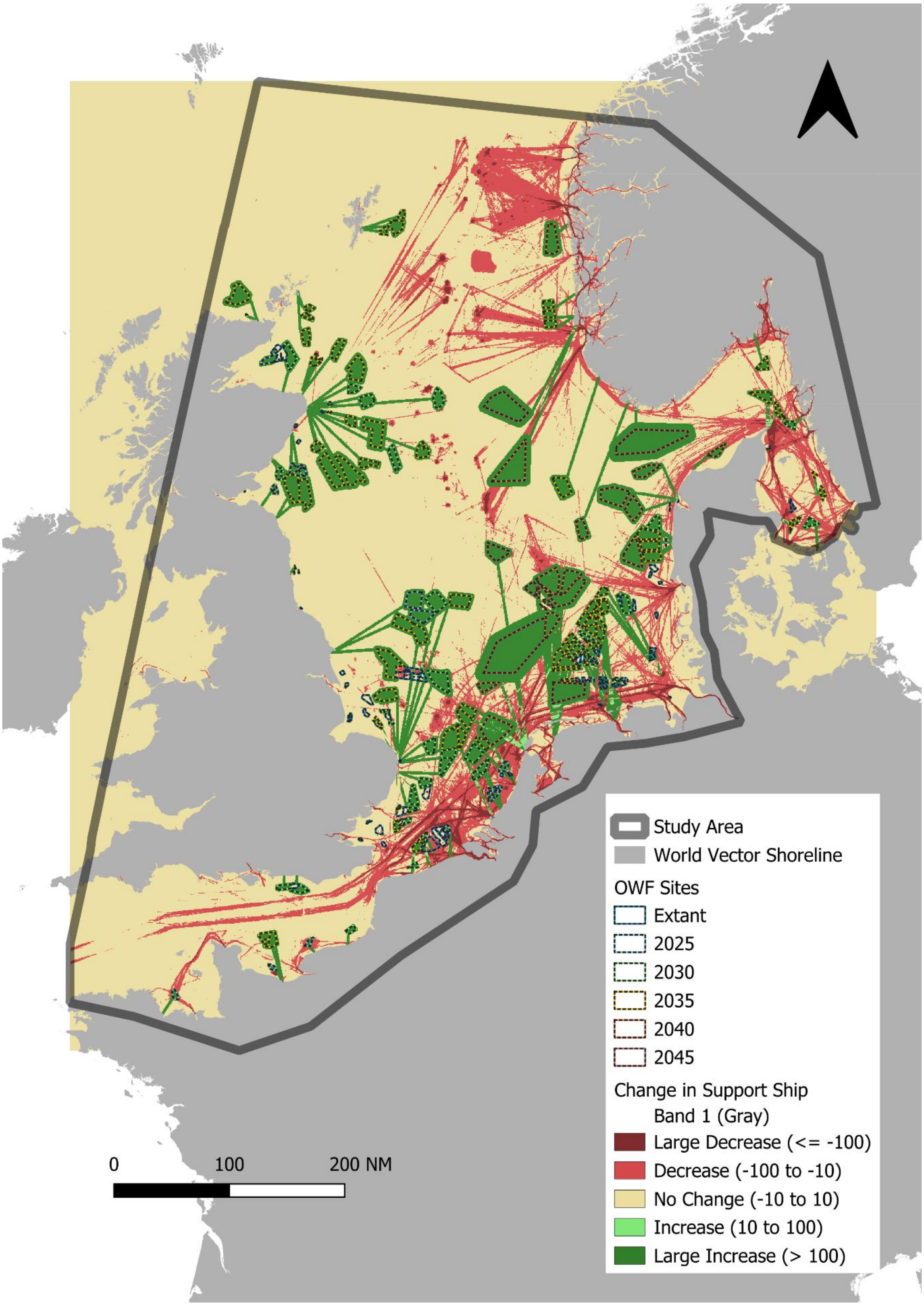

Figure 35: Change in Support Traffic from EMSA 2022 AIS Dataset to Forecasted 2050

4.3 MICRO-SCALE CASE STUDIES

Figure 36 shows the number of tracks per month recorded in the AIS data in the areas around the three OWF chosen for the micro-scale case studies.

Overall, the Hollandse Kust OWFs have the highest volume of traffic, and the Nord See OWFs has the lowest volume of traffic. There is a clear peak in the summer months for both Hollandse Kust I and II, whereas Nord See OWFs stays relatively steady throughout the year.

This increase during the warmer months is mainly due to the increase in fishing and passenger traffic. This can be seen more clearly in Figure 38, Figure 39, Figure 43, Figure 44, Figure 45, and Figure 49.

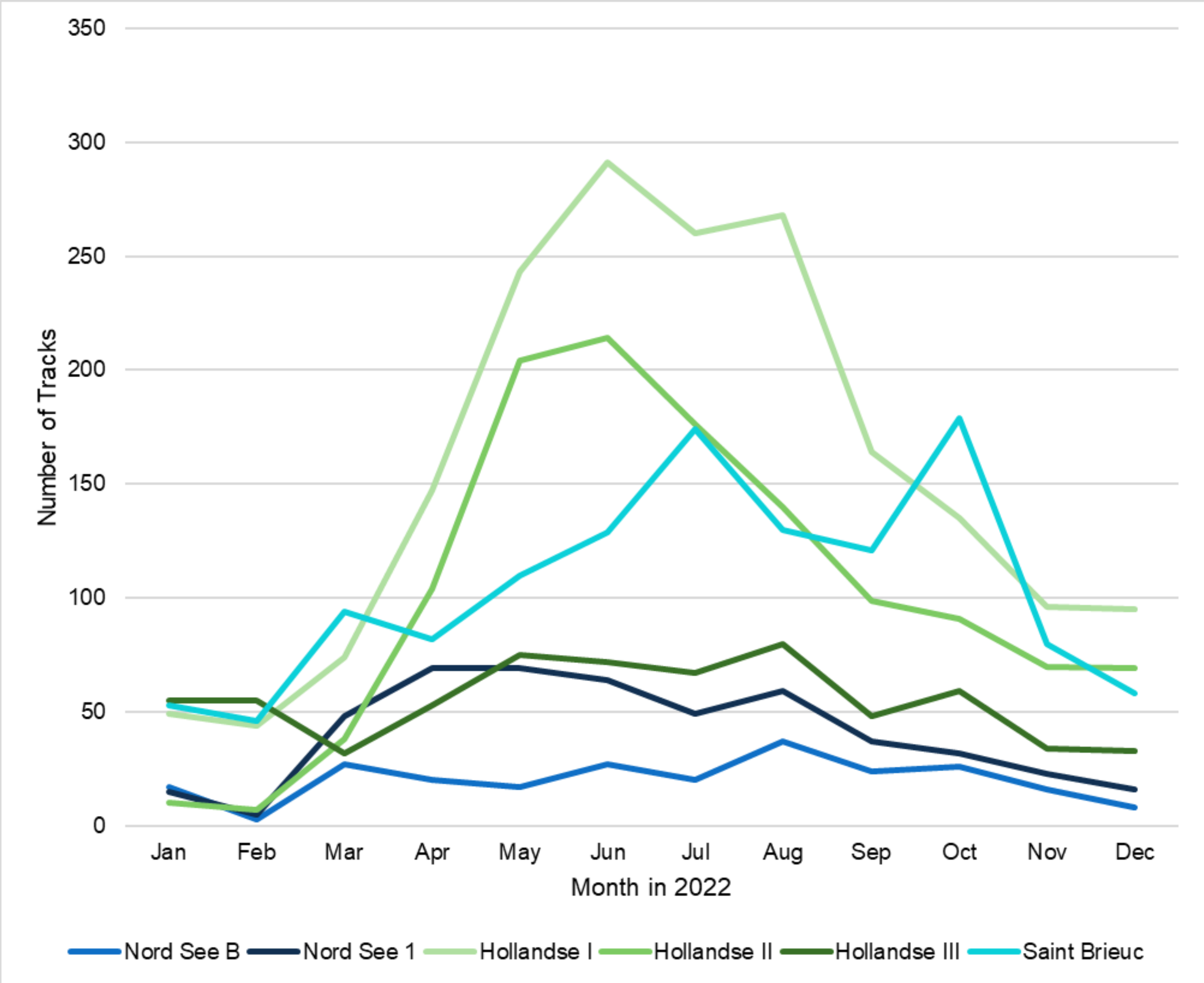

Figure 36: Number of Tracks per Month for the Micro-Scale Case Studies

The maps of AIS tracks for each of the Micro-Scale Case Studies is the same as that found in the Long List (ABL, 2025).

4.3.1 NordSee Cluster B and Nordsee ONE

These OWFs are in an area of dense support vessel movement to adjacent and local OWF, as well as near an important shipping route. The increased movement of support and service vessels between shore and the development will increase the number of crossings of the shipping routes unless service campaigns can be efficiently coordinated with existing OWF in the area.

In future, it is possible that a new route between the service port and OWF may develop, which may offer new opportunities for vessel-vessel interactions to occur compared to present day and consequently impact the risk climate to vessels navigating the immediate area. It is clear from other extant windfarms that OWF sites in such proximity are likely to develop shared operations and maintenance schedules to reduce traffic and cost.

Figure 37 shows the AIS tracks from 2022 around the Nordsee One and B windfarm site. Most of the traffic is in a south-easterly direction towards the nearest port of Eemshaven and Emden. There are also patterns of service traffic, in green, visiting other OWF sites in the area. The tracks of passenger boats can most likely be attributed to supporting Nordsee One. There is also fishing traffic through this area. The gap or corridor created by the OWF in this area force the vessels between them. This can raise collision risk.

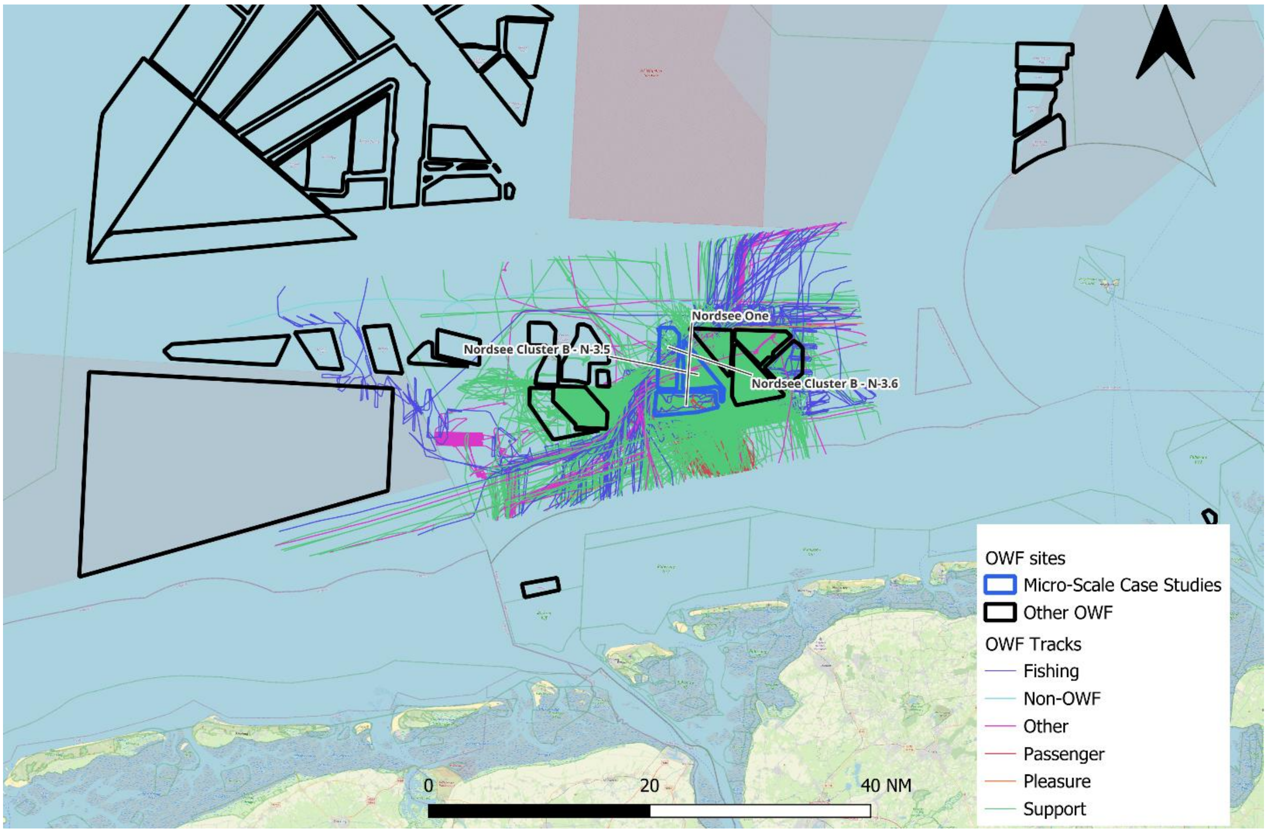

Figure 37: Nordsee One AIS Tracks

Figure 38 shows the traffic volumes by month in 2022 by vessel class for Nordsee One. There is a significant increase in the summer in both support and passenger traffic, which have a maximum of 47 tracks per month and 25 tracks per month, respectively. This passenger traffic could also be serving the OWF as the CTVs can be classed as passenger ships in the AIS data. This increase in support traffic in the summer months is likely due to the planned maintenance of the OWF in the nicer weather.

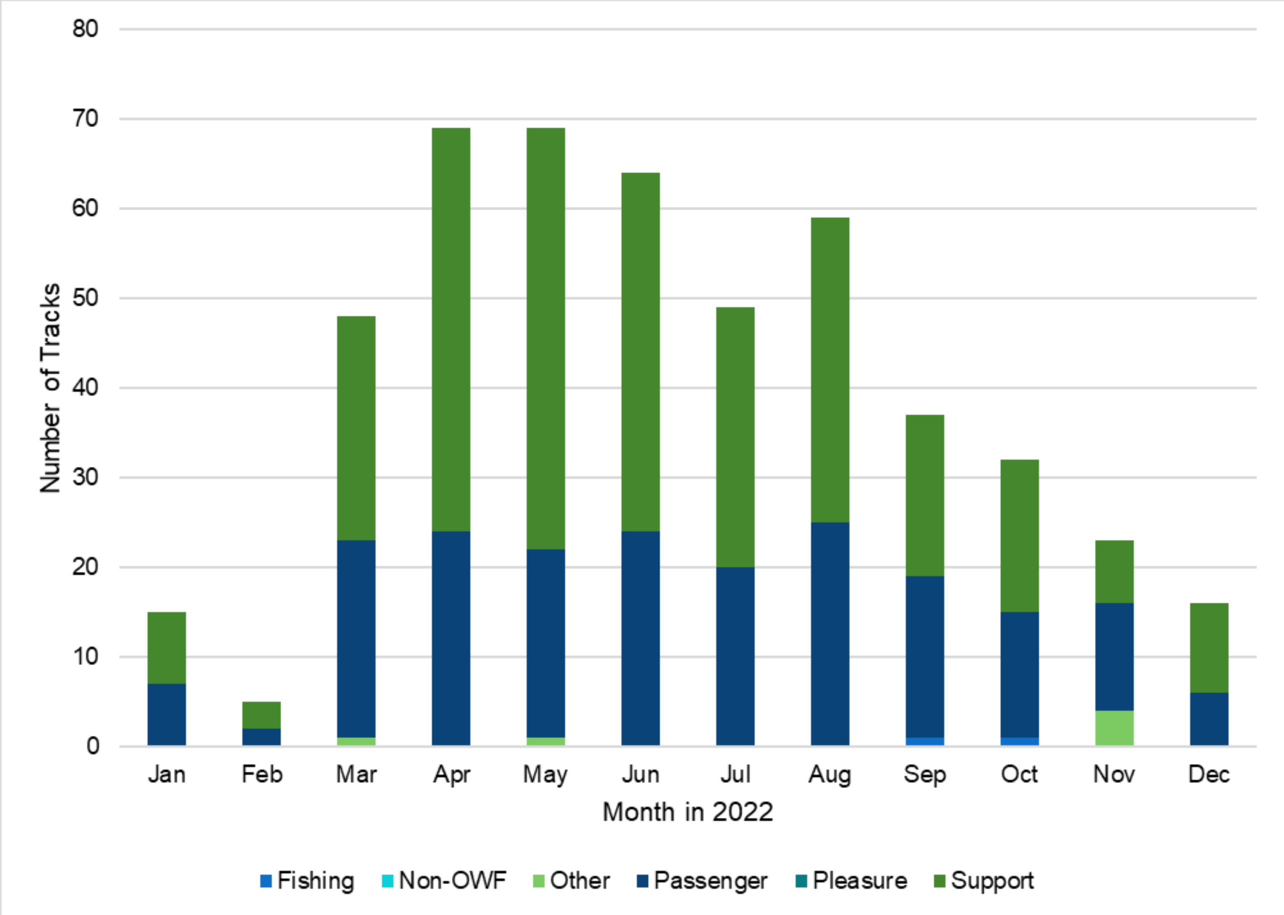

Figure 38: Nordsee One Traffic by Month

HH-M22-45819-BSH-NORSAIC

Figure 39 shows the traffic volumes by month in 2022 by vessel class for Nordsee B. This has a vastly different pattern in traffic volumes from Nordsee One. Although there is an increase in fishing traffic during the summer, it is not as clear as in the Nordsee One data. Additionally, the support vessel traffic is steadier, with an average of 13.6 tracks per month. There is also a greater proportion of other traffic in this area. These vessels are those that do not fit into another category or did not have a vessel category listed on their AIS signal.

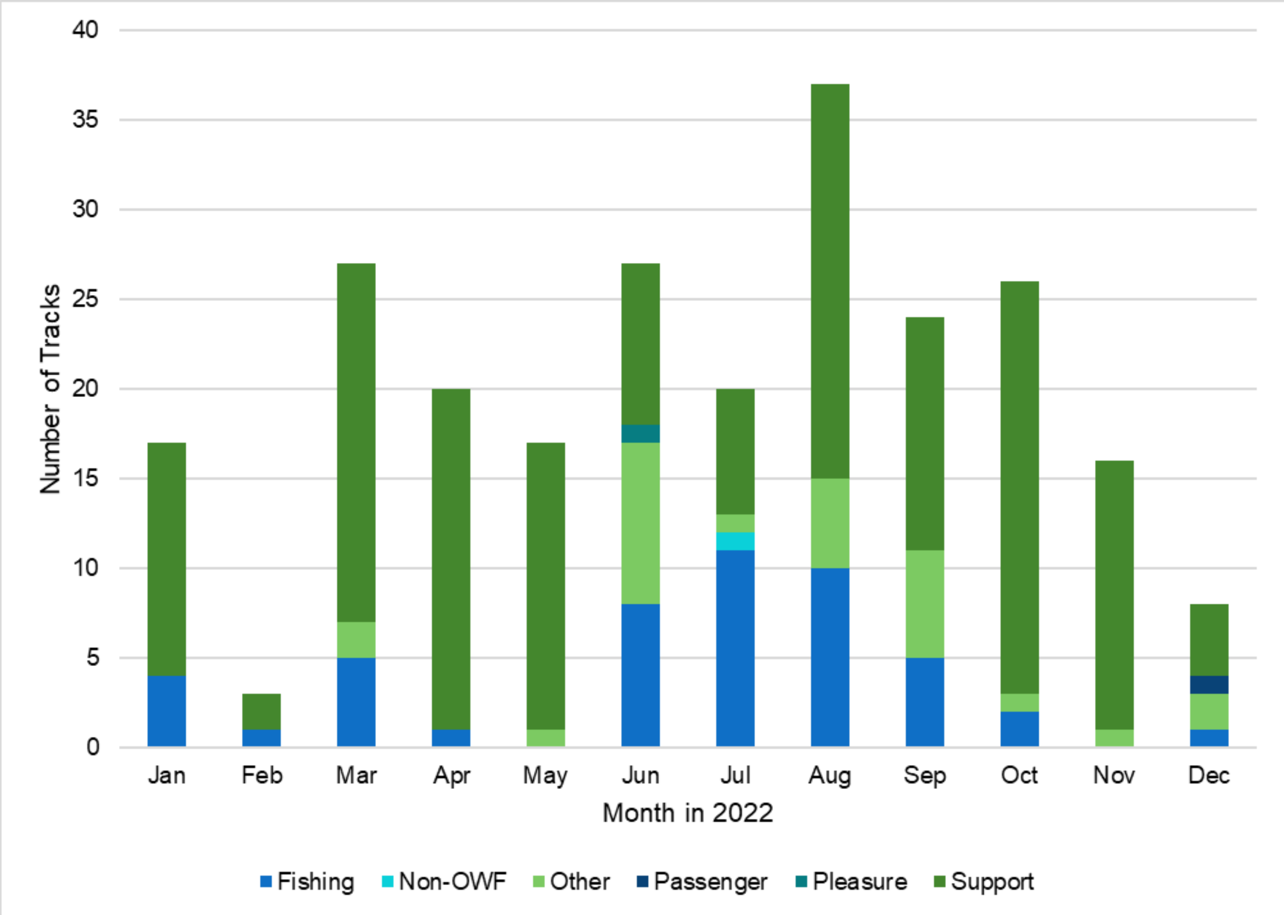

Figure 39: Nordsee B Traffic by Month

Figure 40 shows the forecasted traffic for support ships in 2025 around the Nordsee OWFs. The greatest volumes of traffic are in the OWF sites and the paths of transit to and from nearby OWFs and the port of Eemshaven/Emden. There is also evidence of the shipping channel that run parallel to the coast.

Figure 41 shows the forecasted traffic for support ships in 2050 around the Nordsee OWFs. As explored in Figure 34, the impact of the Netherlands, Denmark, and Germany expecting no oil and gas production by 2050, and thus none of the associated traffic, is that there is no forecasted traffic outside of the OWFs and their predicted transit paths.

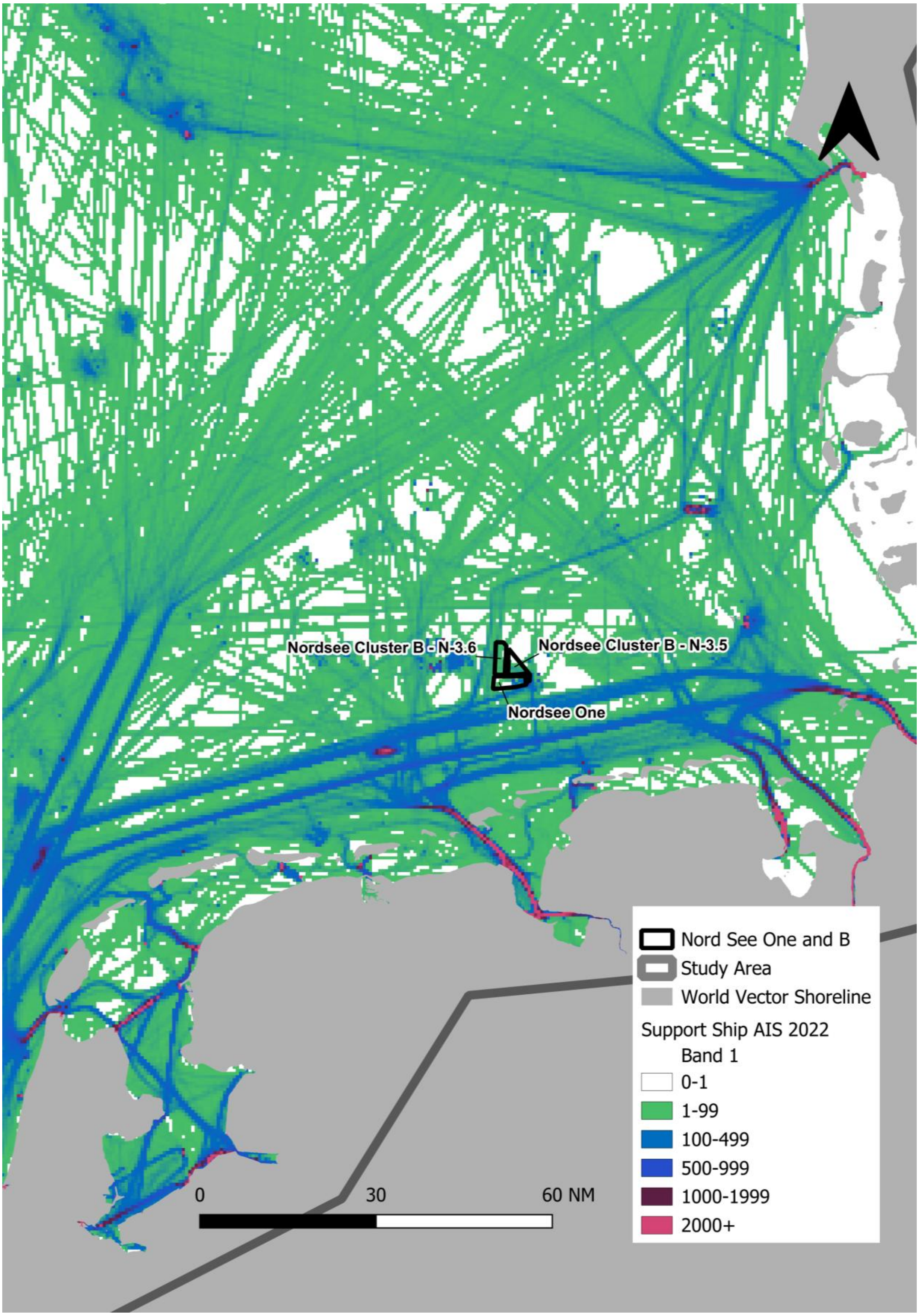

Figure 40: GIS image of Forecasted Support Ship Traffic Volumes around Nordsee OWF in 2022

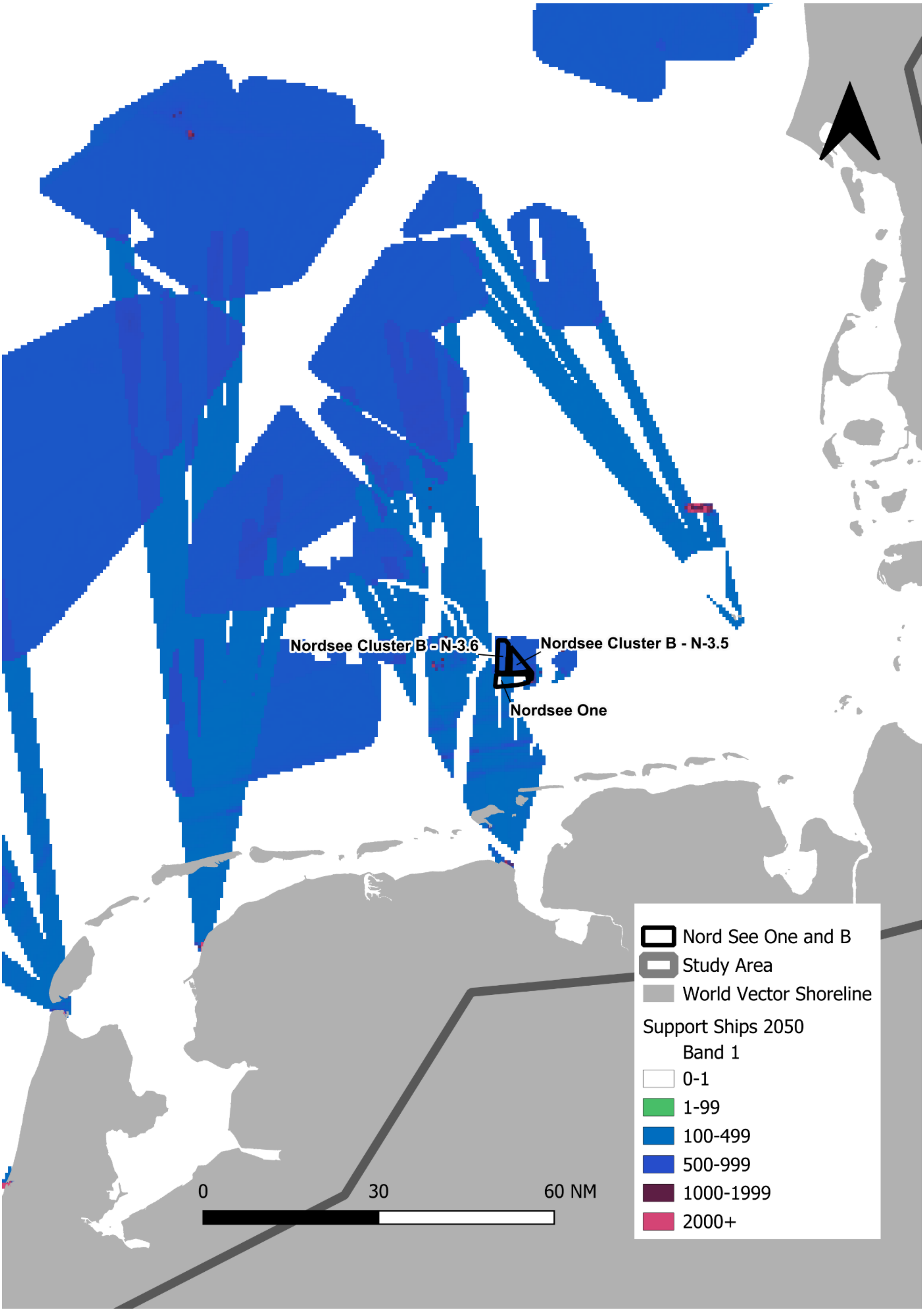

Figure 41: GIS image of Forecasted Support Ship Traffic Volumes around Nordsee OWF in 2050

4.3.2 Hollandse Kust Zuid I to III

The movement of service and support vessels in and around the Hollandse Kust Zuid I to III OWF can be seen to be a highly active during period of the available AIS data. The proportion of local service traffic visiting this OWF represents a significant fraction of total vessel movements in the local area.

Figure 42 shows the traffic from the AIS data in 2022 around the Hollandse Kust I to III. This site has all six classes of traffic: fishing, non-OWF, other, passenger, pleasure, and support. Much of the support traffic is in the OWF sites and transiting to and from the ports or other nearby OWF sites. The passenger and other vessel tracks also follow this pattern so it is likely these are also working in support of the OWF. The other traffic classes make up a much smaller portion of the area.

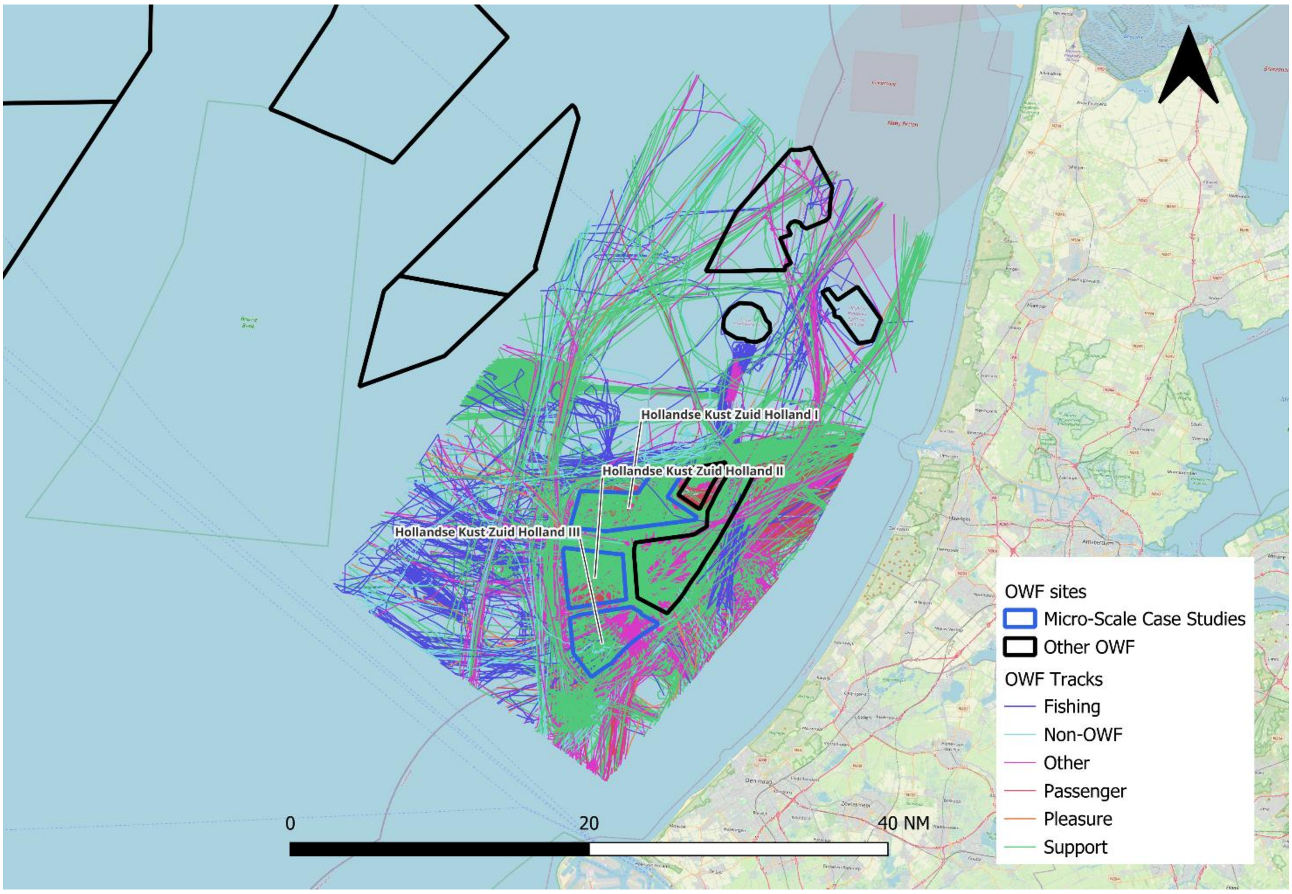

Figure 42: Hollandse Kust I to III AIS Tracks

Figure 43 shows the traffic volumes by month in 2022 by vessel class for Hollandse Kust I. This shows both the increases in shipping and passenger vessels in the summer seen in the traffic of the other OWFs. There are also extremely low volumes of fishing, non-OWF, and pleasure vessels in this area.

Figure 44 shows the traffic volumes by month in 2022 by vessel class for Hollandse Kust II. This graph shows very similar traffic patterns to Hollandse Kust I (Figure 43) with the same low volumes of fishing, non-OWF, and pleasure vessels. However, there is a much steeper increase in traffic in spring (from 7 tracks in February to 104 tracks in April).

Figure 45 shows the traffic volumes by month in 2022 by vessel class for Hollandse Kust III. This graph shows a different pattern of traffic volumes than Hollandse Kust I and II (Figure 43 and Figure 44) as it lacks the clear peak in traffic volumes in the summer with a more steady number of tracks about 55 tracks per month.

Overall, Hollandse Kust III has very little fishing traffic, but much greater proportions of non-OWF and other traffic as it is close to a major shipping channel following the coastline.

HH-M22-45819-BSH-NORSAIC

As all three of the Hollandse Kust OWF sites have low volumes of fishing, non-OWF, and pleasure vessels, this is likely due to restrictions in shipping around the OWF areas which would block these classes of vessels from the areas around OWF to reduce the risk of allisions.

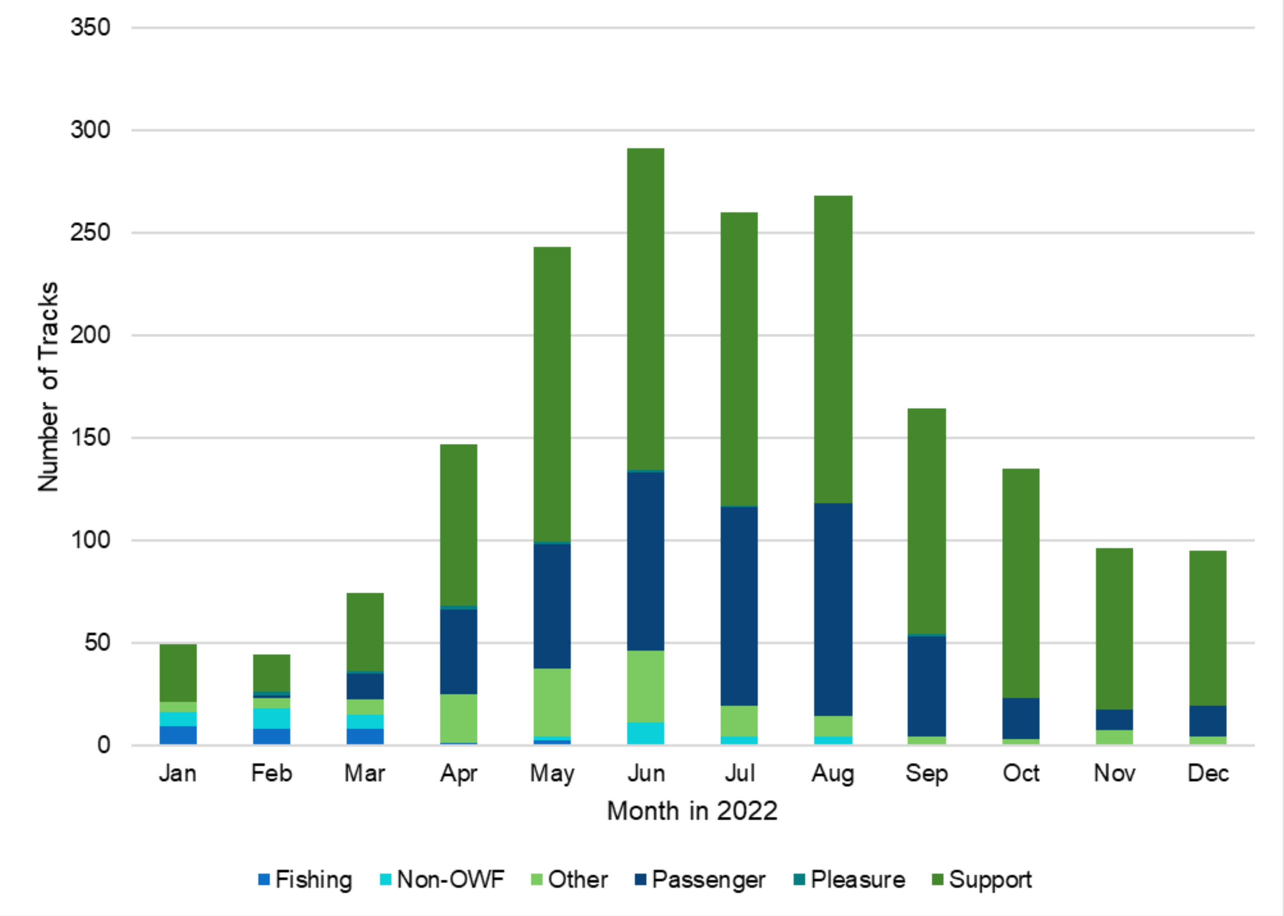

Figure 43: Hollandse Kust Zuid I Traffic by Month

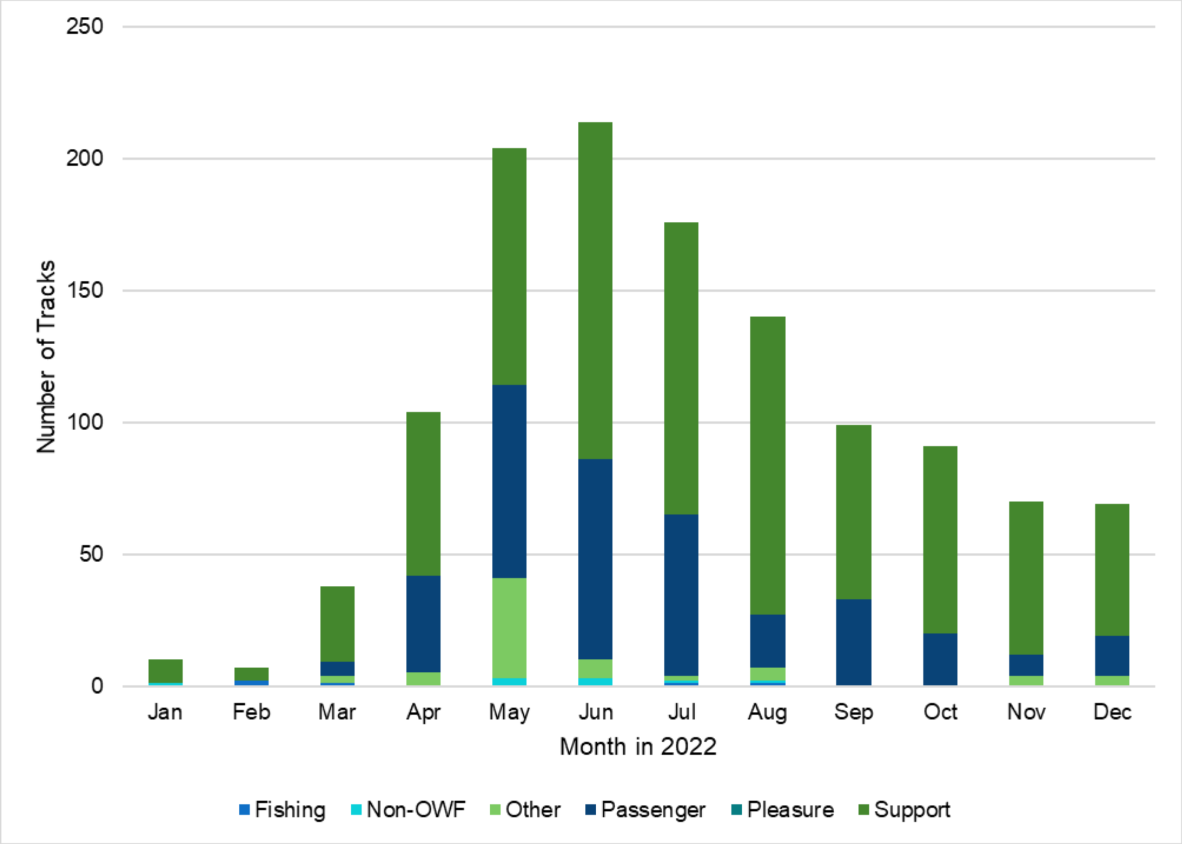

Figure 44: Hollandse Kust Zuid II Traffic by Month

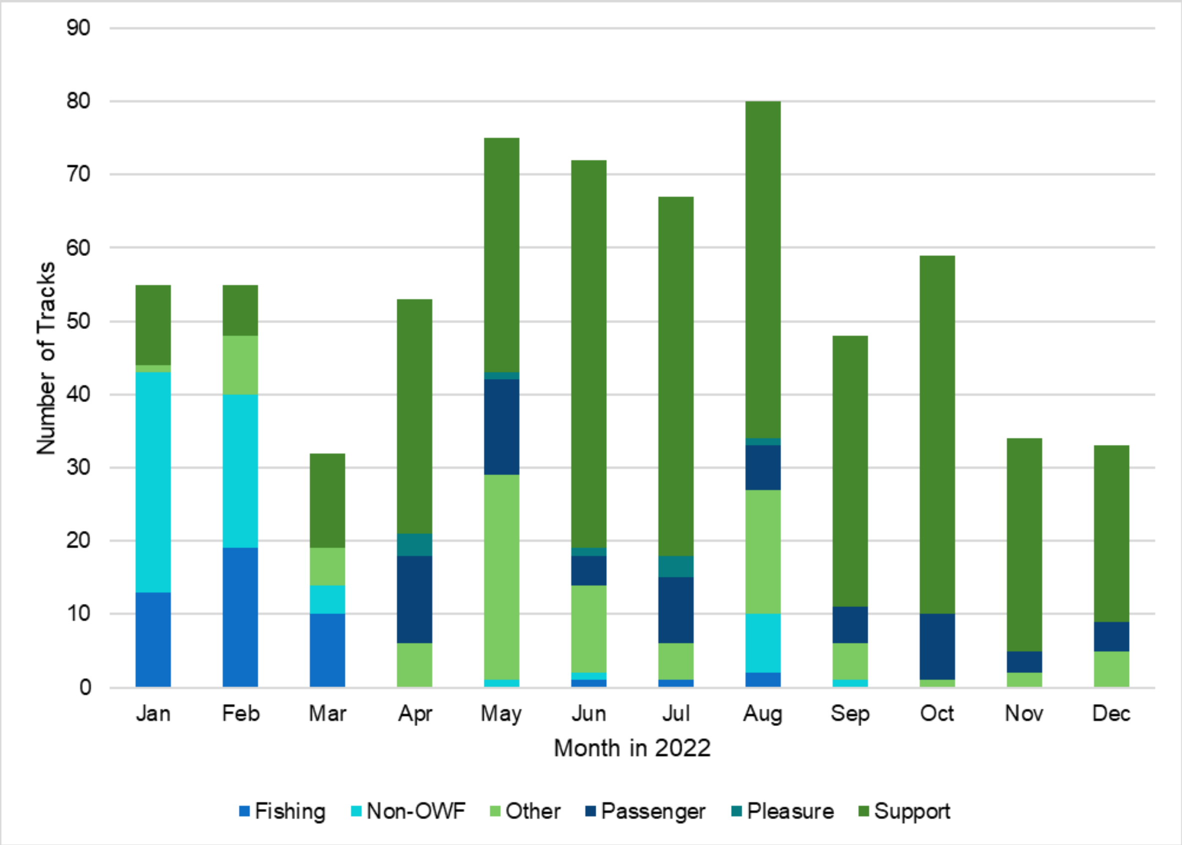

Figure 45: Hollandse Kust Zuid III Traffic by Month

Figure 46 and Figure 47 show how, as additional OWF developments come online, the nature of support vessel movements in the local area will change, through time. Overall, it is anticipated that the total number of support movements will increase, even if the total number of support movements to the Hollandse Kust Zuid OWF remains constant. Due to this OWF being a cluster of individual OWFs, there is also a lot of transit traffic between the OWF sites, which can be very difficult to predict.

Figure 46 shows the predicted support traffic in 2025. Most of the windfarms seem to be supported from the Ijmuiden port. However, there is a lot of support traffic traveling to/from Rotterdam.

Figure 47 shows the predicted support traffic in 2050. Here, the OWF sites to the northwest (Hollandse Kust IV and Oranje Wind) have become operational which shows a predicted uplifted volume of support traffic, both in and around the OWF site but also in the predicted path of travel to the nearest port. It is likely that there will be some transit between this future windfarm development and the existing Hollandse Kust I to III, although this is not shown in the model. This map also shows the impact of the reduction in oil and gas traffic to 0.

The development of additional OWF in the vicinity of Hollandse Kust Zuid may represent an opportunity for efficiency, if support vessels can undertake campaigns that span multiple OWF, but this may introduce additional traffic between the support port and OWF if such cooperation is not possible.

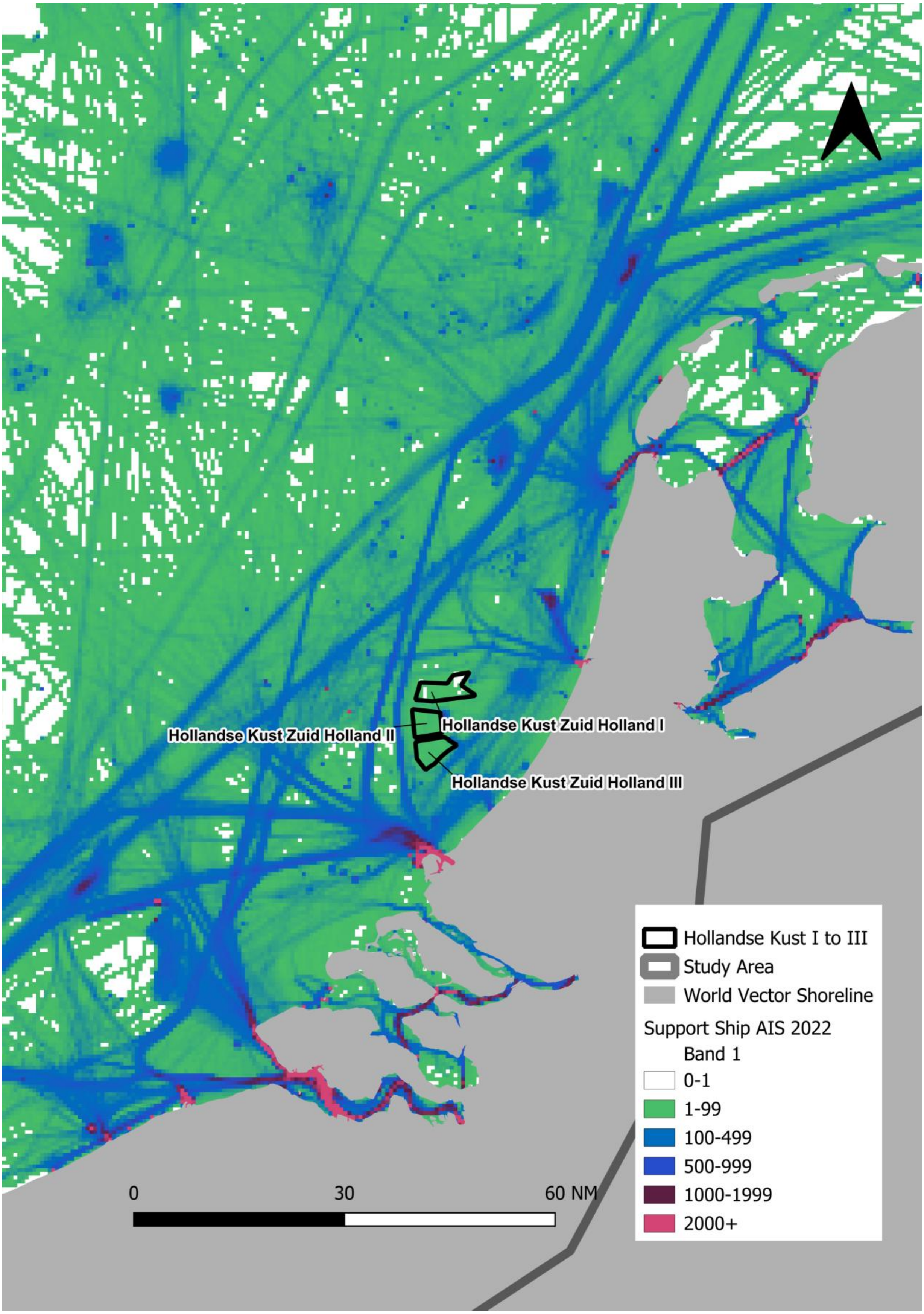

Figure 46: GIS image of Forecasted Support Ship Traffic Volumes around Hollandse Kust OWF in 2022

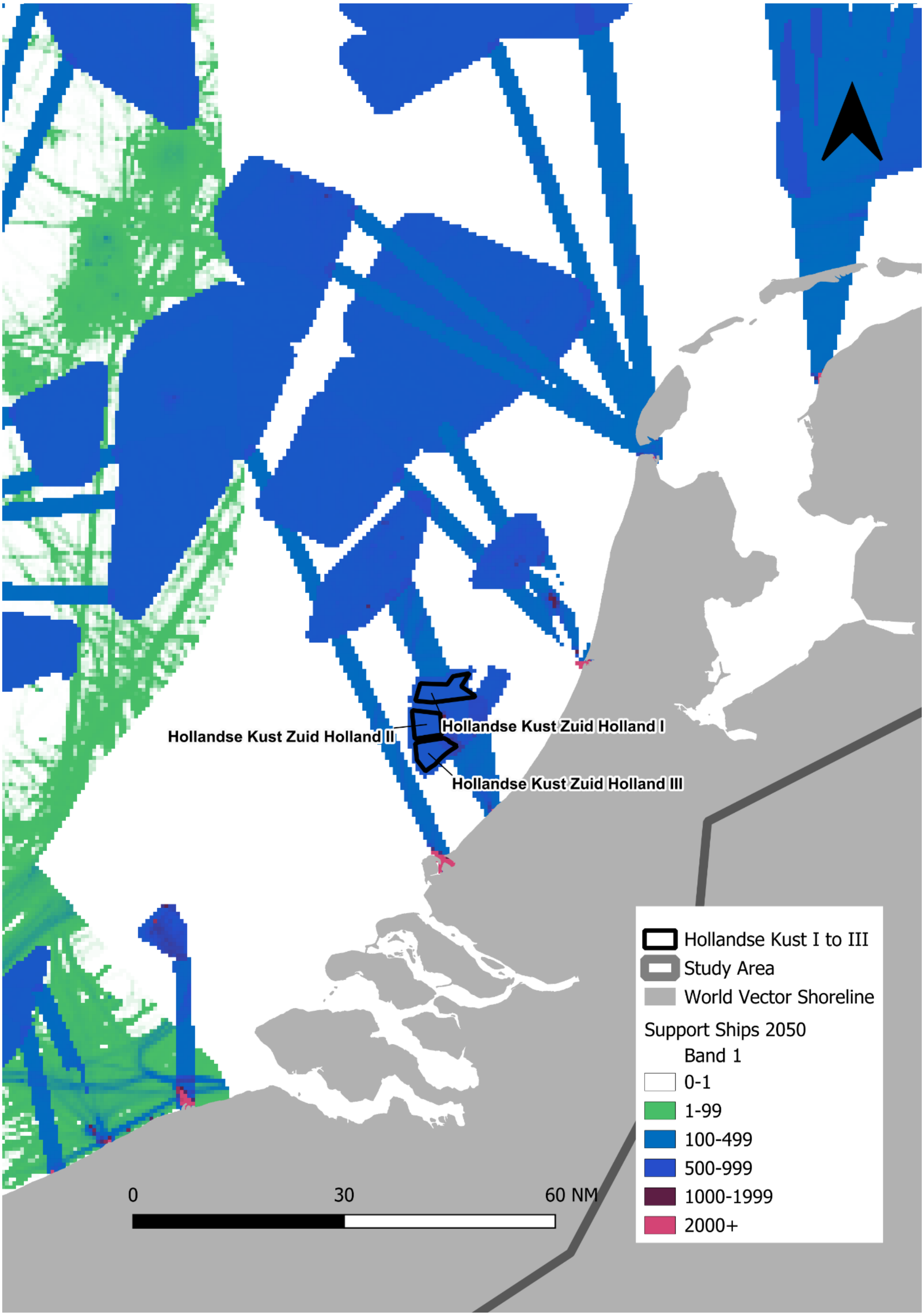

Figure 47: GIS image of Forecasted Support Ship Traffic Volumes around Hollandse Kust OWF in 2050

4.3.3 Saint Brieuc

Figure 48 shows the AIS tracks from 2022 around the OWF site of Saint Brieuc in France. This map shows three clear paths of travel around the OWF. This is more distinct than in the other maps showing AIS tracks (Figure 37 and Figure 42). These point in the direction of the four closest ports, Paimpol, Le Legue, and Saint Malo in France (to the east, south and west, respectively), and St Helier in Jersey (to the northeast). This traffic is made up of support, pleasure, fishing, and some passenger vessels. There is also a high spot of fishing traffic to the southwest of the OWF site, which does overlap with the windfarm extent.

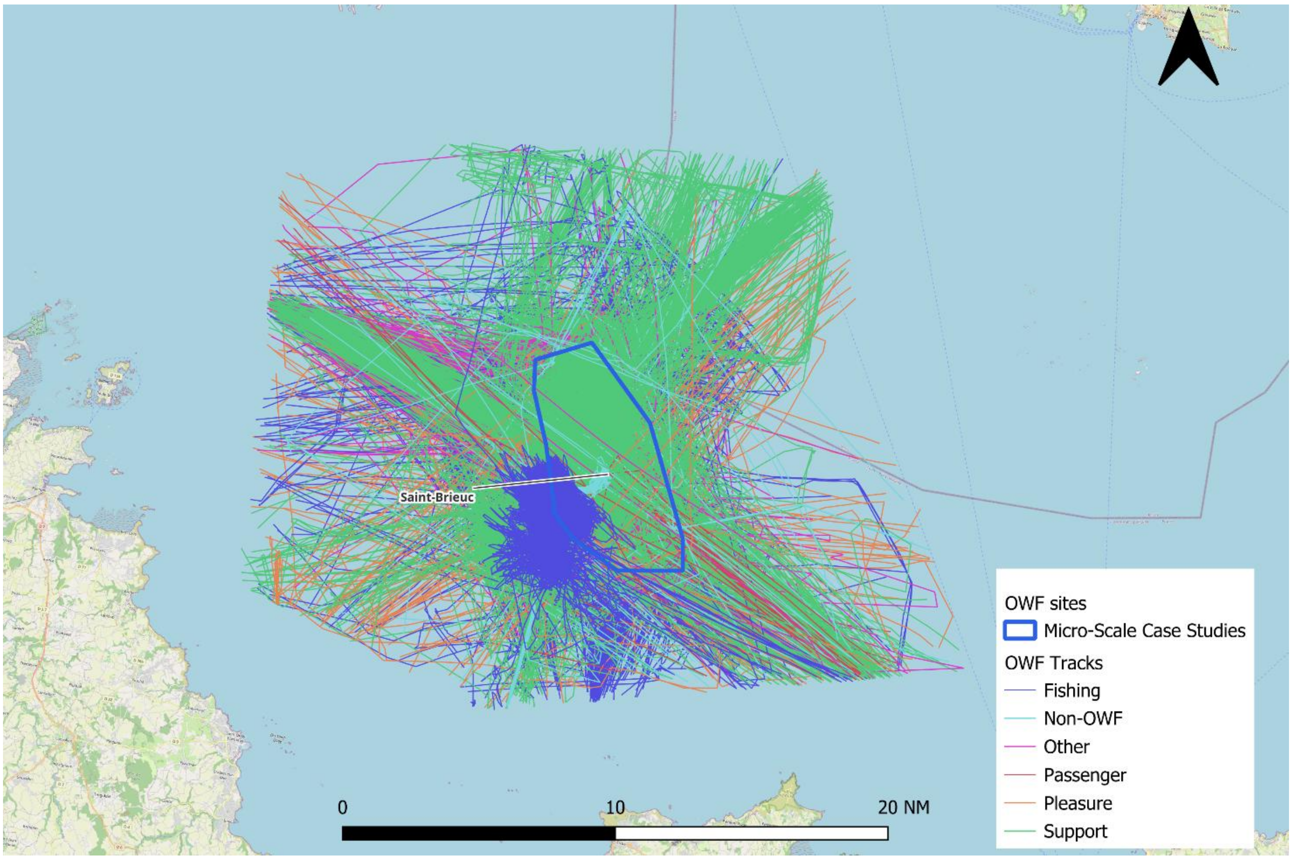

Figure 48: Saint Brieuc AIS Tracks

Figure 49 shows the traffic per month by vessel class for the Saint Brieuc OWF. Here, there is an increased level of fishing traffic from January to June and increased support vessel traffic from July to October, which is consistent with the other OWF sites. There is very little non-OWF, other, or passenger vessel traffic in this area.

The volumes of pleasure boat traffic are much higher than the Nordsee or Hollandse Kust OWFs, especially in June and July. This is due to the location of Saint Brieuc; it is in the bay around Gurnsey and Jersey on the French coast. Due to this location, a greater number of pleasure craft can be expected as these are major holiday destinations with over 100 boat hire locations in the bay area (Google Maps, 2025).

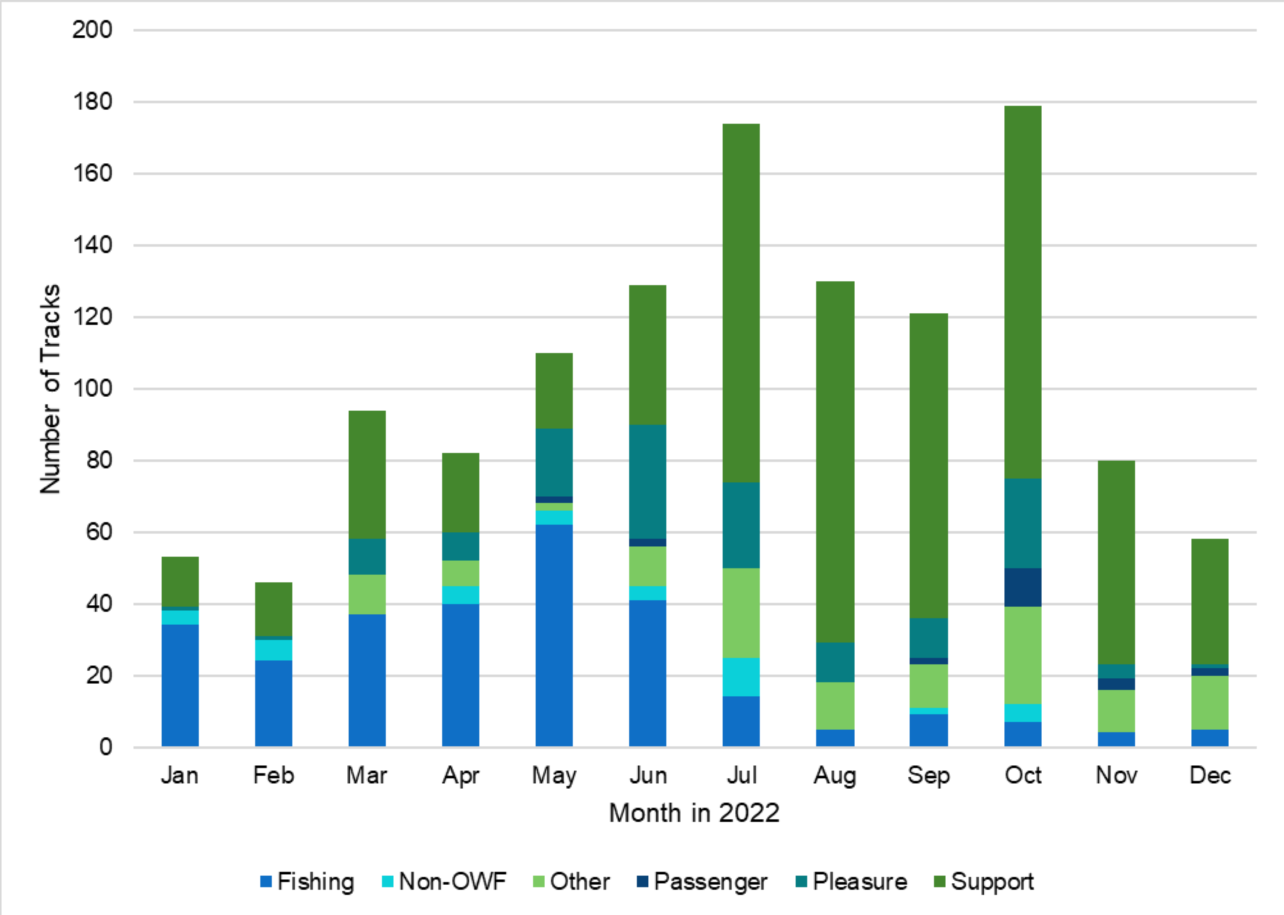

Figure 49: Saint Brieuc Traffic by Month

The density of Support vessels in the vicinity of the Saint Brieuc OWF are shown for future epochs 2022 and 2050, in Figure 50 and Figure 51 respectively. The densities have been inferred from present-day vessel movements and adjusted for the anticipated lifecycle of the OWF. The plots show clearly how the movements of vessels supporting the OWF are not bounded by the perimeter of the development, and that the movements of support vessels between the shore and the OWF will be at a density that is significant compared to background vessel movement activities.

Figure 50 shows the forecasted support traffic in 2022 around the OWF site Saint Brieuc. This shows a similar pattern as seen in the AIS tracks, Figure 48, with the clear paths of travel to the closest ports. As the highest density of traffic for support vessels to the Saint Brieuc OWF was to/from Le Legue, this was assumed to be the service port. Figure 51 shows a predicted decrease in surrounding service traffic, attributed to the reduction in oil and gas activity. .

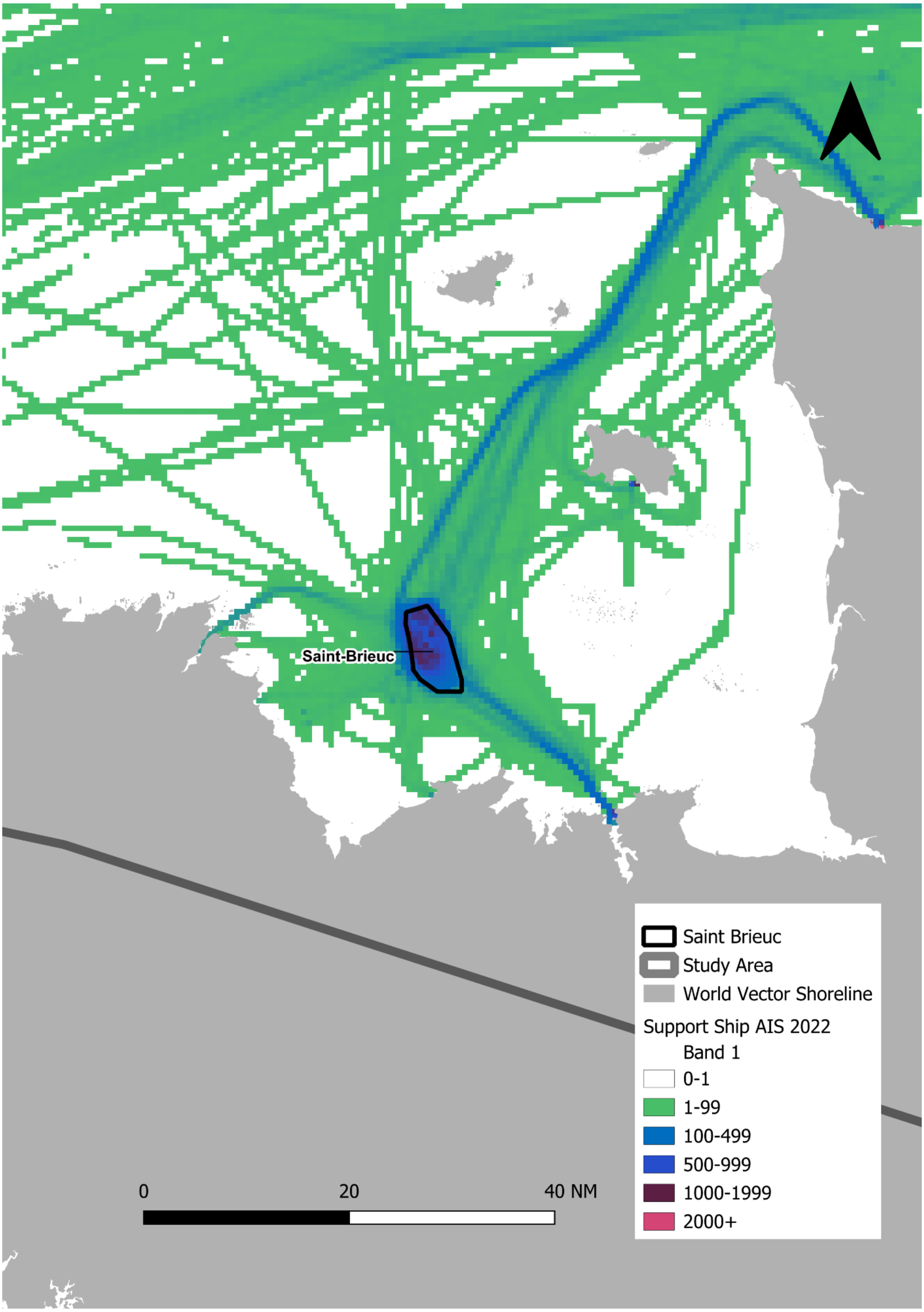

Figure 50: GIS image of Forecasted Support Ship Traffic Volumes around Saint Brieuc OWF in 2022

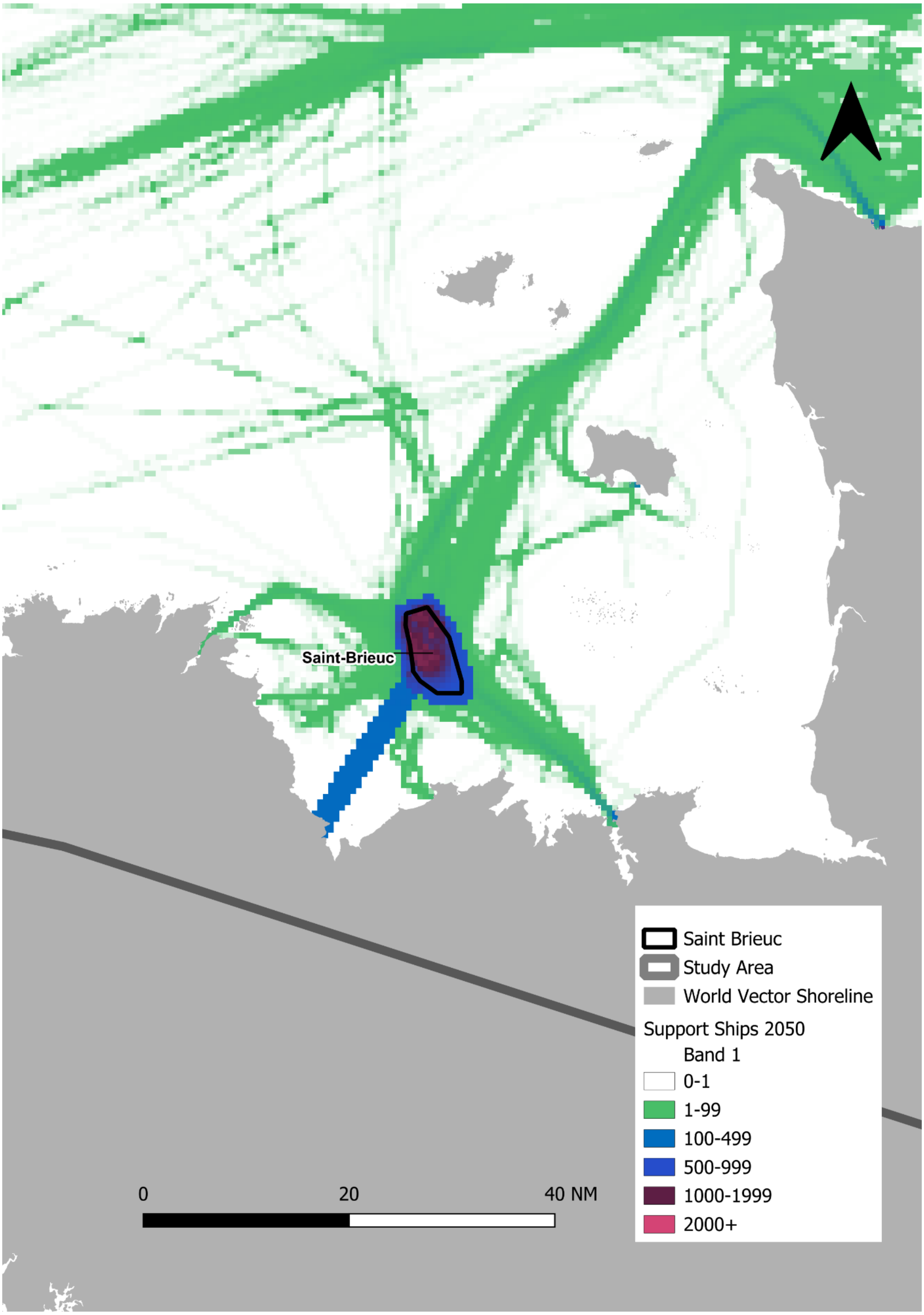

Figure 51: GIS image of Forecasted Support Ship Traffic Volumes around Saint Brieuc OWF in 2050

5.0 CONCLUSION

The future of shipping activity in the North Sea is being shaped by a complex mix of economic, environmental, technological, and regulatory factors. Through analysis of baseline data from 2022 and forecasts extending to 2050, this study explores the predicted changes in patterns of maritime traffic, with a particular focus on areas surrounding OWFs. While support traffic is the majority vessel class type in these areas, especially during the summer, variations in traffic volumes and class distribution suggest the need for localised assessments in marine spatial planning. The findings from micro-scale case studies underscore the importance of considering site-specific traffic dynamics, as shipping activity can significantly vary even in comparable conditions. As the North Sea continues to transform, strategic policy development must integrate these insights to ensure sustainable and efficient maritime operations.

With the rapid expansion of offshore wind farms in the North Sea, especially for those developed in clusters or in proximity, new navigational challenges are emerging. These clustered developments can create corridors, as vessels that would traditionally transit through these areas can be diverted around them, due to their own navigational safety considerations or implemented risk mitigation measures. This redirection would concentrate maritime traffic into narrower routes, increasing the density of vessel movements. Consequently, the risk of allisions and collisions within these corridors could increase. This risk is especially pronounced during adverse weather conditions, such as those in the North Sea during winter. While most shipping classes are forecasted to decline by 2050, OWF support traffic is expected to increase with the development of the OWF sites. As the North Sea becomes increasingly crowded with wind farms, minimising unnecessary traffic could alleviate some risk. This could be particularly true for OWF support vessels, which often do not follow the established shipping lanes visible in AIS data, as they cross open waters to reach their sites. Research into O&M strategies that reduce daily back-and-forth travel between ports and OWFs could reduce this risk. For example, the DanTysk OWF includes an offshore accommodation platform allowing engineers to stay on-site while conducting maintenance across multiple turbines (Ghobadi, 2016). A review of how this model is functioning, its impact on maritime traffic, and its potential applicability to other OWF sites could be a valuable step toward safer and more efficient OWF support.

The micro-scale case studies in this report reveal that shipping activity can vary significantly even under similar conditions, underscoring the importance of site-specific analysis. As the North Sea becomes increasingly populated with windfarms, coordinated planning between government bodies and windfarm developers will be essential. This collaboration would help to coordinate the management of the cumulative navigational risks of OWF in proximity. It would also allow for stakeholders to take advantage of operational efficiencies, for example, through shared trips by operations and maintenance vessels.

Ultimately, strategic policy must reflect these insights to ensure that maritime operations remain safe, sustainable, and efficient in a rapidly changing seascape.

This report provides a foundational assessment of how OWF development may influence future shipping traffic patterns. While the focus has been on planned expansion trajectories, we acknowledge that alternative scenarios, such as exclusive decommissioning, direct reuse with increased vessel activity, or a slowdown in OWF development due to political or economic factors, could significantly alter outcomes. These scenarios are not explored in detail here, as they fall outside the scope of this study and would require additional modelling and assumptions. Nonetheless, they represent important avenues for future research and strategic planning.

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APPENDIX A: EXCLUSION OF ABERDEEN (EOWDC) AND TEESSIDE OWFS

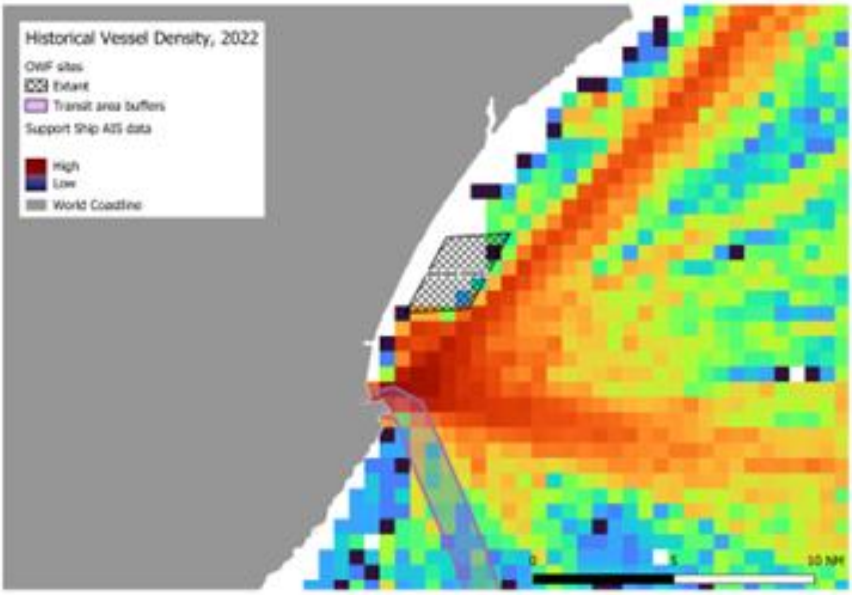

Figure 52: Support Ship AIS around Aberdeen (EOWFC) OWF

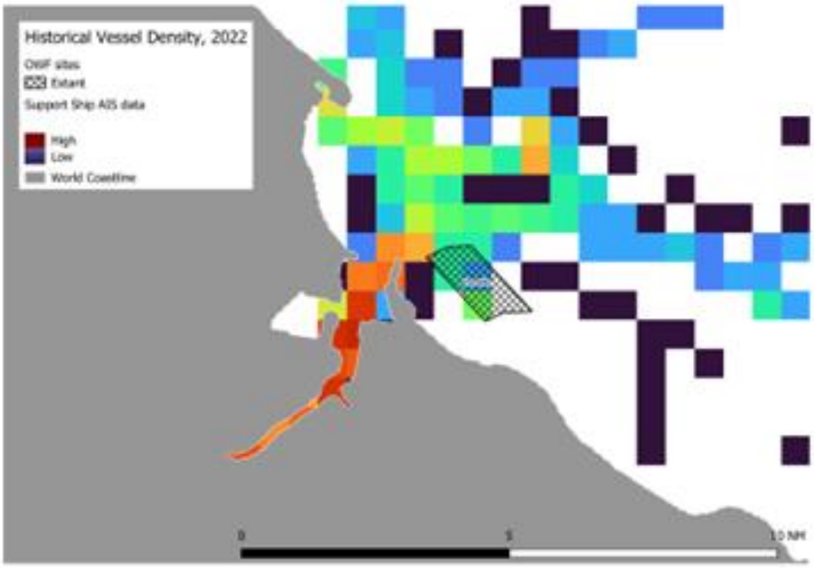

Figure 53: Support Ship AIS around Teesside OWF

Aberdeen (EOWDC) and Teesside OWFs have been excluded from the analysis described and presented in this report. As seen in the Figures, the OWFs are very small, 20 km^2 and 4.3km^2, respectively. They are also both close to the coast, 1100m and 850m respectively. Additionally, the AIS data is sourced from EMSA after the UK left the EU, thus the data from close to the UK coast may not have the same coverage or quality as other parts of the North Sea Basin (EMSA, 2025) (Gov.uk, 2023). This is because it is unlikely to have been relayed to other terrestrial base stations in Europe unless the UK made that extra effort. Due to these three reasons, there is no identifiable vessel tracks going to/from the two OWFs identified. Hence, they cannot be included in this analysis.

APPENDIX B: EXCLUSION OF PLEASURE BOATS

There are no adjustment factors applied to the pleasure boat data as there was no reliable forecast of traffic volume changes in pleasure boats. Further analysis on pleasure boat traffic was conducted by using the number of yachts built per year as a proxy for pleasure boat traffic volumes. As yachts are a large proportion of pleasure boat traffic, it is assumed that the more yachts built will directly correlate to the traffic volumes of pleasure boats.

Figure 54 shows that while there is variation in yachts built each year, there is no overall trend since 2000. The volume of pleasure boats can be more closely tied to other socio-economic factors, such as the peak in 2001 caused by the strong global expansion and dot com bubble leading to more people having the disposable income for yachts, and the decline in 2020 due to COVID-19 and the limitations on production and sales. The small numbers of yachts built in 2024 is most likely due to a lag in reporting of yachts being built.

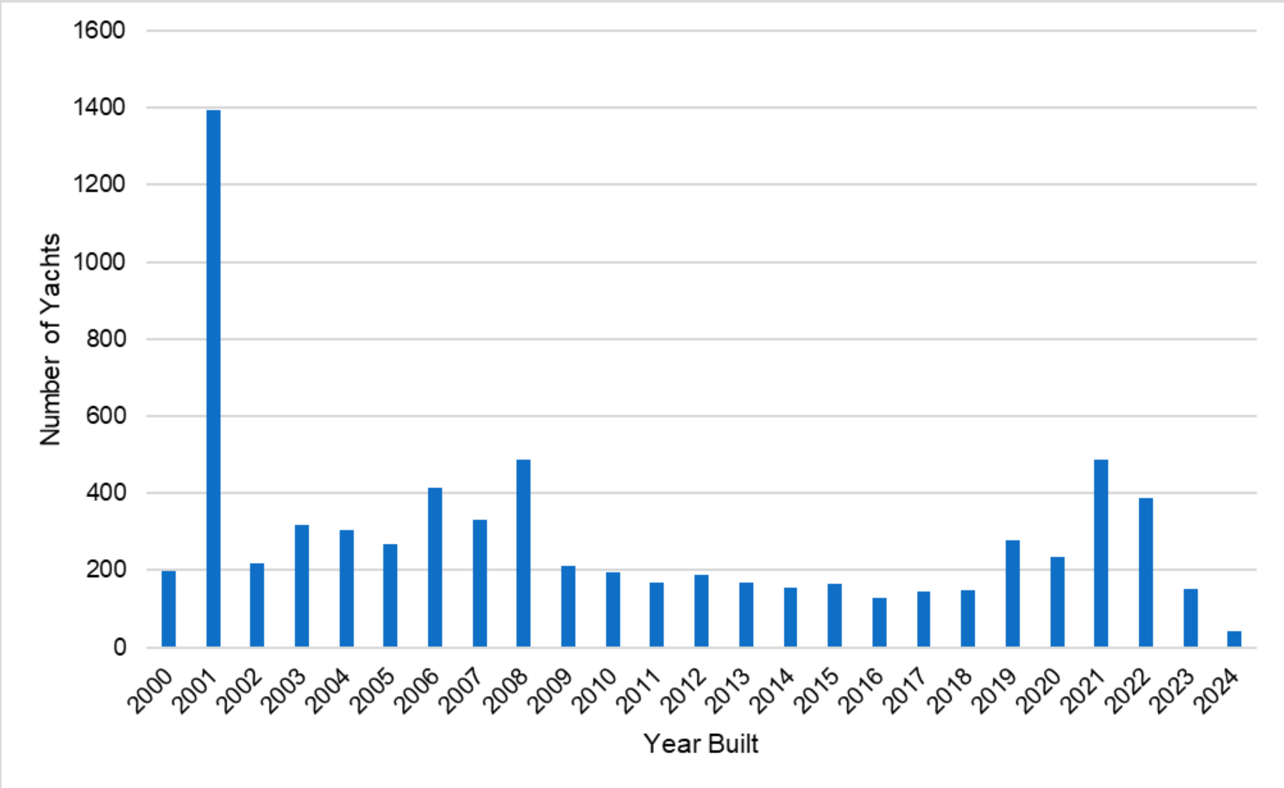

Figure 54: Graph of Number of Yachts Built per Year (Data from seasearcher.com)

APPENDIX C: CLAIMS, ARGUMENTS, AND EVIDENCE (CAE) FRAMEWORK

NB: Blue shading indicates that statement is supported by evidence in Appendix D: CAE Framework References

This Claims, Arguments, and Evidence Framework details all the assumptions and arguments used in the research behind the forecasting of the shipping data for the analysis in this study. The claims, arguments, and evidence are colour coded Red, Amber, and Green (RAG) on the confidence of the claim, argument, or evidence, with green being the highest confidence. This is based on the quality of the sources/refences. These references are linked in the final column, found in the Appendix D: CAE Framework References.

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
1	General Merchant Shipping Traffic					
	1.1	With some fluctuations, general commercial shipping activity within the OSPAR II area, on a per ship basis, will remain roughly constant at 2022 levels, or reduce slightly, through 2050.			Amber	83
		1.1.1	The demand for shipping in the study area will remain approximately constant or decrease, at 2022 levels, through 2050.		Green	
			1.1.1.1	Economic growth in European countries is projected to remain modest through 2050 (~1-1.5% per annum average).	Green	85
			1.1.1.2	What growth there is, is likely to result from less materially intensive parts of these economies (i.e. to be service sector/ technology led), and therefore not entail substantial new material demand.	Green	86
			1.1.1.3	There is little evidence that European material exports will increase substantially through 2050. The total EU flow of goods has been approximately constant for past 10 years.	Green	5
			1.1.1.4	The population of Europe is projected to peak in 2026 and then slowly decline.	Green	87
			1.1.1.5	The population of Europe is projected to age through 2050; this is associated with reduced material demand per capita.	Green	87
		1.1.2	The volume of cargo carried per vessel movement (trip) is projected to remain constant, or to increase through 2050, placing downwards pressure on the number of vessel movements for a given volume of cargo.		Green	
			1.1.2.1	Bulk carrier sizes are projected to increase by 10% through 2050.	Amber	83
			1.1.2.2	Container vessel sizes are projected to increase by 30% through 2050.	Amber	83, 104

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
			1.1.2.3	Gas carrier sizes are projected to increase by 40% through 2050.		83, 104
			1.1.2.4	Other vessel sizes projected to remain approximately constant.		104
			1.1.2.5	V/l utilisation is expected to improve by 25% for deep sea trades other than bulk, 5% for bulk, and 20% for short-sea trades. 50% of these values applied for this study, to balance slow steaming effects (1.1.3).		83
			1.1.2.6	Some uncertainty regarding increases in vessels sizes resulting from changing geopolitical context (lower Western reliance on China leads to preference for smaller vessels/ increased flexibility).		121
		1.1.3	Slow steaming will put some upwards pressure on number of vessels required to service a given volume of cargo, but effect expected to be limited, as extra capacity requirement compensated for by improved efficiency.			
			1.1.3.1	Slow steaming requires sufficient spare capacity in the merchant fleet to meet demand the demand for transport at reduced speeds. It therefore becomes more of a factor where this spare capacity exists.		14
			1.1.3.2	Significant (up to ~15%) reductions in speed are expected to be obtainable without additional shipping capacity through improved logistics efficiency (e.g. reducing 'steam fast, then wait' practices)		88
			1.1.3.3	Incentives to steam slowly increase as the price of bunker fuels increases. The EU Emissions Trading Scheme can be expected to increase bunker fuel prices through 2050, so incentivising slow steaming.		14
			1.1.3.4	Slow steaming is expected to be an economical practice (i.e. there will be economic incentives to adopt the practice), where capacity allows.		11
			1.1.3.5	Slower steaming is expected to be an important mechanism through which GHG reduction targets are met. Almost all new ships are delivered with reduced power ratings/ older ships often de-rated.		88
			1.1.3.6	Effects of slow steaming in container segment expected to be of the order of 10% of capacity in container fleet.		90

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
			1.1.3.7	Current power reduction regulations work more in capping speeds than in reducing typical operating speeds, so effect on ship numbers not expected to be pronounced as average speeds not so affected.		89
		1.1.4	Proliferation of windfarms will disrupt traffic, resulting in increased shipping travel distances within the OSPAR II area and associated upwards pressure on the number of vessels required to service a given cargo volume, but this effect is not expected to outweigh the effect at 1.1.2.			
			1.1.4.1	Under UNCLOS, windfarms (offshore infrastructure) are required to be placed so as not to unduly inconvenience shipping. This is largely the case, with 'sea lines of communication' recognised in MSPs.		91
			1.1.4.2	The anticipated disruption could extend journey lengths by up to 3.5 nautical miles, though in most cases the impact is expected to be significantly less. This level of disruption is proportionally more impactful for short-sea shipping routes.		92
			1.1.4.3	There are various initiatives in place (e.g. MOSES) that - in seeking to improve the efficiency of short sea shipping - can be expected to have a countervailing effect to longer journey distances.		93
	1.2	Use of the Northern Sea Route will increase, through 2050, but pace of expansion limited by geo-political and economic considerations. At the baseline, significant, but not exponential increase in use expected through 2050 (i.e. ~x2, but not ~x8).				
		1.2.1	Ice coverage of the NSR is projected to reduce substantially by 2050 (both spatial extent and duration), however there remains uncertainty regarding the exact rate and extent of change and effects on navigability.			9
		1.2.2	It seems unlikely that the critical mass of NSR use required for exponential increases in traffic will be achieved.			9
			1.2.2.1	Extended use of the NSR requires specially constructed vessels, which are not in abundant supply, are expensive to procure and western-aligned states are not supplying (i.e. ice-class vessels/ icebreakers).		10
			1.2.2.2	The current geopolitical situation will reduce participation in the NSR by some actors into the medium term.		9, 10
			1.2.2.3	Fear of environmental incidents also reduces participation.		6, 13
			1.2.2.4	The economic case for the NSR is not yet made for many transport segments (e.g. container shipping).		10

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
		1.2.3	The North Sea Route is administered by Russia.			12
		1.2.4	Russian, Chinese, and other non-Western-aligned uses of route may increase, however significance for study area may be limited. Effect mainly on routes from Russian Baltic.			10, 17
			1.2.4.1	From a policy perspective, Russia is promoting use of the NSR.		10
			1.2.4.2	Current shipping transits are predominantly between Russian ports, or between Russia/Russian Baltic and China.		17
		1.2.5	Even if relations between Russia and Europe/ the West improve, it will take some time for the organisational and technological infrastructure for western-aligned participation in NSR to materialise (anticipate up to 10 years).			10
	1.3	Projections of change in the composition of the world fleet are mixed. We can anticipate a reduction in oil-carrying activity and increase in gas-carrying activity. Some oil-carrying may be replaced by other tanker activity (e.g. carbon, future fuels).				
		1.3.1	IMO projections for vessel activity by category are mixed, although generally trend upwards at the global level.			7, 83
		1.3.2	It is generally expected that European demand for oil will fall significantly through 2050, and gas will rise.			4
			1.3.2.1	European demand for oil is expected to fall substantially through 2050. DNV annual adjustment factors to be used for carriage of energy-related goods (oil and gas), but not dry goods, for reasons at 1.1 (i.e. assessed that general demand for shipping will not increase).		83
		1.3.3	There is some potential for cross-over in liquid and gas tanker cargoes, however this may not be economical in all cases. DNV factors are conservative for Europe and can therefore be seen as including some vessel repurposing.			21, 122
		1.3.4	Change in container and gas carrier segments expected to occur soonest.			2, 122
2	Environment					
	2.1	As a result of legislative updates and revised guidelines regarding underwater noise impacts on sensitive receptors such as marine mammals, there will be some change in vessel movements around designated sites which have marine mammals as features. Vessels may choose to route around these sites to adhere to guidelines.				

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
		2.1.1	The European Commission have adopted recommendations on maximum acceptable levels for continuous underwater noise (e.g. shipping). This is intended to protect species vulnerable to underwater noise, notably marine mammals and some fish species.			29
			2.1.1.1	The European Commission have developed thresholds under the Marine Strategy Framework Directive (MSFD). To be in tolerable status, no more than 20% of a given marine area can be exposed to continuous underwater noise over a year.		29
			2.1.1.2	In July 2023, the Marine Environmental Protection Committee (MEPC) of the International Maritime Organisation (IMO) issued the revised, non-mandatory guidelines for the reduction of underwater radiated noise from shipping.		28
			2.1.1.3	OSPAR have issued a "Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2030. Objective S8.O1 states: *By 2025 OSPAR will agree a regional action plan setting out a series of national and collective actions and, as appropriate, OSPAR measures to reduce noise pollution*. In the 2023 OSPAR Underwater Noise Thematic Assessment it is stated that this regional plan will include implementing options for reducing adverse impacts of underwater noise on MPAs, with particular focus on those with designated features that are sensitive to underwater noise.		30, 31
		2.1.2	Countries within the OSPAR II region have committed to reduce underwater noise via updated marine strategies.			
			2.1.2.1	Germany is committed to reducing underwater noise via the Round Table on Underwater Noise that is organised by BSH		34
			2.1.2.2	The Netherlands commits to implementing and improving the IMO guidelines in its North Sea Programme 2022-2027		94
			2.1.2.3	Denmark via Danish Shipping support the adoption of the IMO guidelines. It is noted that the guidelines are currently voluntary but recognise that there may be further developments in regulations and guidelines by the IMO to address underwater noise.		33
		2.1.3	In the short term, the easiest mechanism to reduce underwater shipping noise in important areas for marine mammals is to either reduce speed or re-route around designated sites that have marine mammals as a protected feature.			

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
			2.1.3.1	The 2023 IMO guidelines state: *It is recommended to measure and understand the ship's Cavitation Inception Speed (CIS) and then operate below CIS in national and international designated protected areas when practicable.*		28
			2.1.3.2	The 2023 IMO guidelines describe the following measure: *Ships routing measures to avoid national and international designated protected areas including well-known habitats or migratory pathways.*		28
		2.1.4	There is increased emphasis on protection for marine mammals and other noise sensitive receptors within the North Sea.			
			2.1.4.1	In early 2024 33 new Important Marine Mammal Areas (IMMAs) were approved in the Northeast Atlantic Ocean and Baltic Sea		26
			2.1.4.2	The OSPAR Thematic Assessment of Underwater Noise 2023 states that risk assessments will be conducted for species and habitats beyond harbour porpoise.		31
			2.1.4.3	The Interreg Joint Monitoring Programme for Ambient Noise North Sea (JOMOPANS) seeks to monitor underwater noise in the North Sea to enable managers, planners and stakeholders to identify where noise impacts may adversely affect receptors in this region.		32
		2.1.5	Data is still being gathered on uptake of IMO guidelines, best practices, and lessons learned.			
			2.1.5.1	The IMO has approved an experience-building phase (EBP), which commenced in July 2023 to collect information on best practices and lessons learned following the implementation of the revised guidelines. The EBP will last for 3 years, with possibility of extension by a further 2 years.		28
			2.1.5.2	BIMCO alongside other shipping associations have launched a survey to log vessels that have adopted the IMO guidelines. At the time of writing this survey is still live.		37
		2.1.6	It is estimated that 10% of vessels will re-route to avoid designated sites with marine mammal as features.			
			2.1.6.1	Uptake of the IMO guidelines on underwater noise issued in 2014 is described as "low", although no quantification is available.		37
			2.1.6.2	The revised IMO guidelines on underwater noise issued in 2023 are currently non-mandatory.		28

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
	2.2	Avoidance of designated sites with marine mammals as protected features is likely to decrease from 2035 onwards.				
		2.2.1	New ships will incorporate updated technologies that will result in lower underwater noise emissions therefore resulting in vessels being able to transit through designated sites without emitting high levels of noise.			28
			2.2.1.1	The 2023 revised IMO guidelines provide information on design and build measures for new vessels to reduce underwater noise emissions.		28
			2.2.1.2	The global maritime industry is working on new solutions for reducing underwater noise through the SATURN (Developing Solutions for Underwater Radiated Noise) project.		36
	2.3	Marine traffic within other designated sites (those without marine mammals listed as features) will remain approximately constant at 2022 levels.				
		2.3.1	No evidence of current or future vessel movement restrictions have been identified within designated sites in the OSPAR II region. This is excluding fisheries restrictions, which are addressed in Section 5.			25
3	Climate Change					
	3.1	Climate change stimuli occur in the North Sea and will intensify as we approach 2050; changing offshore and nearshore conditions and inducing/increasing various metocean risks for maritime operations				
		3.1.1	Average regimes in waves and wind are not expected to change significantly in the North Sea, hence no major changes in day-to-day weather windows are foreseen through 2050.			
			3.1.1.1	According to a review of recent publications about the impact of climate change on wind, the long-term wind distribution is not expected to change significantly in the North Sea region through 2050.		69
			3.1.1.2	A review of several studies and projections revealed a consensus that the intensity of waves will increase along the East Coast of the North Sea.		69
			3.1.1.3	The conclusion is not unanimous, and De Winter et al. (2012) propose that no increase in mean wave height, annual max conditions, or reduction in return periods for extreme wave events would occur.		69

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
			3.1.1.4	Shifting seasonality of our climate in the context of climate change has an impact on waves. A recent study for the North Atlantic seasonal regimes indicates that winter conditions of waves are weakening (starting later and ending earlier) while summer conditions are increasing (starting earlier and ending later).		69, 81
		3.1.2	There is some evidence of changes in hail phenomena resulting from climate change.			
			3.1.2.1	There is limited information about past and future changes in hail occurrence in Europe.		126, 80
			3.1.2.2	However, there is an observed increasing trend in hail occurrence in Germany. An increase of hailstones diameter is observed which can damage maritime infrastructure.		126, 80
		3.1.3	Reduced visibility may result from more intense/frequent rainfall (no strong trend linked to fog identified). This may induce delays in berthing and cargo handling operations.			
			3.1.3.1	High confidence of 10% increase for the total precipitation quantity over the North Sea during winter (Dec to Feb) under business-as-usual scenario (SSP2-4.5). No strong agreement for the summer period.		69, 82
			3.1.3.2	High confidence that the intensity of rainfalls will increase with the increasing air and sea surface temperature.		69, 82
			3.1.3.3	An 8-12% decrease in visibility in the Arctic and 0-5% in the North Atlantic is predicted over the 21st century under the RCP4.5.		72
		3.1.4	Extreme weather events more frequent and severe will affect more frequently offshore and nearshore activities onwards 2050			
			3.1.4.1	Under the high emission scenario (SSP5-8.5), up to a 5% increase in 99th percentile winds in winter and 5% decrease in summer are projected. There is a large degree of scatter across most of the literature for the changes in Europe, but it can be concluded that strong winds are not likely to change significantly whereas extreme winds may increase in frequency and intensity. Extreme wind could increase by as much as 10% above present days extremes. This can affect berthing and cargo handling.		69

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
			3.1.4.2	More intense and frequent extreme sea level events will increase expected annual flood damages by 2-3 orders of magnitude by 2100 (high confidence) due to changes in surge events (little statistically significant evidence or minor trends) and local sea level rise (main factor).		76
			3.1.4.3	Extreme temperatures and heatwave intensity and frequency are expected to increase due to climate change over the whole of Northern Europe. Working days for crew and machinery may be impacted.		66
			3.1.4.4	Current 99th percentile wave heights are projected to occur an estimated 5-8% of the time by the end of the 21st century.		69
			3.1.4.5	The latest Copernicus Ocean State Report (OSR8) for European seas shows that the tallest 5 % of global ocean waves have grown much higher in recent years.		70
		3.1.5	There is some limited evidence that climate change may induce changes in lightning events.			
			3.1.5.1	According to the literature, there is no clear trend on the changes in lightning occurrence due to climate change.		79,80
			3.1.5.2	Working group I of IPCC AR6 (2021) the most up-to-date physical understanding of the climate system and climate change, does not mention any changes on the frequency of such events.		66
			3.1.5.3	However, older IPCC AR4 reports (2007) mentioned an expected increase in frequency of lightning events with the predicted rise in the frequency and intensity of thunderstorms, hurricanes, and tornadoes.		79
		3.1.6	Air temperatures in the North Sea are projected to increase.			
			3.1.6.1	Air temperature is increasing in the North Sea. Since 1850-1900, the average increase in mean surface air temperature is around 2.2°C for Europe (3°C for the Arctic).		77
		3.1.7	Sea temperatures in the North Sea are expected to increase.			
			3.1.7.1	Marine heatwaves are also projected to increase in frequency, duration, spatial extent and maximum intensity. Such changes could have widespread effects on marine species and cause the reconfiguration of marine ecosystems.		76

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
			3.1.7.2	Areas of this region suffering marine heatwaves in any given year grew from around 20% to over 90 % between 1982 and 2023.		70
			3.1.7.3	Since 1980, there has been an increase in sea surface temperature of about 1.1°C in Europe.		77
			3.1.7.4	Sea surface temperatures in the North Sea are projected to increase by 1.0°C (–0.7 to 1.8°C) and 2.4°C (1.2 to 4.6°C) for the North Sea by 2100 for the ensemble medians under SSP1-2.6 and SSP5-8.5, respectively.		76
		3.1.8	To the extent that sea ice is a relevant factor in the North Sea, this is expected to reduce.			
			3.1.8.1	Raising air and sea temperature reduced sea ice formation, growth, and persistence throughout the year.		68
			3.1.8.2	Since 1979, 4% of the mean annual sea ice is lost in the arctic per decade.		68
			3.1.8.3	Declining sea ice extent and thickness allows ice drift speeds to increase which may result in a greater number of ice hazards drifting at higher speeds for maritime traffic or port operations.		68
			3.1.8.4	However, sea ice is rare in the North Sea due to warming from Gulf Stream (whereas the Baltic Sea is partly frozen every year).		69
			3.1.8.5	There is a decrease in the number of frost and icing days for the North Sea region and cold weather events are expected to be shorter.		70
		3.1.9	Mean sea levels are expected to increase through 2050.			
			3.1.9.1	Global mean sea level (GMSL) is rising (virtually certain) and accelerating (high confidence).		68, 70
			3.1.9.2	The sum of glacier and ice sheet contributions is now the dominant source of GMSL rise (very high confidence).		68, 70
			3.1.9.3	Sea level rise is not globally uniform and varies regionally (thermal expansion, ocean dynamics, and land ice loss).		68, 76
			3.1.9.4	In the Northwest Shelf of Europe, the average sea level rise per year is about 2 to 4mm, between 1993 and 2022. This rate has been increasing in the last 10 years and will keep increasing onwards 2050		70

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
			3.1.9.5	Total sea level rise in the North Sea is projected to reach the following levels in 2100, relatively to the 1995-2014 baseline: -0.63m under SSP2-4.5 scenario (intermediate) -0.83m under SSP5-8.5 scenario (very high emission scenario)		76
	3.2	Climate change is expected to have a broadly adverse effect on fishing activity.				
		3.2.1	Effects of climate change on sea water temperature and storm conditions can affect the performance of fishing vessels or gears, as well as vessel safety and stability at sea.			69
			3.2.1.1	The winter of 2013/14 was the stormiest in the last 66 years regarding the southern North Sea and this is known to have coincided with major disruption to the fishing industry throughout the region.		69
			3.2.1.2	Surveys and studies in southern England indicate that adverse weather conditions significantly influence fishing operations, with many crews choosing to remain in port to avoid gear loss and increased fuel consumption.		69
		3.2.2	Climate change is expected to have a broadly adverse effect on global marine biomass in the North Sea, although effect will vary by class of fishing activity.			
			3.2.2.1	Projected decreases in global marine animal biomass and fish catch potential could elevate the risk of impacts on income, livelihood and food security of the dependent human communities.		57, 59
			3.2.2.2	There is little evidence of significant changes in catchability of demersal trawl gears in the North Sea because of climate change or poor weather conditions.		58
			3.2.2.3	The global biomass of marine animals, including those that contribute to fisheries, is projected to decrease with a very likely range under RCP2.6 and RCP8.5 of 4.3 ± 2.0% and 15.0 ± 5.9%, respectively, by 2080–2099 relative to 1986–2005.		68
			3.2.2.4	The maximum catch potential is projected to decrease by 3.4% to 6.4% (RCP2.6) and 20.5% to 24.1% (RCP8.5) in the 21st century.		68
	3.3	Climate change will continue to drive changes in relevant regulatory frameworks though 2050.				
		3.3.1	New regulations to protect marine species or regions that are threatened by the effect of climate change.			30

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
			3.3.1.1	Increased pressures on ecosystems can lead to increase environmental regulation. This may add complexity to wind farm permitting (although it is expected that offshore wind farms will be supported for the mitigation of climate change)		30
			3.3.1.2	There is an EU Biodiversity strategy for 2030 to protect nature and reverse the degradation of ecosystems		124
		3.3.2	New regulations to limit GHG emissions are in train			
			3.3.2.1	European fitfor55 package.		14
			3.3.2.2	Reaching carbon neutrality by 2050 will require to regulate fossil fuel usage. Maritime traffic being a hard sector to decarbonize, shipping may be less impacted than other transports		14
			3.3.2.3	Transition fossil fuels towards more sustainable fuels may require adaptation of vessels		14
			3.3.2.4	Cold ironing strategies are being considered/ implemented at may ports.		1, 14
			3.3.2.5	There is consideration of limiting manoeuvres and activities in ports to limit air pollution and GHG emissions		1, 14
	3.4	Shoreside infrastructures are expected to be adversely affected by climate change				
		3.4.1	Sea level rises will cause problems.			
			3.4.1.1	Greater agitation in harbours and ports, meaning increased likelihood of damage to supporting onshore infrastructure or delay in berthing and mooring		4
			3.4.1.2	Coastal erosion damaging coastal infrastructure		4
			3.4.1.3	More frequent floods (storm surge, flood linked to various climate change and weather stimuli such as SLR, extreme wind, high tide, ...) in coastal areas damaging temporary or permanently some infrastructure and way of access to port infrastructure and vessels		4
		3.4.2	Ports and harbours are parts of a complex system. Therefore, a climatic event happening onshore can impact ports.			
			3.4.2.1	Ports are linked to the cities through supply chains. Events such a La Dona in Valencia (2024) can affect the regional supply chain. Ports are considered critical nodes in the global supply chain.		83
			3.4.2.2	Ports essential resources for emergency response for climatic events inland.		4, 74
			3.4.2.3	Adaptation of shoreside infrastructure (quays, wave breakers, ...) is required to make them resilient and robust.		4, 74

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
	3.5	Maintenance of OWF is likely to be adversely affected by climate change				
		3.5.1	Assets will be more frequently damaged/ subject to wear requiring more regular visits and maintenance planning. Access may be complicated.			
			3.5.1.1	Drifting ice damaging the foundation.		6
			3.5.1.2	Frost or ice events damaging the WTG assets and affecting the efficiency of mechanical equipment		6
			3.5.1.3	Extreme wind events damaging blades and complicating access		108
			3.5.1.4	Sea level rise affects design of foundation. So far only climate change stimuli considered into standards for design.		4
			3.5.1.5	Scouring of subsea electrical power cables. Coastal erosion may impact cable landfall.		125
			3.5.1.6	Increased size of hail and number of events can damage blades and structure		126
			3.5.1.7	Increased occurrences of lightning (medium/low confidence) can induce corrosion initiation and loss of WTG control systems.		108, 127
		3.5.2	Conditions to perform maintenance, construction are likely to worsen.			
		3.5.3	WTGs constructed to withstand some level of adverse weather events.			
			3.5.2.1	Sea level rise affects agitation in harbour and vessel access and coastal erosion		4, 74
			3.5.2.2	Coastal erosion induced by sea level rise and extreme water level events can damage coastal infrastructures supporting offshore wind farms		74
			3.5.2.3	Weather windows for the use of cranes may be less frequent		44
			3.5.2.4	Flood risk can affect supply chain (onshore/offshore), harbours, way of access, logistic hubs for construction or maintenance		4
			3.5.2.5	Changes in precipitation patterns, estuaries water levels and hydro-sedimentary regime: affect bathymetry of harbour and vessel access		128
	3.6	International routes are affected by climate change, with potential knock-on effects for North Sea shipping activity.				
		3.6.1	Suez and Panama canals (global international routes) are impacted by climate change			
			3.6.1.1	Panama Canal is facing record breaking droughts which are directly impacting its operations and transit of vessels through the canal. Panama Canal it is 12.000 commercial vessel / year and 65k$ to go through the canal.		73

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
			3.6.1.2	Over the course of the year in 2023, administrators cut the number of daily canal transits by nearly half (from around thirty-eight to twenty-two vessel per day).		73
			3.6.1.3	These droughts are directly linked to climate change and El Niño climate processes.		73
			3.6.1.4	Panama Canal authority is now considering the droughts in the planning for the booking of vessel traffic.		78
			3.6.1.5	Extreme climatic events in other regions of the world may stress international traffic and so paralysing movement in some key and strategic points like Suez or Panama canals.		108
			3.6.1.6	Egypt's coastline is highly vulnerable to sea level rise and flooding. In addition, the progressive increase in drought and desertification can lead to an increase in sand and dust storms, which would make navigation difficult		115, 116
		3.6.2	There are reasons to believe that Arctic shipping will remain relatively more costly or limited			
			3.6.2.1	Even after melting of permanent ice cap, icebergs will remain common in the Arctic Ocean.		6
			3.6.2.2	Refuelling and supplying will be complex (difficulty to access the coasts of the Arctic Ocean, lack of infrastructures, lack of competition)		13
			3.6.2.3	For the same reason search and rescue mission are costly in this region, driving insurance costs		6
			3.6.2.4	Canada and Russia may charge a fee for traveling along the portions of the Northwest passage and Northern Sea route that cross their territorial waters		9
			3.6.2.5	All positive effects vanish if navigation in the Arctic is more than 2.5 times costly than elsewhere [1].		129
			3.6.2.6	The opening of Arctic routes will pose various environmental, social and cultural impacts to surrounding regions, including risk of maritime accidents and lack of infrastructural support.		67
			3.6.2.7	The benefits and disadvantages of the opening of new routes across the Arctic Ocean are unequally distributed. There is also a high uncertainty related to the results.		13
			3.6.2.8	When looking at 2015 trade flows, it appears that distance reduction is relevant to a small number of countries only. This reflects the fact that most of world trade happens between countries that are relatively close (in 2015, 25% of world trade is conducted by countries less than 2.100km away and 50% by countries less than 6.000km)		65
4	Windfarm Activity					

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
	4.1	Total survey activity is expected to increase in intensity through 2035, before moderating. Per site survey activity, however, is expected to reduce in intensity through 2050.				
		4.1.1	Collaboration and changes in the approach to data acquisition may lead to a reduction in site survey activity			40, 42, 43
			4.1.1.1	Countries within the OSPAR II region have implemented state-led / state-supported surveys for certain offshore wind areas: Germany - Preliminary Investigation of Sites Netherlands - Doordewind offshore wind farm zone UK - Celtic Sea (though outside OSPAR II region, may include North Sea in the future)		40, 42, 43, 123
			4.1.1.2	The multi-client (MC) model (prevalent in O&G) may be adopted for floating offshore wind where licenced blocks of data for vast areas are sold to those with an interest, including offshore wind developers and others.		
		4.1.2	Technology improvements may lead to increased efficiency and / or a reduction in site survey activity			40, 41
			4.2.1	Survey technologies such as Ultra-high resolution 3D seismic surveys may improve surveys such that additional and / or repeat work is not required (i.e. a 'one and done' approach).		40, 41
			4.2.2	Investigations such as site characterisation and UXO may be performed by Autonomous Surface Vessels (ASVs), rather than traditional survey vessels (e.g.: Sulmara).		
			4.2.3	As floating offshore wind technology matures, 'over specification' in surveys will reduce due to the increase in confidence and efforts to optimize / reduce costs.		
	4.2	Construction activity is expected to increase in intensity through 2035 and then moderate through the end of the forecast period. Efficiencies in construction activity are expected to result from improvements in vessels and in operating concepts.				
		4.2.1	Offshore wind construction activity is forecast to continue and grow in the short and medium term against targets.			46, 47, 119
			4.2.1.1	Offshore installation activity is expected to cumulatively increase across the OSPAR II region.		46, 47, 102, 119
			4.2.1.2	The Northern Sea Route may be more utilised owing to an increase in components from capable yards in the Far East.		119
		4.2.2	Industry developments, particularly the scale of projects, continues to influence construction vessels.			
			4.2.2.1	Windfarm components are forecast to continue to get larger. Vessels can carry less components per voyage, therefore requiring more vessels or more transits.		119

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
			4.2.2.2	Ever larger specialist construction vessels are being commissioned.		119
			4.2.2.3	Vessels with the highest day-rates shall be optimised to reduce project costs and dedicated to very specific tasks such as installation, changing the traditional method of transporting components from integration ports.		119
			4.2.2.4	Greater uptake of 'feeder' concepts is expected, increasing the requirement for barges and other transport vessels.		119
			4.2.2.5	Smaller construction vessels are expected to be drawn into performing operations activities, reducing the availability of construction vessels.		102, 119
		4.2.3	Owing to their more sensitive installation condition requirements, the construction of floating windfarms may be more restricted to summer periods and therefore take more seasons to complete.			112, 119
	4.3	In general, the vessel intensity of windfarm operations is projected to reduce over the forecast period. This will be a function of changes in the character of the 'average' windfarm within the study area, increasing vessel sizes and improvements in technology and operating models.				
		4.3.1	Changes in vessels involved in operations are expected but may vary in the extent and intensity depending on the characteristics of the windfarm. Refer to 'buckets'.			
			4.3.1.1	Offshore based' strategies (i.e.: using SOVs) are preferred from sites located further than around 30 nautical miles / 50 km from the shore / O&M port.		104
			4.3.1.2	Shore based' strategies (i.e.: using CTVs) are expected to remain viable for sites located less than around 30 nautical miles / 50 km from shore / O&M port.		104
			4.3.1.3	Outliers to this broad categorisation are likely to be special cases such as demonstrators and / or so called 'stepping stone' projects.		105
		4.3.2	Developments in technology may be highly disruptive to the current state of windfarm operations and maintenance activities.			
			4.3.2.1	Drone (UAV / ASV) technology may considerably reduce the need for vessels for: the transfer of materials, equipment and potentially personnel (particularly for nearshore sites) and for conducting routine surveys etc.		108
			4.3.2.2	Improvements in data collection, transfer and subsequently in AI and Machine Learning has the potential to optimise vessel operations and maintenance activity.		108

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
			4.3.2.3	Tow-to-Port operations for floating windfarms will be replaced with in-situ replacement technologies.		110, 111, 112
			4.3.2.4	Adoption of 'Game changing' technologies such as Self-Hoisting Cranes of balloons (Sky Lifter) may eliminate the need for certain vessels during operations.		111
			4.3.2.5	The adoption of alternative / green fuels for vessels may considerably adjust their operational profiles (e.g. electric vessels charging in-field)		120
		4.3.3	The dimensions of vessels serving offshore windfarms are overall increasing in size, so marginally reducing the number of vessels at each windfarm.			
			4.4.3.1	More flexible 24 PAX CTVs are increasing in popularity relative to 12 PAX CTVs, meaning fewer vessels may be required for crew transfer operations.		103, 104, 105, 120
			4.4.3.2	SOVs are increasing in popularity vs CTVs as windfarms in the OSPAR II area generally become further from shore, reducing the number of vessels and transits.		
			4.4.3.3	The sizes of new build SOVs are larger than those built 5-10 years ago.		120
			4.4.3.4	The popularity of CSOVs (larger still than SOVs) is forecast.		120
			4.4.3.5	The use of daughter craft (small vessels ~6-9 PAX) deployed from SOVs / CSOVs in the field is increasing.		120
			4.4.3.6	The use strategic use of helicopters may offset some vessel requirements.		120
		4.3.4	Changes to approaches / operational philosophies of windfarms may change the intensity of windfarm vessel requirements and require vessels over a longer overall duration.			
			4.3.4.1	Operators responsible for multiple projects are expected to share vessels between them (e.g.: fewer CTVs serving several near shore sites, or a large CSOV serving multiple far from shore sites).		107, 108, 109
			4.3.4.2	Collaboration between operators of different sites may increase vessel sharing and / or the types of vessels used during operations.		
			4.3.4.3	Collaboration between different industries may increase vessel sharing and / or the types of vessels used during operations.		
			4.3.4.4	To achieve longer operational lifetime, a greater amount regular maintenance is expected to be required, increasing the requirement for technician transfers and therefore the number / size of vessels.		

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
			4.3.4.5	The renumeration model of the windfarm is likely to change over time, meaning the intensity of maintenance activity may change when the financing model changes (e.g.: from CfD to wholesale market).		109, 120
		4.3.5	Windfarms will require vessels over a longer overall duration.			
			4.3.5.1	Windfarms are being designed for longer lifetimes of 30 years are increasingly common (also 30+ years and up to 35 years), requiring a longer period of operations than previously seen.		120
	4.4	Subject to uncertainty derived from changes in windfarm project economics and in the legislative environment, there is a trend towards longer windfarm lifespans.				116, 117, 118
		4.4.1	Decommissioning is becoming later in the life of the windfarm			
			4.4.1.1	To become economically viable / more attractive to investors, windfarms being designed for longer lifetimes of 25+ years are increasingly common (also 30 years and up to 35 years), requiring a longer period of operations than previously seen.		120
			4.4.1.2	Earlier projects now closer to planned decommissioning are being considered for life-extension.		120
			4.4.1.3	Windfarms may not be fully decommissioned, rather repowered or replanting may occur, adjusting the decommissioning requirement.		117, 118
		4.4.2	There is uncertainty around requirements (legislative) for decommissioning, precise requirements may change.			116, 117
5	Fishing Vessel Traffic					
	5.1	Fishing activity will decrease within several designated sites within the OSPAR II region from 2025.				
		5.1.1	Restrictions have been implemented within designated sites by various countries that fall within the OSPAR II region.			
			5.1.1.1	In the UK seven MPAs that fall within the OSPAR II region have had a byelaw implemented since March 2024 which restricts the use of bottom trawling within these sites.		130
			5.1.1.2	Four sensitive subzones have been designated the Flemish Banks SAC in the Netherlands. Fishing is only allowed in these subzones fishing using environmentally friendly techniques, or under specific conditions.		27

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
			5.1.1.3	In Belgium the 'Vlaamse Banken' SCI will be further protected in the Belgian MSP, only fishing techniques that do affect the seabed will be allowed there, this includes restrictions to bottom trawling.		27
			5.1.1.4	New regulations introduced in Dec 2022 introduced measures for four German (Sylt Outer Reef, Borkum Reef Ground, Dogger Bank and Eastern German Bight) and two Dutch (Cleaver Bank and Frisian Front) Natura 2000 sites, as well as the Frisian Front and Central Oyster Grounds MPAs. Mobile bottom contacting gears have been banned.		131
	5.2	Fishing activity will reduce further in some areas of sensitive habitat within the OSPAR II region.				
		5.1.2	Further measures to protect sensitive habitats such fisheries may be implemented in some countries.			
			5.1.2.1	In Norway Norwegian Environment Agency and the Directorate of Fisheries, with support from the Institute of Marine Research have made steps to evaluate how cold-water corals can be further protected from fisheries.		51
			5.1.2.2	Norway have successfully implemented fisheries restrictions to protect cold water corals since 1999.		51
	5.3	There will be increased fishing vessel activity in the central and northern North Sea and will decrease in the English Channel and southern North Sea from 2025 onwards.				
		5.3.1	Reviews of historic trends have demonstrated that there has been northwards shift in the distribution of many North Sea fish species.			
			5.3.1.1	Research undertaken by Engelhard *et al.* (2013) has shown that North Sea cod have exhibited a shift of distribution to northern and northeastern parts of the North Sea. The northern change in shift has been attributed to warmer temperatures in the North Sea, however the shift to the east has been attributed to increased fishing pressure.		53
			5.3.1.2	Research undertaken by Beare et al. (2004) which reviewed trawl data within the North Sea demonstrated that fish species with traditionally southern distributions have increased within the northern North Sea since 1925.		97

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
			5.3.1.3	Research undertaken by Perry et al. (2005) on distribution of 36 fish species in the North Sea demonstrated a northward shift in nearly all species reviewed. The rate of change observed was between 48 km to 403 km.		98
			5.3.1.4	A study undertaken by Simpson et al. (2011) reviewed the impacts of climate change on commercially important species within the northeastern Atlantic, the results showed 72% of species were responding to increased temperatures.		60
			5.3.1.5	Mobile marine species are shifting their geographical ranges polewards at an average of approximately 72km per decade.		54
		5.3.2	Fishing pressure has been historically higher in the southern part of the North Sea.			
			5.3.2.1	ICES data on fishing activity in the North Sea from 2017-2019 demonstrates higher fishing effort in the southern part of the North Sea.		56
		5.3.3	Predictive models indicate that the distribution of commercial species will exhibit northwards shift for many species.			
			5.3.3.1	Research undertaken by Townhill *et al.* (2023) to project fish species distribution through to 2070 predicts that there will be suitable habitat in the future for commercial species in the central and northern North Sea and less suitable habitat in the English Channel and southern North Sea.		48
			5.3.3.2	Research undertaken by Gordó-Vilaseca *et al.* (2024) indicates that the North Sea is likely to see increased species richness at higher latitudes in the future. However, the study also notes that polar species are at a higher risk of extinction and may not be fully replaced by expanding species.		99
			5.3.3.3	Research undertaken by Payne et al. (2021) predicts the risk to European fisheries from climate change impacts upon commercial fish species. Within the North Sea the areas that are at the highest risk are UK fishing fleets, with the lowest risk being within northeastern North Sea countries (Norway and Sweden).		57
	5.4	Fishing vessel activity will occur in deeper waters from 2025 onwards.				

	Factor	Claim	Arguments	Evidence	Confidence RAG	References
		5.4.1	Historical records show that demersal fish species have moved into deeper water in response to increased water temperatures within the North Sea.			
			5.4.1.1	Research by Dulvy *et al.* (2008) indicates that the distribution of the demersal fish assemblage within the North Sea has deepened by approximately 3.6 m per decade.		100
			5.4.1.2	Deeper areas of the North Sea have been noted as being areas of climate refugia.		56

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APPENDIX D: CAE FRAMEWORK REFERENCES

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APPENDIX E: GEOPDFS OF TRACK VOLUMES PER VESSEL CLASS PER EPOCH

Please find this as a separate document in the submission folder.