Celtic Sea Floating Offshore Wind Leasing Round 5

Site Selection Methodology

Credit: BW Ideol V Joncheray

OffshoreWind | THE CROWN ESTATE

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Marine Plan Areas: Supplied by WG and MMO.
Limits: Supplied by UKHO.

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Contents

Executive Summary

At The Crown Estate we have announced an ambition to unlock up to 4.5GW of new floating offshore wind capacity in the Celtic Sea by 2035, enough to power almost four million homes. Floating wind is the next frontier in the green growth story, and we are proud to be playing a key role in its deployment.

The Crown Estate is responsible for leasing seabed space for renewable energy projects in the waters around England, Wales and Northern Ireland. Our approach is designed to help address the evolving strategic challenges in our increasingly complex marine environment, so the UK can maximise the green energy potential of its seabed and shoreline. We are excited about the huge potential of floating offshore wind in the Celtic Sea to support the development of a UK supply chain for this nascent industry and to help deliver on the government's net zero ambitions.

During early 2022, we reviewed the potential scale of the opportunity in the Celtic Sea, taking account of the continued and growing market interest, the views of stakeholders, and the spatial capacity in the Celtic Sea. This document explains how we have identified five broad Areas of Search (AoS) and gone through a process of spatial refinement to identify optimal locations for floating offshore wind Projects Development Areas (PDAs).

The overall aim of this analysis was to characterise opportunities and risks, with the purpose of identifying economically viable PDAs that also minimise as much as possible the impact to other users and interests within the marine environment.

The analysis:

- supports early engagement with stakeholders to enhance understanding of spatial interactions, co-location opportunities and risks to other seabed activities;
- provides a spatial context to inform statutory marine planning and other policy development;
- enables a stakeholder-validated evidence base to feed into the spatial modelling process and subsequent spatial refinement;
- informs the leasing process, which will be formally launched in December 2023 with the publishing of an Information Memorandum.

The document uses these terms:

Areas of Search (AoS)	Large areas of sea space identified in the Celtic Sea region, presented in this report following detailed spatial modelling and stakeholder engagement, within which smaller Project Development Areas will be located.
Refined Areas of Search (RAoS)	Smaller areas of sea space identified through further stakeholder engagement, environmental and technical analysis.
Project Development Areas (PDAs)	The final areas of sea space identified through targeted bilateral engagement with market and marine stakeholders, within which an individual floating offshore wind project could be developed. These areas will be offered up to tender.
Hard constraints	Activities and receptors that currently preclude development such as existing infrastructure and rights, and areas where health and safety or policy reasons mean development is unfeasible.
Soft constraints	Activities and sensitivities that may be subject to varying levels of impact from development, but will not necessarily preclude development.

Market (community of offshore wind developers and their partners/advisors) and marine stakeholder engagement has been at the very heart of our work and has helped guide our decision-making at every stage of the spatial design process. It has been structured in three phases. A questionnaire in November 2021, a workshop with marine stakeholders in February 2022 attended by over 70 organisations, and bilateral meetings with targeted stakeholder organisations held from March 2022 to June 2023 on topics such as fisheries, the environment, aviation, defence, navigation, and telecommunications cables. In addition, we also sought feedback directly from the market for a minded-to scenario, detailed in section 4.3.2.

This approach ensures we can build a more complete picture of the seabed and the views of its users, to inform the development of floating offshore wind based on a balanced and holistic view of the marine environment.

This enables us to:

- build our understanding of what data is available for us to consider;
- ensure that the way in which we analyse the data for spatial modelling is widely circulated and understood;
- gain insight into the appropriate distances between projects and 'hard constraints' – that is, physical features that would prevent development. Further detail on these is provided below.

Figure 1 (below) presents the three PDAs identified through the spatial design process. These have been defined in accordance with the methodology set out in this document and reflect the outcomes of a peer review of the approach to spatial design (published in our document library), stakeholder engagement, and a Plan-Level Habitats Regulations Assessment (HRA).

In line with our statutory obligations, the Plan-Level HRA will assess the potential impacts of our leasing plans on the most valuable habitats in the UK and the UK offshore marine area forming the UK National Site Network. We have taken a new, iterative approach to the HRA for floating offshore wind in the Celtic Sea, whereby mitigation (if required) to reduce potential impacts identified in the assessment has been fed back into the spatial refinement process. This has allowed us to proceed at pace, whilst retaining robust environmental standards.

The next sections of this report provide further details of the methodology we have used.

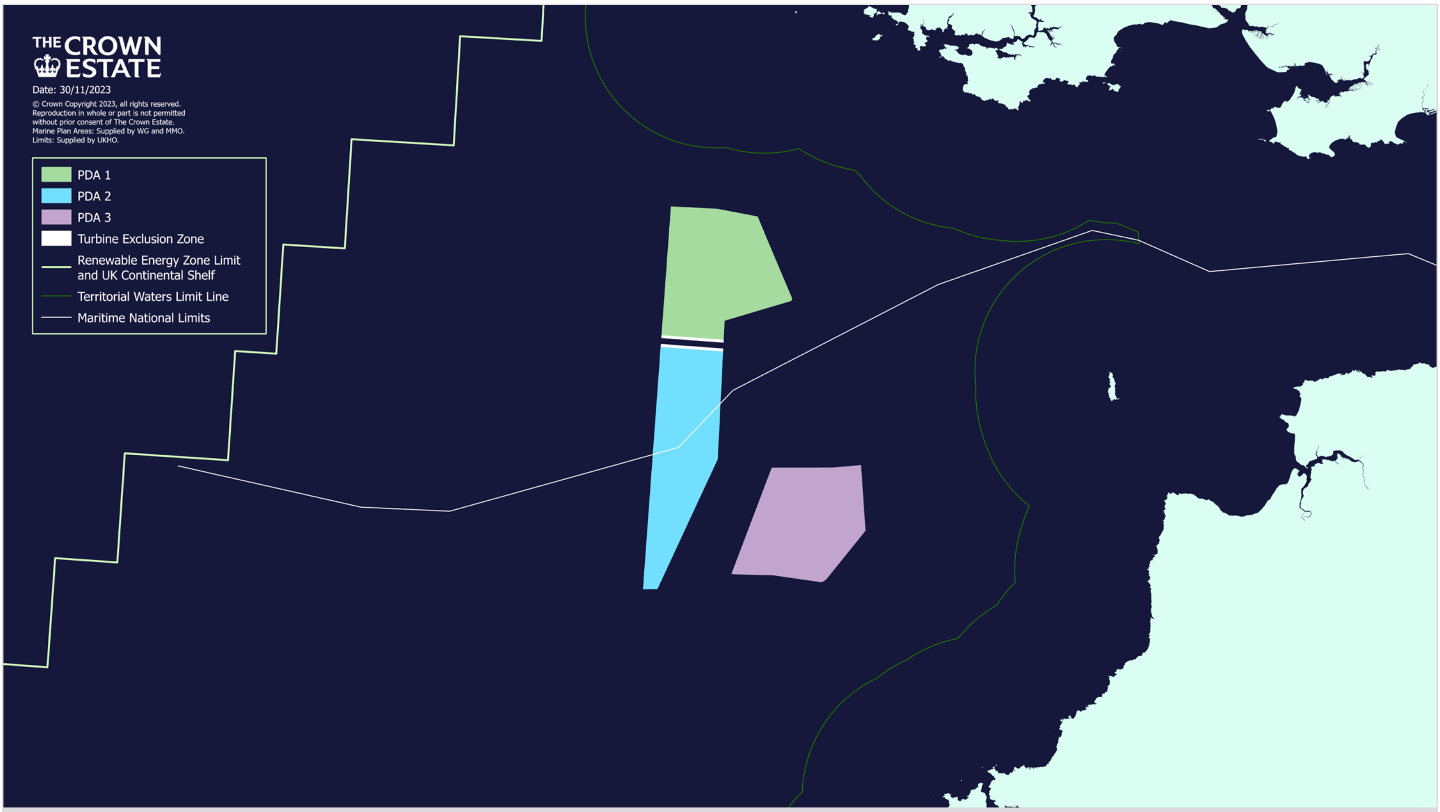


Figure 1: Three floating offshore wind PDAs identified through the spatial design process

1. Introduction to the analysis

1.1 INTEGRATED HRA AND SPATIAL DESIGN

Before awarding seabed rights for floating offshore wind development, The Crown Estate will need to undertake a Plan-Level HRA. This process requires us to assess the potential impact of leasing plans on the most valuable habitats in the UK and the UK offshore marine area.

We are undertaking a modified approach to Plan-Level HRA for floating wind leasing, with an integrated spatial design and HRA process that is taking place ahead of the tender. When the tender is concluded, we will carry out an assessment to check the conformity of projects which have been assessed within the Plan-Level HRA that has already been undertaken, prior to entry into Agreements for Lease (AfLs).

This strategic approach ensures that stakeholders and potential bidders have detailed information on key environmental issues at the earliest opportunity, enabling us to identify favourable areas for projects and, over time, minimise environmental risk and work towards achieving environmental net gain. This approach will also reduce the time between the conclusion of the tender process and the award of seabed rights for successful projects. The process, including PDA identification, has been led by ourselves in consultation with the market and environmental stakeholders. To support delivery, we are working with our independently overseen HRA Expert Working Group. This includes engagement with sector-specific technical experts, the relevant UK statutory marine planning authorities, statutory nature conservation bodies and relevant non-governmental organisations.

1.2 AREA OF INTEREST (AOI)

To inform our market understanding and leasing round design, we carried out two market engagement exercises with developers, technology providers and industry commentators: one in November 2020 and a more recent exercise in November 2021. This engagement helped to establish a baseline of developer needs for viable projects in the region. The first engagement explored the market's general appetite and capability for floating wind and sought feedback on preferred development regions.

The Celtic Sea was the strongly preferred region which, along with our own analysis, directed us towards the Celtic Sea region as the right place to initiate floating wind leasing. The second market engagement covered: grid; technology; ports and supply chain; project size; sequencing and sites; and the relative weighting of soft constraints.

The feedback received confirmed significant market interest and provided valuable insight into the market's view of floating wind projects in the Celtic Sea.

The Celtic Sea is a favoured market (set against competition from other markets) based on:

- strong wind resource
- favourable seabed and water-depths
- proximity to centres of power demand
- historic stability/ favourability of UK policy and market context.

Figure 2 shows the spatial extent of the initial Area of Interest (AoI) within the Celtic Sea, upon which the spatial analysis described in the following sections was undertaken. The AoI was identified by taking the boundary for the Celtic Sea as defined by the International Hydrographic Organisation and clipping it to the Exclusive Economic Zone (EEZ) boundary as well as the mean high water (MHW) mark.

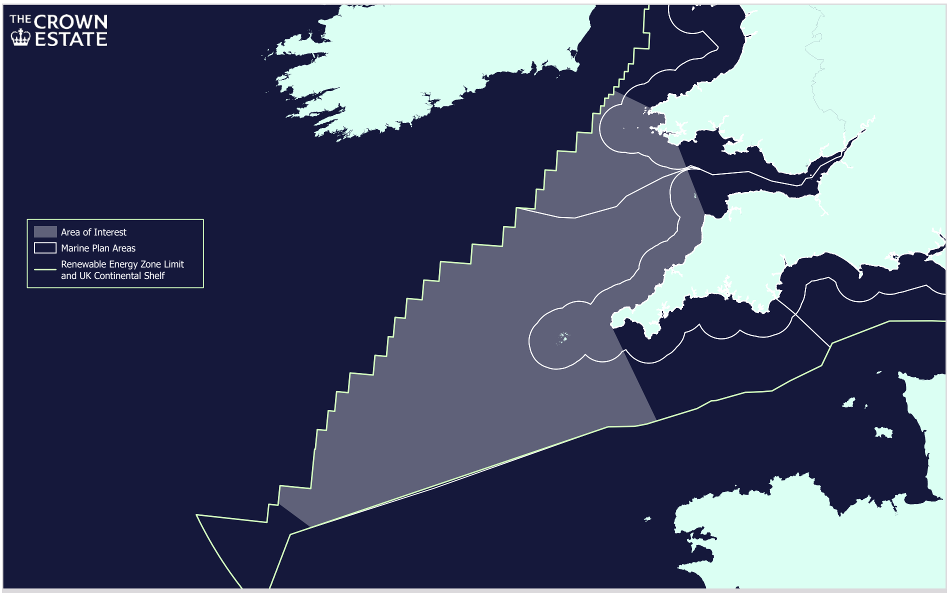


Figure 2: Initial Area of Interest (AoI) within the Celtic Sea

[1] https://iho.int/

1.3 SCOPE

The resource and constraints assessment completed by The Crown Estate was based on the following scope:

- Only investigating within the areas suitable for floating foundation offshore wind
- No prerequisites in terms of floating foundation technology type (i.e. technology agnostic) or size of turbines;
- Analysis is limited to consideration of offshore array i.e. excluding export cable routes and terrestrial infrastructure; and,
- Analysis is limited to the Celtic Sea AOI.

Our analysis has been informed by, and in collaboration with, targeted external stakeholders, as well as drawing on expertise and knowledge within The Crown Estate and our consultant partners. An independent peer-review of the draft process taken for spatial design was undertaken over summer 2022 to validate the process and inform the remaining spatial refinement work. The findings of the peer-review are presented alongside this final spatial methodology report and can be found in our Round 5 Document Library.

1.4 OVERALL APPROACH TO THE ANALYSIS

When identifying areas of seabed for floating offshore wind development, it is vital we strike a balance between the economic potential for developers and local communities, and minimising potential harm to the environment and other users of the sea.

In addition, we have been mindful of the relative immaturity of the floating wind market and the wide range of technological solutions that can be made available. As a result, have aimed to bring forward areas within which a range of foundation technologies could be deployed.

Our approach to spatial analysis, informed through previous experience of resource and constraints assessments and offshore wind leasing, follows six steps, each of which identifies progressively smaller, less constrained and technically attractive areas of seabed. **Figure 3** details at a high level how spatial opportunity is refined from a Key Resource Area (KRA) to Project Development Areas (PDAs).

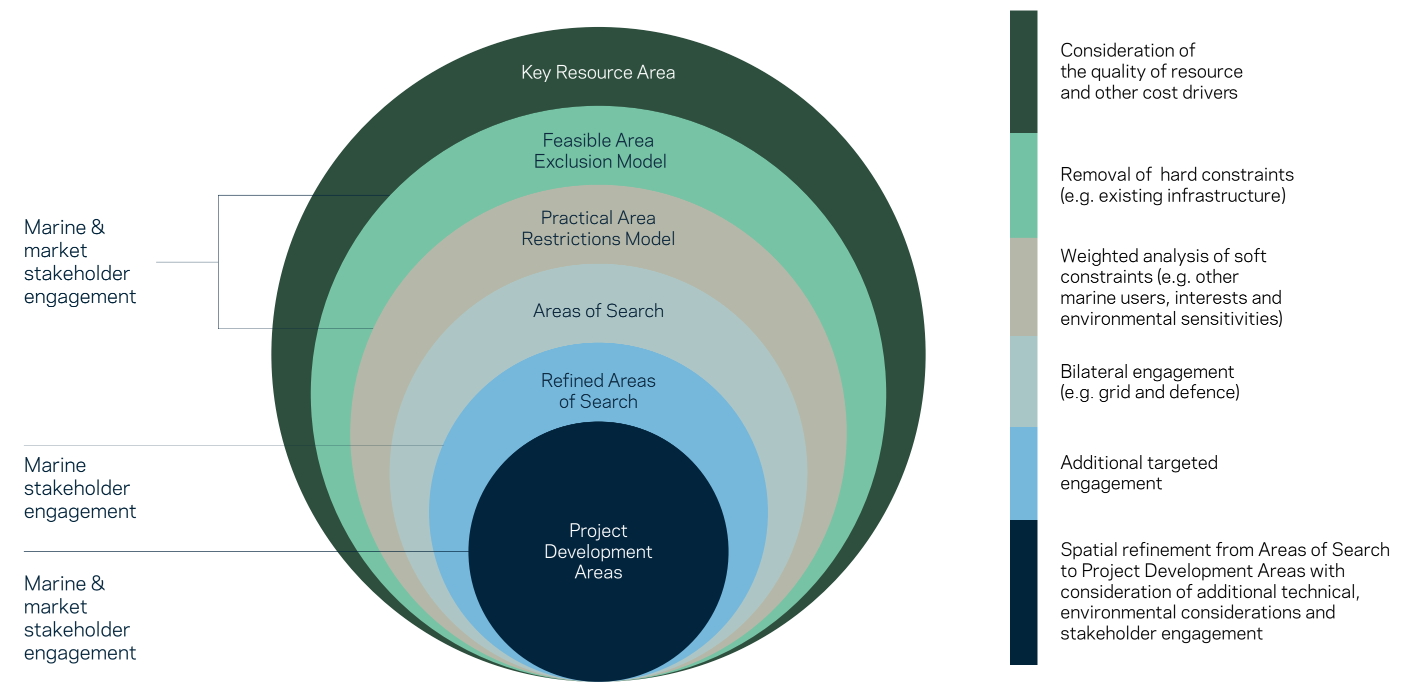


Figure 3: High-level stages of spatial assessment showing decreasing spatial footprint at each stage

The list below summarises each stage:

01

Key Resource Area (KRA): This is the starting point of the analysis and is defined through consideration of the quality and availability of resource, as well as other key cost drivers. Please see Section 2.2.1.

02

Feasible Area 'Exclusions Model' Defined by removing activities and receptors from the KRA that will preclude development such as existing infrastructure and rights, and areas where health and safety or policy reasons mean development is unfeasible. These activities and receptors (input criteria) in the 'Exclusions Model' are termed 'Hard constraints'. Please see Section 2.2.2.

03

Practical Area 'Restrictions Model' This model includes all other spatial criteria which are structured and weighted in terms of the risk each presents to development. The input criteria in this model are termed 'soft constraints'. Please see Section 2.2.3.

04

Areas of Search (AoS): These are defined from the result of combining steps 1 to 3. A percentage threshold of the restrictions model defines the least constrained area and AoS are defined within this area through a range of further detailed considerations including Levelised Cost of Energy (LCoE), stakeholder engagement and internal expertise. Please see Section 2.2.4 and Section 2.3.

05

Refined Areas of Search (RAoS) These are defined through a spatial refinement process including targeted bilateral engagement on topics such as fisheries, the environment, aviation, defence, navigation and telecommunication cables. Please see Section 4.2.

06

Project Development Areas These are defined through a further period of spatial refinement following stakeholder engagement and detailed consideration of a range of factors. It is these areas that will be included within the leasing offer. Please see Section 4.3.

2. Spatial Design

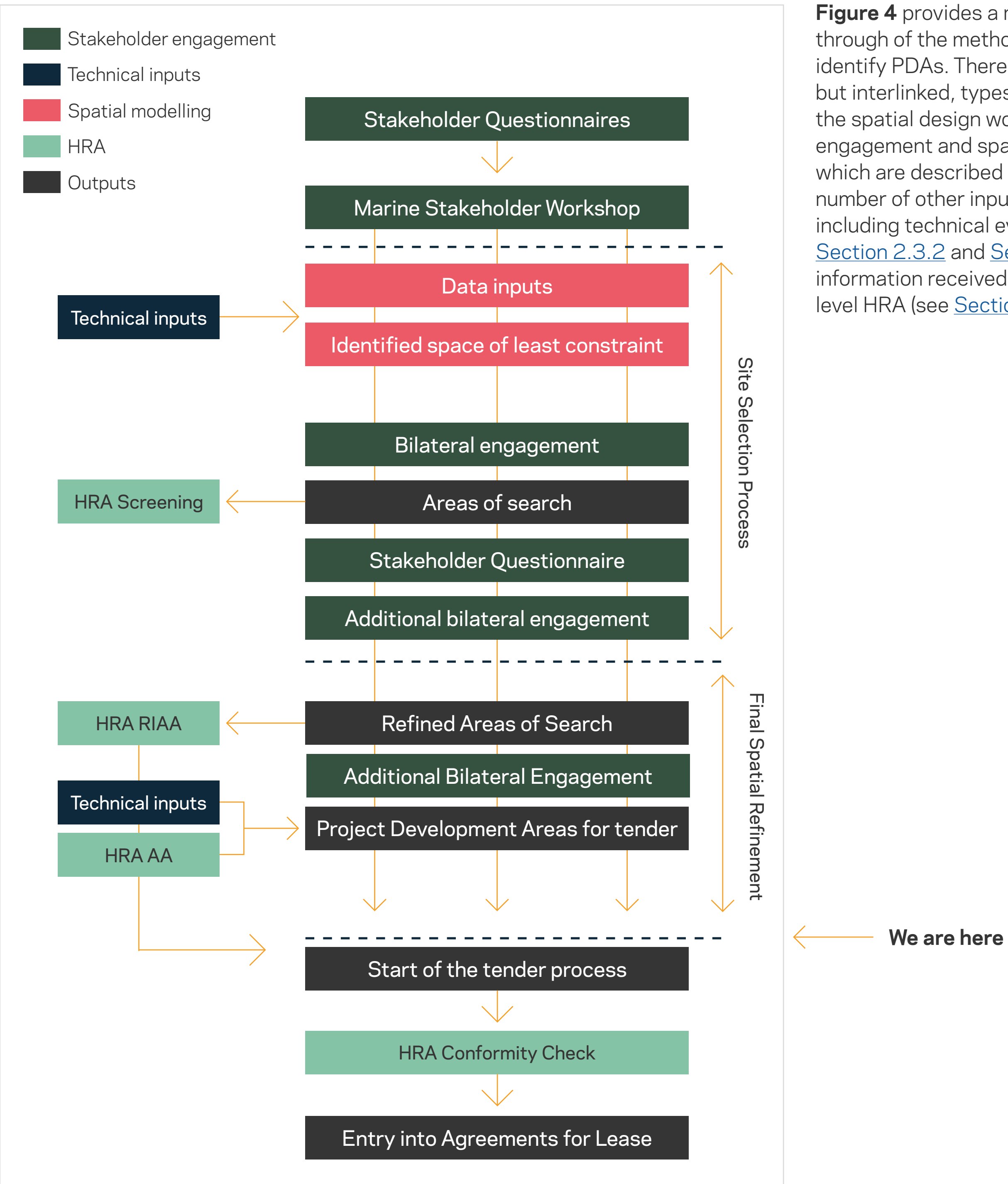


Figure 4: Outline of the integrated approach to spatial design and HRA within the Celtic Sea

Figure 4 provides a more detailed step through of the methodology taken to identify PDAs. There are two distinct, but interlinked, types of activity within the spatial design work: stakeholder engagement and spatial modelling, which are described below. There are a number of other inputs to the process, including technical evidence (see Section 2.3.2 and Section 4.6) and information received through the Plan-level HRA (see Section 2.3.1).

2.1 STAKEHOLDER ENGAGEMENT

Stakeholder engagement has been central to our spatial design, ensuring that both stakeholder views and data could be fed into the modelling process before it began, as well as throughout the identification of AoS. Details of the engagement approach are provided in Sections 2.1.1 and 2.1.2.

Additional detail on the engagement approach to finalise PDAs can be found in our Summary Stakeholder Report.

2.1.1 MARINE STAKEHOLDER QUESTIONNAIRE

In November 2021 we provided an online stakeholder questionnaire to obtain detailed information from stakeholders on the approach to spatial design for floating offshore wind in the Celtic Sea, as well as views on the potential risks of floating offshore wind development to other seabed users, interests and sensitivities. Stakeholders were also asked to share information regarding any additional datasets to be considered in the spatial modelling process.

Additional detail on the engagement approach to finalise PDAs can be found in our Summary Stakeholder Report.

The questionnaire was sent to our marine stakeholder network whilst a separate questionnaire seeking the views of the Market was run in parallel. Due to the complexity of the issues on which views were being sought and the resultant length of the questionnaire, we decided to employ a tailored approach to questions depending on the remit of the individual stakeholder. Thereby, stakeholders from sectors which had a broad interest and remit, such as statutory bodies, were asked all questions.

However, if a stakeholder had a specific topic interest such as fisheries or shipping and navigation, they were only asked specific questions on these topics.

2.1.2 SPATIAL WORKSHOP

The results of the questionnaire were used to inform a spatial workshop that took place on 10th February 2022. Over 70 marine stakeholders attended the online workshop and heard updates from The Crown Estate on the spatial approach to Floating Offshore Wind development in the Celtic Sea.

Stakeholders were also engaged in two separate breakout sessions:

- Breakout Session 1 gathered views on the suitability of proposed buffers around hard constraints, as well as the identification of risks and opportunities associated with co-location and displacement of various activities or interests.
- Breakout Session 2 considered the weighting of soft constraints using pairwise comparisons to help inform the relative weighting of data (please see Section 2.2.3 and Appendix 2 for more detail).

As well as building on the questionnaire responses at the workshop to understand what is important to the different stakeholder groups, we also held a discussion around any additional datasets that would be useful that we had not yet considered. The outputs of the engagement exercises fed directly into the spatial modelling, and we wish to thank stakeholders for their invaluable input. The following sections outline the step-by-step approach to the spatial modelling.

2.2 SPATIAL MODELLING

This section describes the analysis carried out in more detail, including the specific spatial modelling steps undertaken using Geographic Information System (GIS) tools which fed into AoS identification (see Section 2.3). As well as utilising the standard suite of ArcGIS geoprocessing tools throughout the analysis, the spatial modelling (comprising the exclusions and restrictions models) was undertaken using our Marine Resource System (MaRS) tool.

MaRS is a scalable, flexible and auditable decision support tool that uses multi-criteria decision-making and GIS to perform analysis. The MaRS system analyses many layers of spatial information, combining them to help answer key resource planning questions, which is increasingly important as the marine environment becomes ever more spatially constrained. MaRS supports our understanding of optimal development locations through weighted spatial analyses of data layers, which represent soft constraints. Analysis can yield outputs that help to identify areas of technical opportunity or, indicate areas where other users or interests might limit access to given resources.

The assessment of constraints relies on expert opinion to assess relative importance of input data layers and apply weightings across each data layer (or sub classification if the data describes intensity or density). This means that the analysis is a relative assessment and cannot identify specific thresholds of opportunity or consenting risk. However, the output does provide a strategic indication of the relative level of potential planning constraint to development, in relation to the activities and receptors included in the GIS model.

MaRS has been used in several previous leasing and marine planning exercises including Offshore Wind Leasing Round 4, wave and tidal stream demonstration zones, and the Marine Management Organisation's (MMO's) marine planning options process for the East Marine Plans.

A data audit was completed ahead of the spatial analysis and a number of datasets were pre-processed ahead of modelling. For more information, please see Appendix 1.

The following sections detail each step of the spatial analysis process.

2.2.1 KEY RESOURCE AREA (KRA)

In October 2020, we published the Broad Horizons report[2], a study that surveyed the evolving technology landscape to assess how practical limits to offshore wind installation will develop between 2020 and 2040. Working in partnership with Everoze, we mapped engineering solutions against the physical characteristics of the sea and seabed to define the future technology profiles resulting in the identification of fixed and floating offshore wind Key Resource Areas (KRAs). A KRA represents an area of seabed in which a given technology is projected to be technically viable over a given timeframe, classified according to the most appropriate engineering solution. **Figure 5** shows the extent of the floating offshore wind KRA which forms the first stage of the spatial analysis within the Celtic Sea through identifying areas of the seabed with suitable technical conditions to support economic development (see **Figure 3**).

The floating offshore wind KRA is predominantly driven by water depth, metocean conditions and geology. In high-level summary the study concluded the below:

1. **Water Depth:** The costs of the overall floating system (substructure and mooring system) will increase with water depth.
2. **Metocean conditions:** As metocean conditions become more onerous, floating structures and mooring and anchoring systems have to accommodate higher extreme loads, becoming more complex and expensive.
3. **Geology:** Floating wind turbines must be securely moored to the seabed, to keep them in place. The appropriate means of attachment depends primarily on the type and depth of sediment on the sea floor.

With the identification of these criteria and their associated specific characteristics, we were able to spatially define areas that contain suitable technical conditions for a range of floating wind substructure types through mapping of national-scale datasets[3].

Further technical and cost modelling is undertaken later in the spatial optimisation process (see Section 2.3.2).

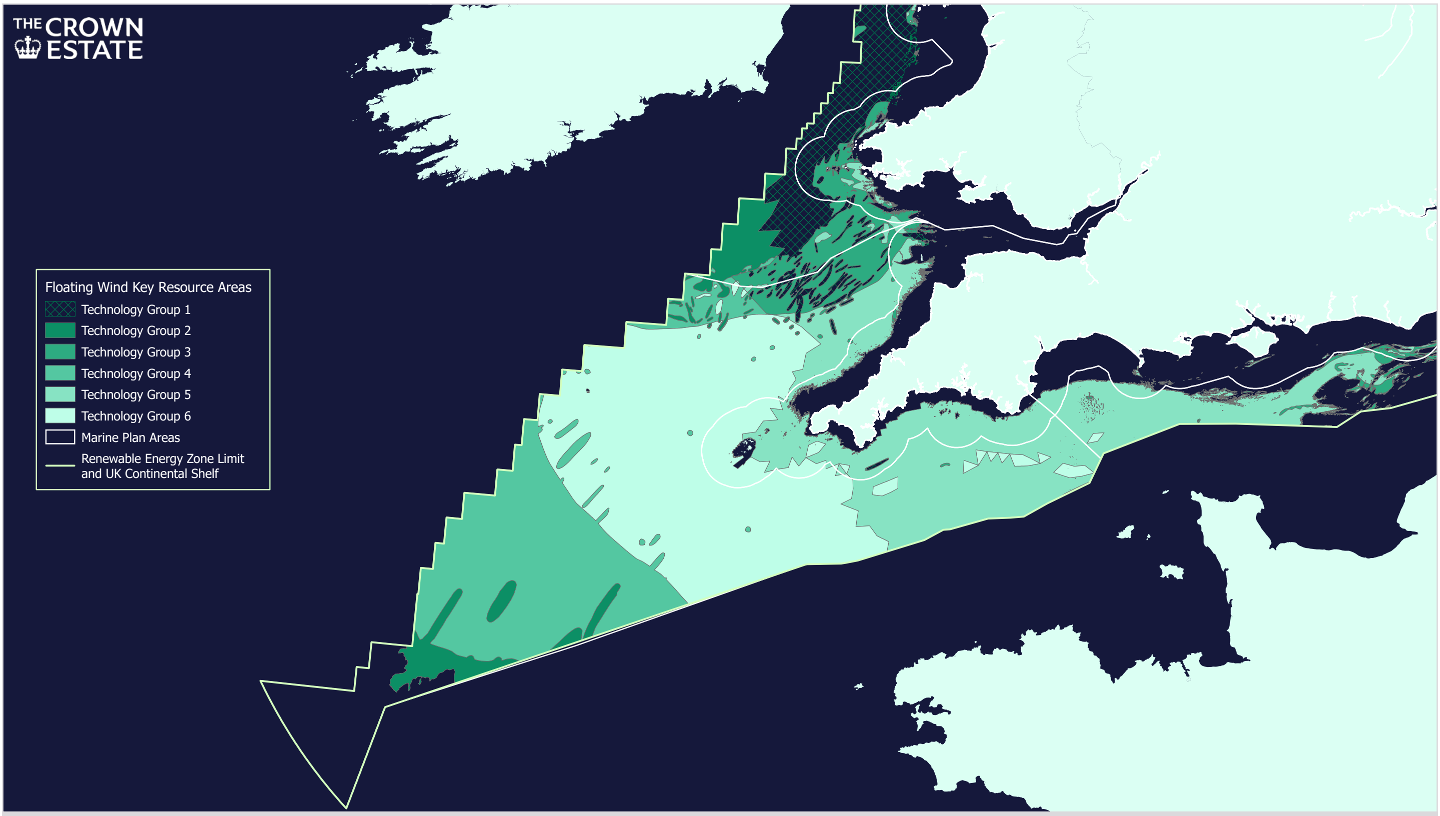


Figure 5: Floating offshore wind KRA (https://www.thecrownestate.co.uk/media/3642/broad-horizons-offshore-wind-key-resource-area-summary-report.pdf)

[2, 3] Everoze Partners Limited. 2020. BROAD HORIZONS: Key resource areas for offshore wind Summary Report. August 2020 (https://www.thecrownestate.co.uk/media/3642/broad-horizons-offshore-wind-key-resource-area-summary-report.pdf)

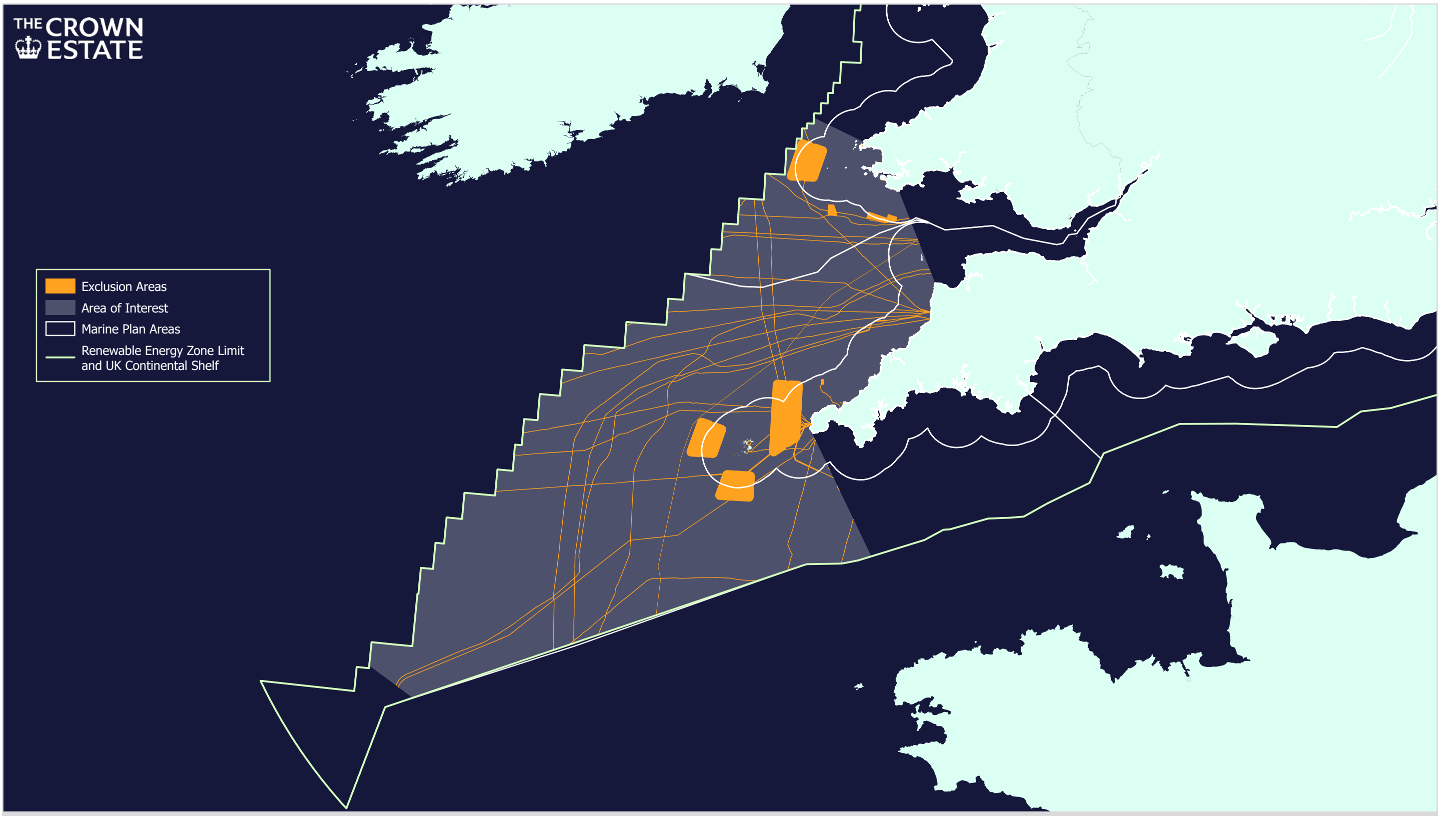


Figure 6: Excluded areas based on hard constraints outlined in **Appendix 3**

2.2.2 EXCLUSIONS MODEL (HARD CONSTRAINTS)

The next step of the analysis is an Exclusion Model (see Figure 3) which identifies and removes areas from the model that are not suitable for development. Data inputs relating to legal or physical barriers which would currently preclude floating offshore wind development, including any buffer distances around these features, were agreed following engagement with stakeholders in February 2022. Features in this category are excluded on the basis of any of the following reasons:

1. There is existing infrastructure in place that would preclude development.
2. Safety reasons would inhibit development (e.g. International Maritime Organisation (IMO) shipping routes and oil and gas safety zones).
3. Existing rights have been granted over the seabed which precludes granting rights for offshore wind development.

A full list of the data included in the Exclusions Model (i.e. considered hard constraints) is provided in Appendix 3.

The exclusions model output, which collates, dissolves and removes the data from the subsequent analysis, is presented in Figure 6.

2.2.3 RESTRICTIONS MODEL (SOFT CONSTRAINTS)

The next stage of the process is the Restrictions Model (see **Figure 3**). This model contains all other spatial criteria which are structured and weighted in terms of the risk that development may present on the represented activity or sensitivity (i.e. soft constraints). This includes data on environmental designations, navigation, fisheries and visibility from landscape designations.

It should be noted that some data layers were deemed unsuitable for inclusion in the spatial model for various reasons, for example, data resolution, data coverage or due to the nature of the constraint being too complex to appropriately reflect the activity or sensitivity (e.g. radar interference and associated mitigation measures). These datasets were further considered through the identification and characterisation of PDAs.

Two GIS datasets were created specifically for inclusion in the restrictions model including:

1. Visibility from landscape designations;
2. High intensity fish nursery and spawning overlap count

Details of how these were produced are included in Appendix 1.

As per the Exclusions Model, suitable buffers for relevant datasets within the Restrictions Model were discussed as part of the stakeholder workshop in February 2022 and taken forward into the modelling. A full list of data and any associated buffer distances included in the Restrictions Model is provided in Appendix 4.

One method of weighting soft constraints is through a process called Analytic Hierarchy process (AHP). AHP is a method to analyse complex decisions through a series of structured comparisons of criteria or data (called pairwise comparisons). The approach has been well developed and tested through academic research and peer reviewed publications since its development in the 1970s. The methodology ensures that a robust, traceable, repeatable and defendable prioritisation is undertaken.

An assessment by independent consultants of the appropriateness of AHP (used previously in Round 4) concluded that the approach should form the basis of the spatial modelling within the Celtic Sea. More detail on AHP and the pairwise analysis can be found in Appendix 2.

The structure required to conduct AHP starts by grouping a number of similar criteria into themes and sub-themes which can then be built up in tiers and combined. Appendix 2 outlines what each tier of the model represents but in summary:

- Tier 1: represent the highest level themes (Economic, Social, Environment)
- Tier 2: represents sub-themes that accommodate the large number of criteria that fall within each theme

Tier 3: holds all of the discrete data layers which are outlined in Appendix 4.

AHP allows the relative barriers to development of each data layer to be defined in a coherent, structured format with statistical rigor applied to how the input criteria will impact on the final output. It also has the benefit of breaking models down for stakeholders. This allows focussed discussions about the relative importance of similar assessment criteria and clearer incorporation of stakeholder views into analysis. As a result, a more transparent modelling methodology is utilised.

Figure 7 outlines the final AHP model structure defined following marine stakeholder engagement.

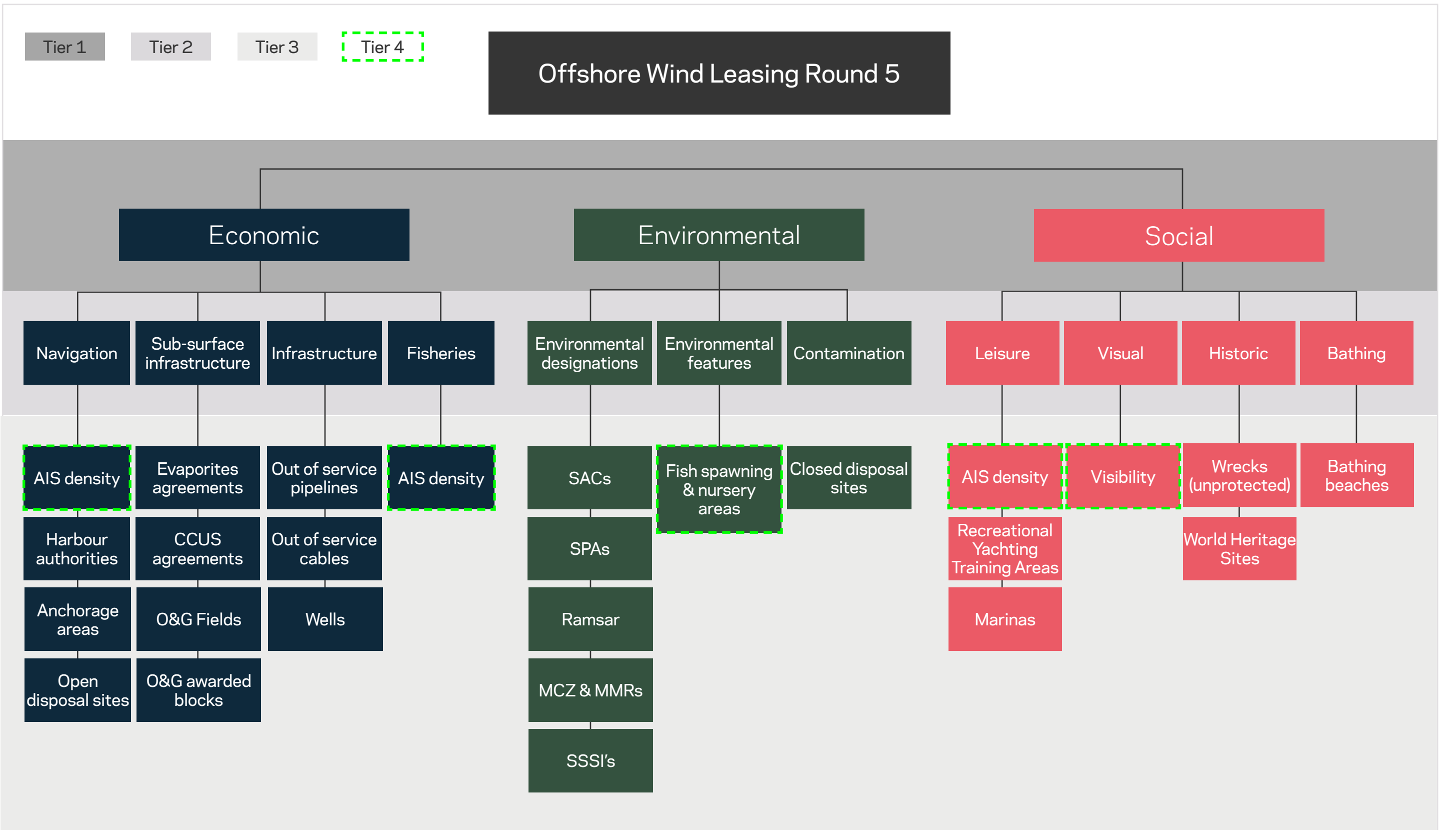


Figure 7: Final AHP tiered model structure

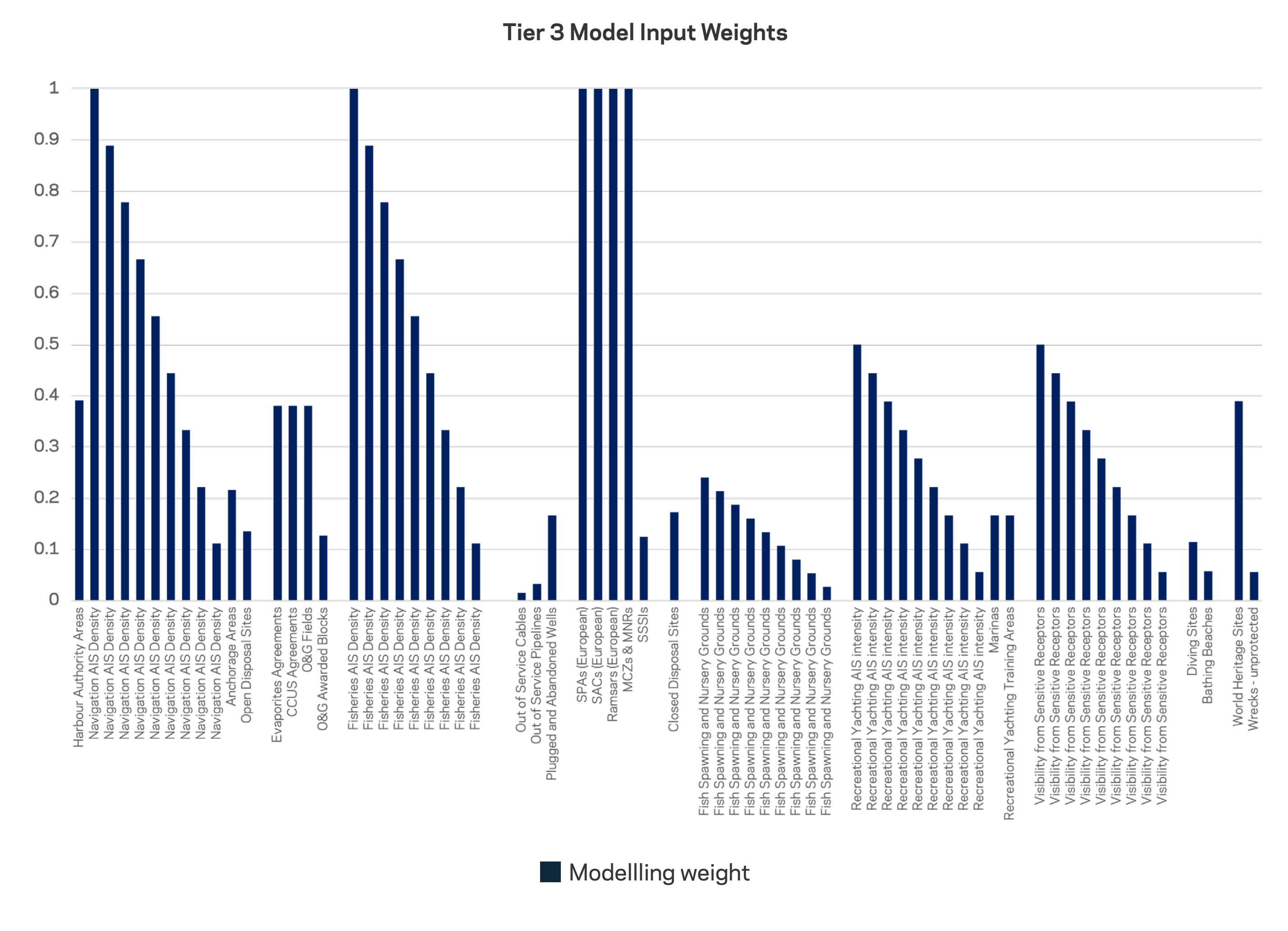


Figure 8: Final relative data weightings within the Restrictions Model

Within breakout groups at the workshop in February 2022, we shared an example AHP structure and ran the pairwise comparisons process with stakeholders for Tiers one to three in the model using Spice Logic software[4] (please see Section 2.1.2). The aim of this was to seek stakeholder expertise and acquire input to the comparisons proposed for floating offshore wind leasing from key stakeholders.
These comparisons informed the relative weightings of each criteria or spatial dataset in the final restriction model alongside feedback received through bilateral engagement.

Figure 8 presents the final relative weightings of all data layers included within the model. The detailed AHP methodology and pairwise comparisons process, as well as how these were converted to data weightings within the model before being input into MaRS, is included in Appendix 2.

[4] https://www.spicelogic.com/Products/ahp-software-30

Figure 9 shows the spatial output of the weighted Restrictions Model for floating wind in the Celtic Sea region informed by stakeholder engagement. The darker purple areas indicate areas that are less suitable based on other interests, users and sensitivities and the lighter purple areas indicate higher suitability.

Following an assessment of Levelised Cost of Energy (LCoE) in the region (see Section 2.3.2.2), it was determined that a 200km maximum distance from grid connection points should be used as a cut off for analysis (see Figure 10). The reasoning for this was to limit the costs associated with grid infrastructure (i.e. lengthy export cables) and their impact on the projects' cost of energy. This also took into consideration the fact that adequate relatively unconstrained seabed could be identified within the 200km radius, to accommodate 4.5GW of floating offshore wind capacity.

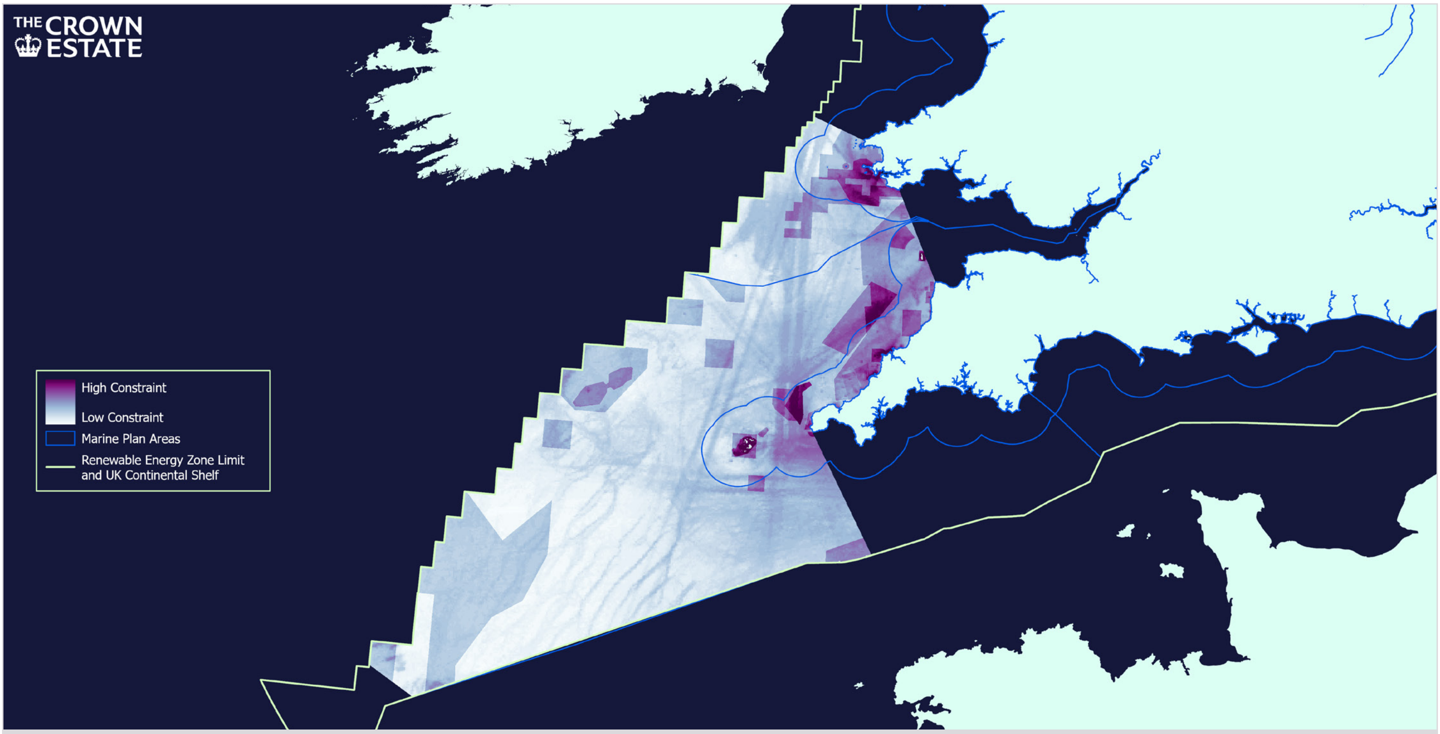


Figure 9: Weighted Restrictions Model output for floating wind in the Celtic Sea region

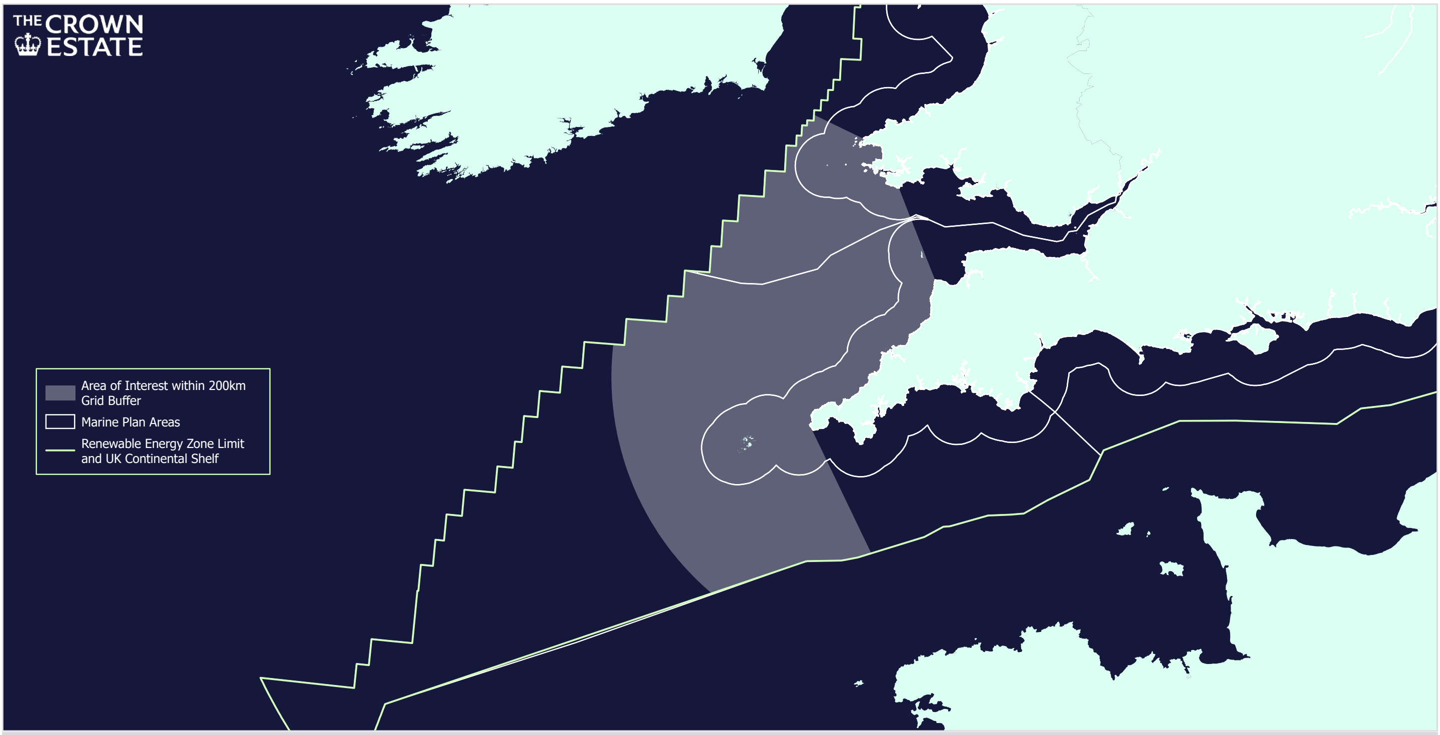


Figure 10: Revised AoI based on a 200km maximum distance from grid connection points

2.2.4 NORMALISED OUTPUT

Using the revised AoI (Figure 10) to identify opportunity for floating offshore wind development, the three component parts of the analysis were combined (Key Resource Area, Exclusions Model and Restrictions Model) in the GIS. The process followed is summarised below:

1. Set the area of analysis to the extent of the floating offshore wind Key Resource Area within the revised AOI;
2. Run the Exclusions Model to the extent set within Step 1;
3. Run the Restrictions Model to the extent set within Step 1;
4. Extract the exclusions model from the restrictions model output;
5. Normalise the combined output from 0 to 100 to create a percentage of constraint output.

Figure 11 shows the final normalised output of the combined KRA, Exclusions and Restrictions Models.

The model in Figure 11 has been normalised and split into ten groups containing equal areas of seabed which represent the range in suitability for floating offshore wind development within the Celtic Sea. Each category represents a band of constraint based on the weighted restrictions model informed through stakeholder engagement.

Bands range from the top 10 per cent of the model output (or the least constrained area of the model) through to the 90 to 100 per cent banding (or the most constrained areas within the model output).

This normalised output identifies navigation channels, high intensity fishing grounds and areas containing environmental sensitivities as generally being the most constrained areas (pink colour scale) due to the number of highly weighted receptors overlapping in these areas. The light blue colour scale represents areas of least constraint.

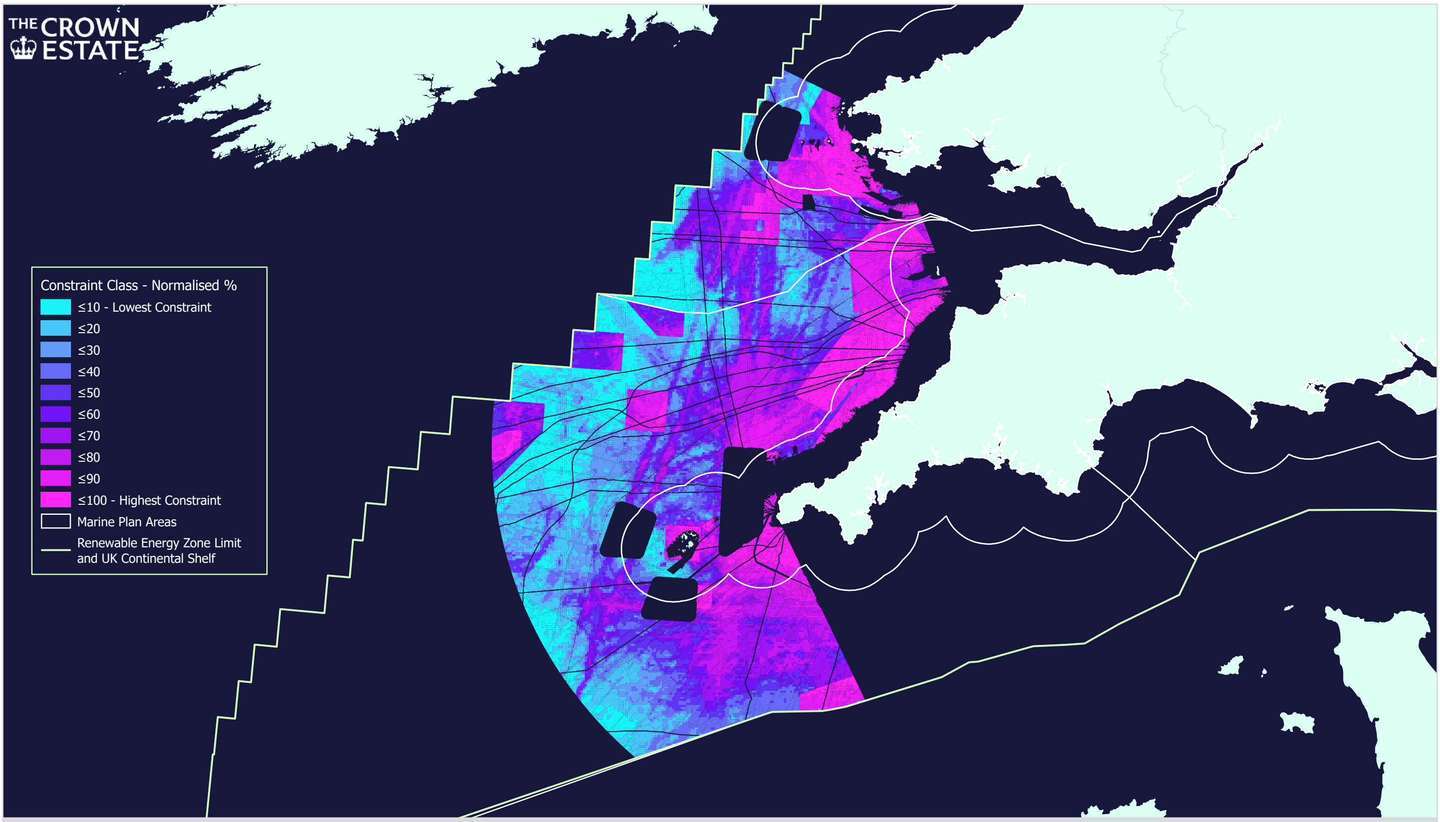


Figure 11: Final normalised output of the combined KRA, Exclusions and Restrictions Models

Figure 12 shows the top 50 per cent most favourable areas (or least constrained half of the model output) as they represent least interaction with other sea users, interests and sensitivities. Precedent for using the top 50 per cent aligns with previous peer-reviewed offshore wind leasing spatial design practice.

The output in Figure 12 depicting the least constrained 50 per cent of the model was taken forward into the analysis for identifying Areas of Search (AoS).

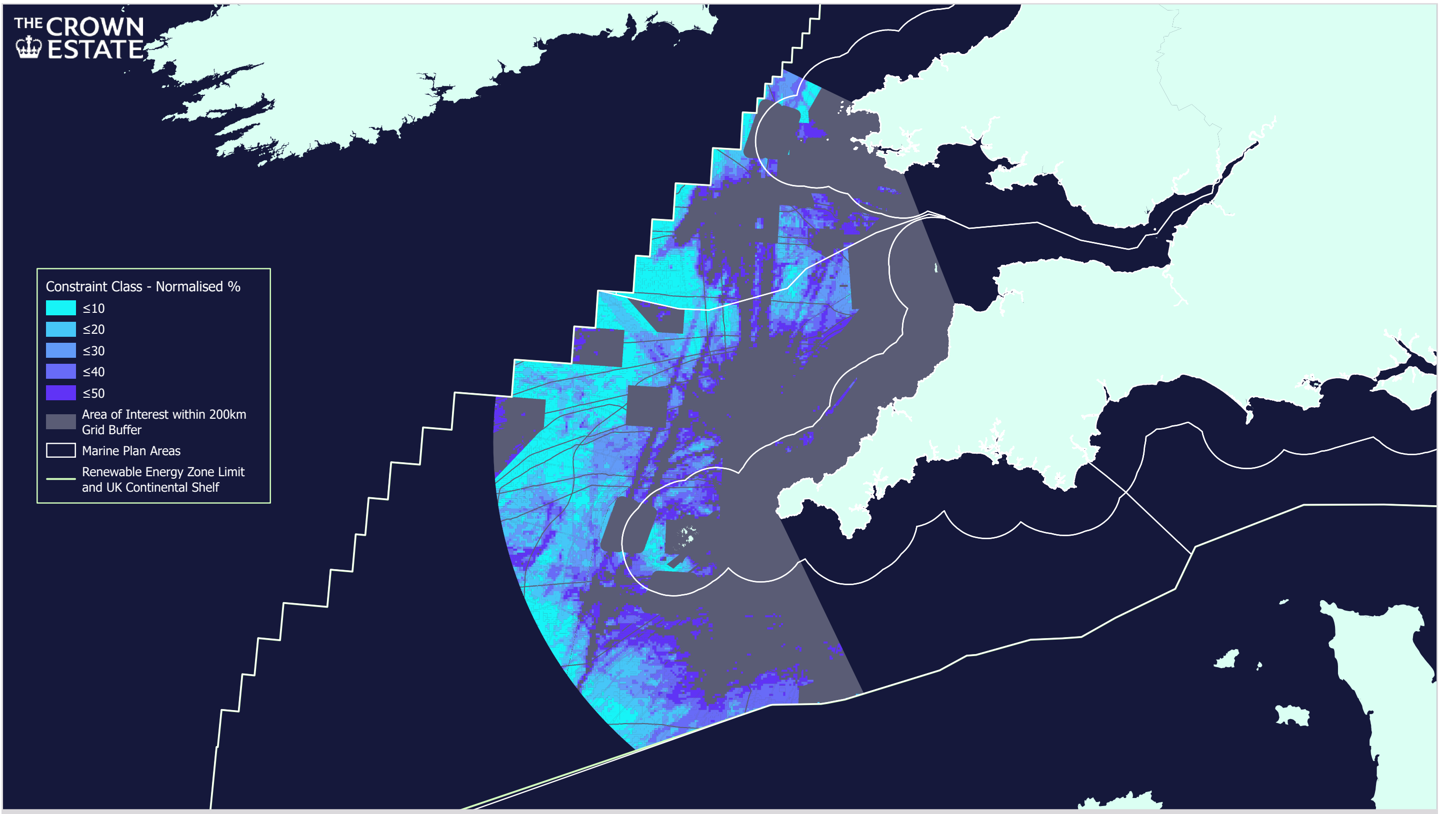


Figure 12: the top 50 per cent most favourable areas (or least constrained half of the model output)

2.3 ANALYSIS TO IDENTIFY AREAS OF SEARCH (AOS)

Following detailed spatial modelling of a range of technical and environmental considerations (See Section 2.2), AoS were identified through a consideration of the below:

1. The MaRS model output (See Section 2.2)
2. Further consideration of Environmental Designation Risk (see Section 2.3.1)
3. Engineering and Levelised Cost of Energy assessment (See Section 2.3.2)
4. Bilateral engagement (See Section 2.3.3)

Figure 13 shows the five identified AoS which are based on locations within the least constrained 50 per cent of the model output. The five broad areas represent just over 11,000km^2 of potential opportunity for floating offshore wind development within the AoI.

It should be noted that the final identified PDAs are significantly smaller in size (see Section 4).

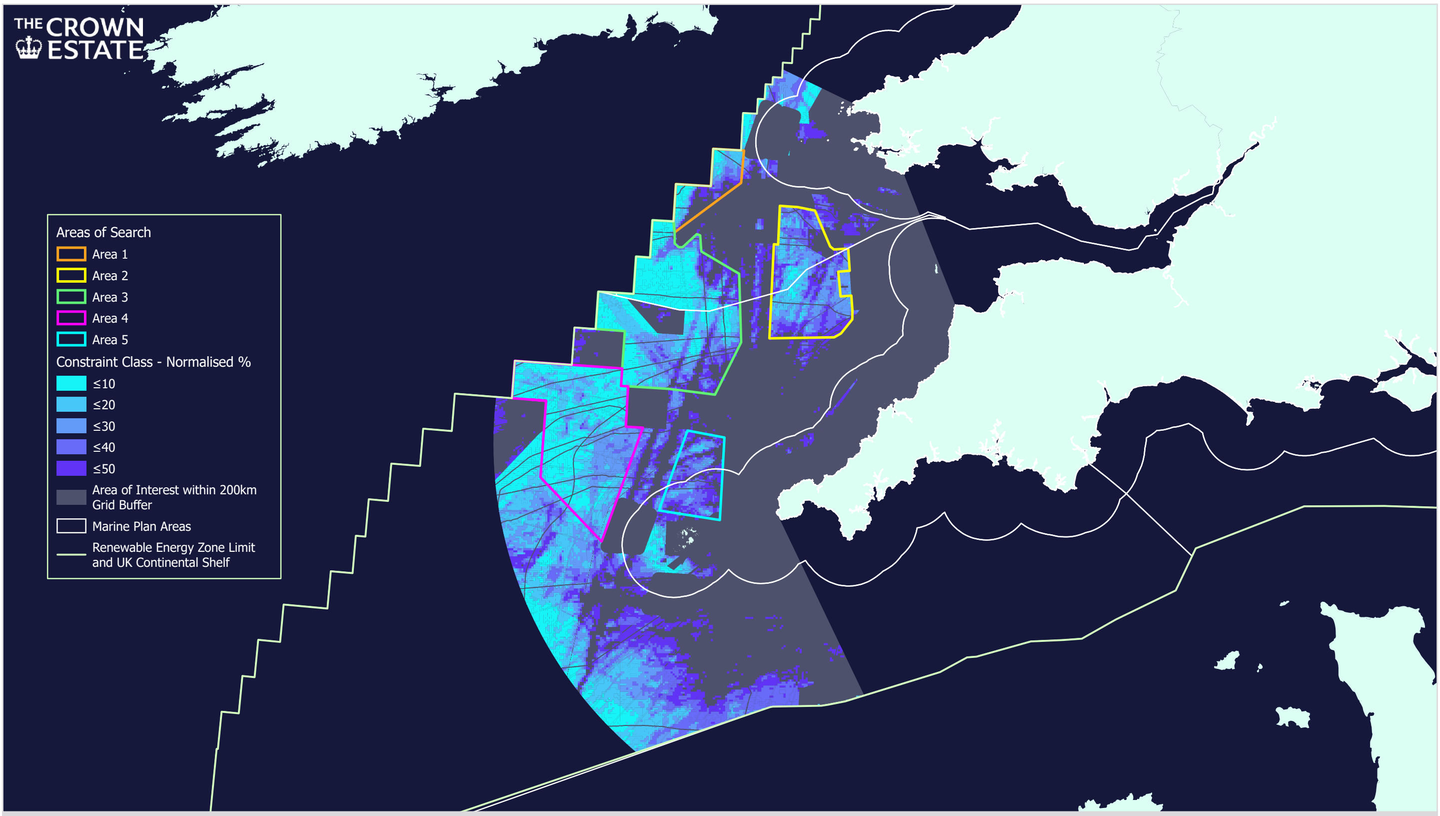


Figure 13: Five identified AoS overlaid with the top 50 per cent most favourable areas (or least constrained half of the model output)

Figure 14 shows the identified AoS more clearly - it is these areas that were shared during bilateral engagement. The following sections go into more detail as to how the AoS were identified.

2.3.1 ENVIRONMENTAL DESIGNATION RISK

With the support of our Spatial and HRA independent consultants, we have developed a spatial representation of the relative risk to features of UK designated sites from floating offshore wind development. The process to develop the risk layers uses a variety of information, including feature sensitivity, feature condition, and feature distribution (so far as it is known) to identify the unmitigated potential risk which can be broken down by feature or aggregated by feature groupings (Breeding Birds, Non-Breeding Birds, Marine Mammals, Benthic, Fish and Marine Conservation Zone (MCZ) features).

We have reviewed this assessment of relative risk against the outputs of our spatial design processes to identify species or regions of greatest risk. This was developed into a more detailed review of the potential impacts and possible mitigation, ahead of formal assessment within the HRA or MCZ Assessment. This early sight of potential impacts has helped shape the AoS and, alongside considerations identified through engagement with our marine stakeholders, supported the process of refining the AoS into PDAs, improving environmental outcomes and reducing the risk of significant adverse effects as a result of the floating offshore wind plan in the Celtic Sea.

2.3.2 ENGINEERING & LCOE

It is important to the realisation of our objectives that the spatial design process results in wind farm sites which are both technically and economically viable. Areas of seabed that present high risk to safe design, construction and operation must be excluded and due consideration given to the variation in estimated cost of energy across the Area of Interest.

We have previously commissioned a detailed study into both fixed and floating technology trends[5], which forms the basis of our approach to the Celtic Sea. In addition, we have undertaken a number of further studies, which are described in Sections 2.3.2.1 to 2.3.2.3 below.

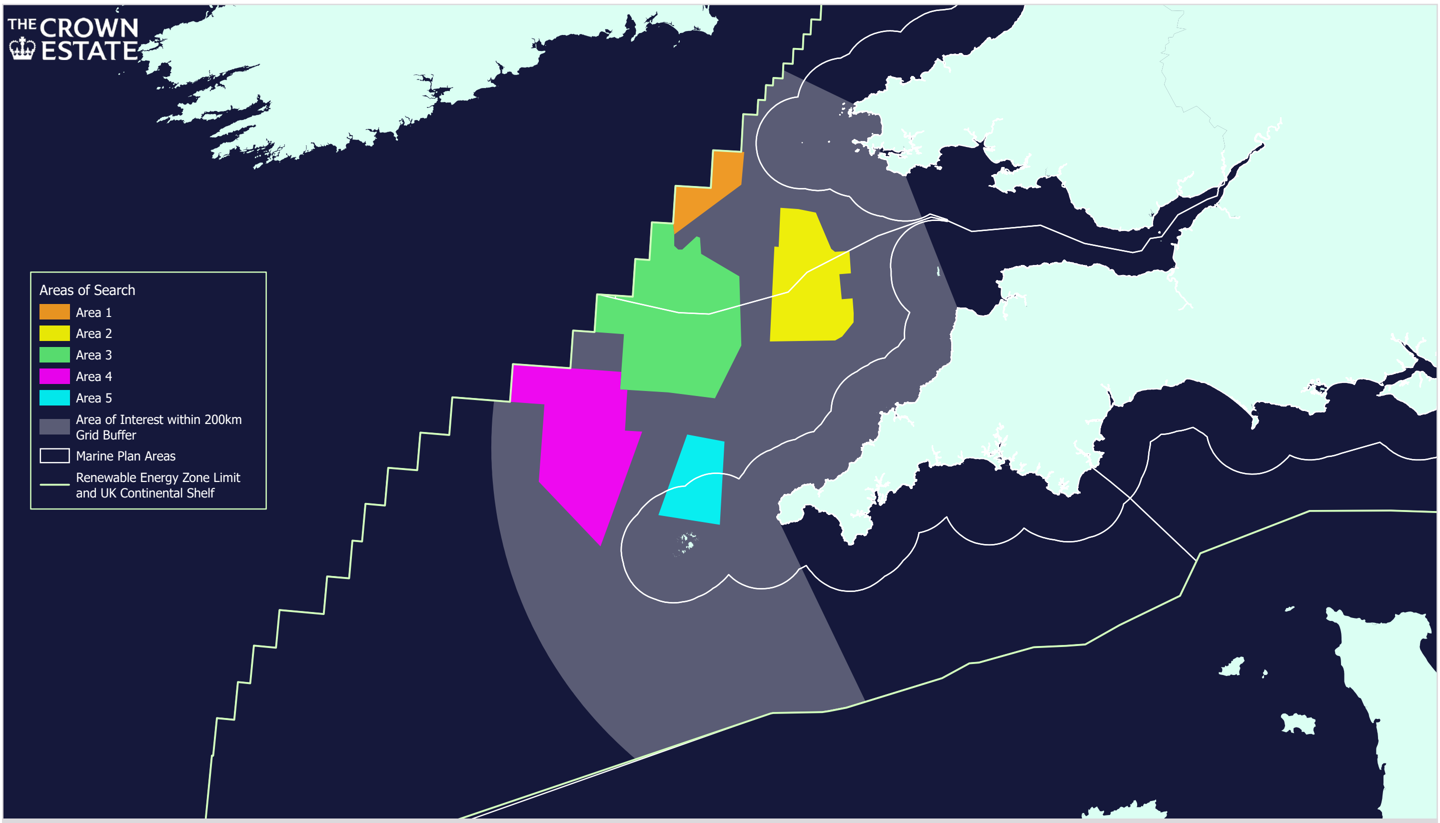


Figure 14: Five identified AoS

[5] 2020, Everoze, Characterisation of Key Resource Areas for Offshore Wind, A Report for The Crown Estate | Marine Data Exchange

2.3.2.1 TECHNICAL FEASIBILITY

Building on The Crown Estate's understanding of the technical KRA (See Section 2.2.1), engineering specialists were engaged to assess the following characteristics across the Area of Interest.

- Wave/current conditions based on bespoke wave and hydrodynamic modelling;
- Mean and 50-year extreme wind speed at representative 150m hub-height, based on modelled wind data (bias-corrected ERA-5 data);
- Geo-technical parameters (sediment depth, sediment type and bedrock type), based on British Geological Survey data;
- Bathymetry, based on DEFRA data.

These outputs were compared against the technical limitations of various floating sub-structure, mooring and anchor concepts, informed by structural engineering experts, in order to enable the identification of exclusion zones (i.e. areas of practically insurmountable risk to wind farm construction or operation) where relevant. No such exclusion zones have been identified in the Celtic Sea AoS.

Grid feasibility was also assessed at high-level, with both High-Voltage Alternating Current (HVAC) and High-Voltage Direct Current (HVDC) concepts under consideration.

This analysis confirmed that the identified AoS are technically feasible. This was revisited and refined in subsequent stages of optimisation as we moved towards defining PDAs (See Section 4.6).

2.3.2.2 LEVELISED COST OF ENERGY (LCOE)

LCoE modelling can be used to spatially assess variation in the cost to construct and operate a wind farm project per unit energy (MWh) output. We have engaged with LCoE experts to produce a LCoE map covering the AOI (Figure 15). This combines much of the technical feasibility modelling described in the previous section with additional cost modelling.

This analysis has initially been used to justify excluding seabed outside of a 200km radius from the nearest grid connection location on the grounds of high cost (i.e. due to long export cables).

This preliminary analysis, the associated input assumptions and data sets were reviewed and improved where possible over the remainder of the spatial design process. The final analysis fed into managing the balance between technical risk, cost of energy and environmental/social impact during the selection of PDAs (See Section 4.6).

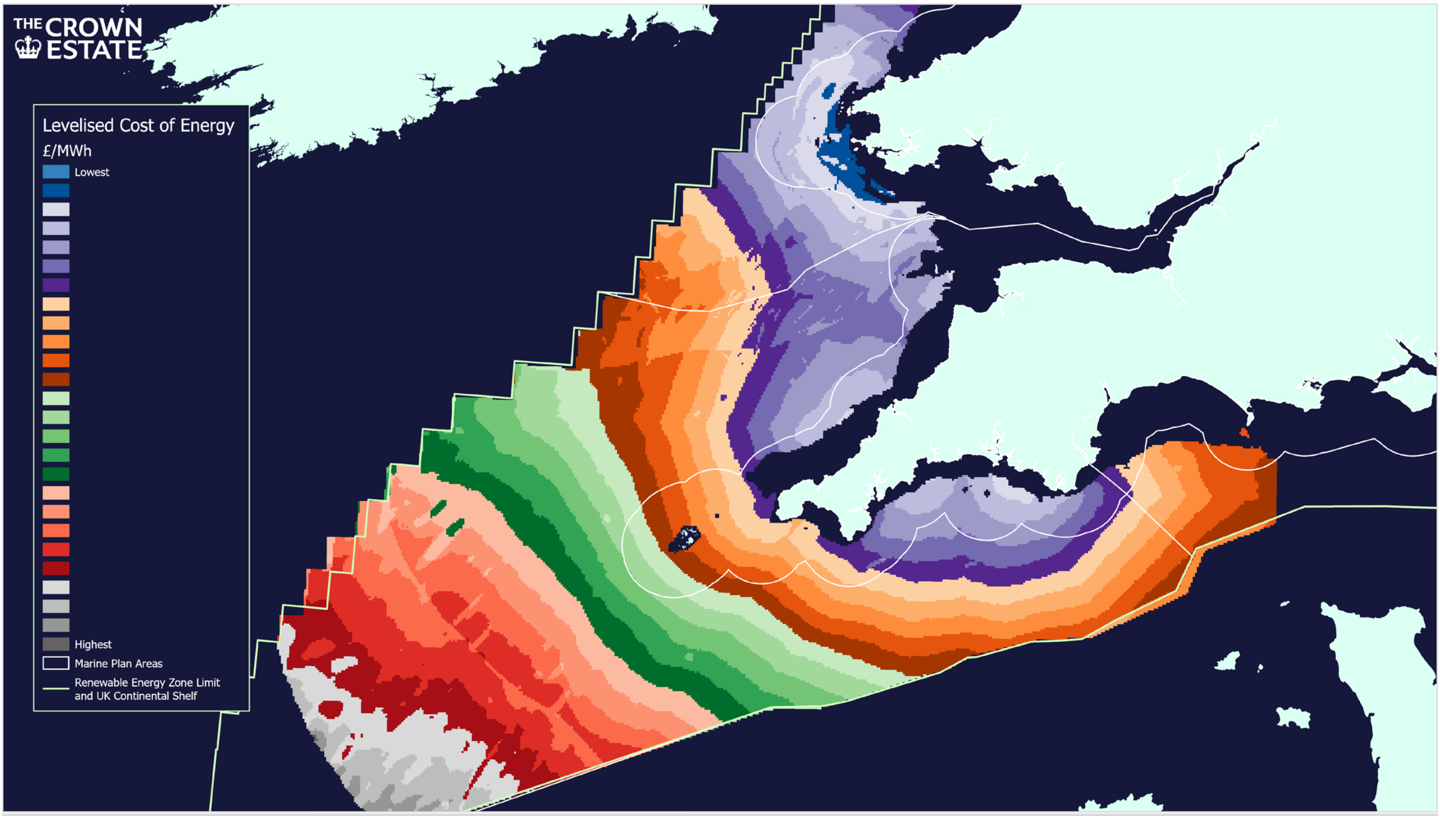


Figure 15: Spatial variation of relative Levelised Cost of Energy (bands are in £1/MWh graduations)

2.3.2.3 PROJECT PARAMETERS

The spatial extent of floating offshore wind farm projects within the Celtic Sea is linked to two key parameters: project capacity (MW) and power density (MW/sq. km).

Project capacity is determined based on a number of factors, including market trends, supply chain and consenting considerations and an assessment of the most cost-effective means of connecting projects to the national grid (taking into account potential co-ordinated grid solutions).

Power density is directly linked to inter-turbine spacing and affects both energy losses due to wake affects and engineering risk due to turbulence-induced mechanical fatigue loading. As part of our approach we have considered Levelised Cost of Energy (LCOE) to inform the location of PDAs. Further risk analysis included design optionality, installation and operational parameters such as extreme wave height and depth to bedrock. Individual PDA characteristics have been outlined in targeted PDA Characterisation Reports, which can be found in our document library. Section 4.6 covers the analysis completed in more detail.

2.3.3 BILATERAL ENGAGEMENT

From February to June of 2022, additional targeted engagement on specific topics was carried out to identify AoS within the least constrained 50 per cent of the restriction model output. Topics for targeted engagement included those discussed at February's workshop:

- Defence
- Navigation
- Civil Aviation
- Fisheries
- Environmental
- Cables

In addition to this, early spatial outputs were shared with National Grid Electricity System Operator (NGESO) to understand any grid related considerations. Continued engagement has helped to ensure opportunities for coordinated grid are explored in line with work underway through the Offshore Transmission Network (OTNR) review. Engagement was also sought with the North Sea Transition Authority (NSTA) on Carbon Capture Utilisation and Storage (CCUS) resource considerations. Lastly we held a number of bilateral engagement sessions with statutory marine stakeholders including Welsh Government and Government of Ireland.

Specific targeted engagement has continued throughout the spatial refinement process. Section 3 and Section 4 outline how sector specific considerations helped to shape the final PDAs. The following short sub-sections detail how we engaged with the variety of specific sectors and activities.

2.3.3.1 DEFENCE

The Crown Estate provided the Ministry of Defence with early spatial outputs. These were taken away for further analysis and we continued to work with the Ministry of Defence during spatial refinement to ensure alignment of priorities was understood and taken into account.

Bidders should note the potential need for Ministry of Defence (MoD) and civil radar mitigation measures for offshore wind development in this area. Enabling the co-existence of aviation and wind farm activity is being progressed through the cross-government and industry Joint Air Defence and Offshore Wind Mitigation Task Force. This includes the development of a strategic approach to providing mitigation across a number of wind farms (rather than project by project), in particular, for air defence radar. This work is also exploring potential requirements for developers to share the costs of funding the air defence radar mitigations required.

2.3.3.2 NAVIGATION

Navigation is a critical consideration to siting offshore wind development in respect of safety as well as the economic benefits it brings. We consulted with navigation experts from the Maritime and Coastguard Agency (MCA), Trinity House and Chamber of Shipping on early spatial outputs to help characterise navigational traffic in the region.
Stakeholder feedback identified potential risks of siting floating offshore wind within, or in close proximity to major navigational channels including routes into Milford Haven, those extending towards Ireland and northern routes extending past South Pembrokeshire. The characterisation supported the spatial refinement of the Areas of Search.

2.3.3.3 CIVIL AVIATION

The Crown Estate engaged with radar experts, National Air Traffic Services (NATS) to understand how civil radar may impact where floating offshore wind can be located. Through discussion, the process by which radar interference from offshore wind can be managed was understood in more detail. It was discussed that appropriate mitigation measures are available that wouldn't preclude development. Due to this complexity, civil radar interference data was removed from the spatial model. The data was instead reviewed against the model output alongside additional engagement with civil aviation stakeholders to inform the identification of PDAs.

2.3.3.4 FISHERIES

On-going engagement with the fisheries industry has yielded positive inputs to spatial design. Most notably, following an Offshore Wind Evidence and Change programme (OWEC) project which sought to work with offshore wind, government and fisheries stakeholders to identify ways of working to integrate fisheries knowledge into spatial design, a new Automatic Identification System (AIS) dataset[6] from EMODnet was identified.

[6] https://www.emodnet-humanactivities.eu/search-results.php?dataname=Vessel+Density+

The data provided greater representation of fishing effort, primarily in respect of the extent and resolution it provides. The dataset was engaged upon in the workshop in February 2022 within a targeted fisheries breakout room. The feedback in the session highlighted that it was the most appropriate dataset to use in the spatial analysis.

In addition we have engaged with the Welsh Fisheries Association (WFA) and the National Fisherman's Fishing Organisation (NFFO) to share early spatial outputs. Conversations yielded confirmation that the AoS identified have successfully sought to avoid important fishing grounds where possible.

Further engagement took place with the fisheries industry as the AoS were refined down to ensure the variety of fishing activities (both in terms of scale and gear type) and locations were accounted for and impacts are minimised.

2.3.3.5 ENVIRONMENTAL

Both statutory and environmental non-governmental organisations (NGOs) were engaged further to understand in more detail environmental considerations within the identified AoS. The South of Celtic Sea Deep Marine Conservation Zone (MCZ)[7] located within Area 3 was identified as a potential constraint.

The MCZ contains features associated to broad-scale habitat inclusive of; moderate energy circalittoral rock, subtidal coarse sediment, subtidal mixed sediments and subtidal sand. It was also raised that the area within 12NM inside Area 5 was highlighted as a potential issue from a visibility perspective, particularly in relation to the Isles of Scilly.

2.3.3.6 CABLES

The Crown Estate informed the European Subsea Cables Association (ESCA) of our spatial design approach. ESCA is a key stakeholder within the Celtic Sea region given the amount of cables that already navigate into coastal landings (see Figure 6) and the importance of this region for new cable connections. An update to the Cable Route Identification and Leasing Guidelines for floating offshore wind was funded by The Crown Estate, and will help to guide developers in the development of their floating offshore wind sites to ensure alignment with critical cable infrastructure.

Bilateral engagement with the range of organisations identified a number of potential risks within the AoS which are depicted within Figure 16. These hatched areas represent identified issues such as navigational safety, visual or environmental risks. An additional area of opportunity was also identified through engagement, also presented in Figure 16. This, alongside further feedback has supported the identification of PDAs.

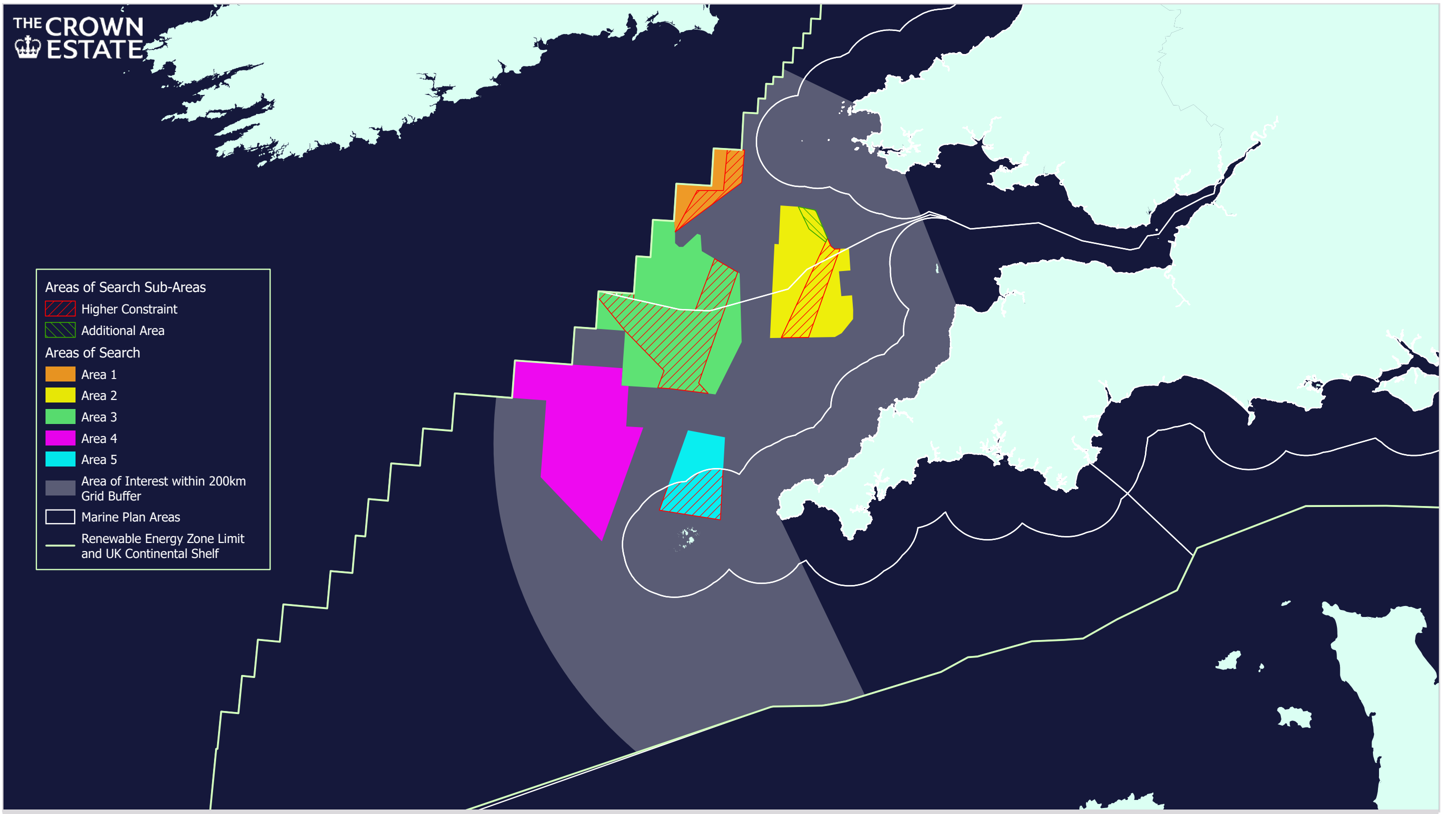


Figure 16: Areas of Search depicting potential risks and opportunity identified through bilateral engagement

[7] https://jncc.gov.uk/our-work/south-of-celtic-deep-mpa/

3. Areas of Search

The following sections provide a high-level characterisation of the known interactions that have the potential to impact floating offshore wind development for each AoS. The characterisation was informed by the spatial analysis and bilateral engagement following this (see Section 2.2 and 2.3).

3.1 AREA 1

Figure 17 shows Area 1 of the identified AoS and Table 1 outlines some of the initial risks flagged through the analysis and bilateral engagement on AoS. Area 1 is approximately 634km² in size.

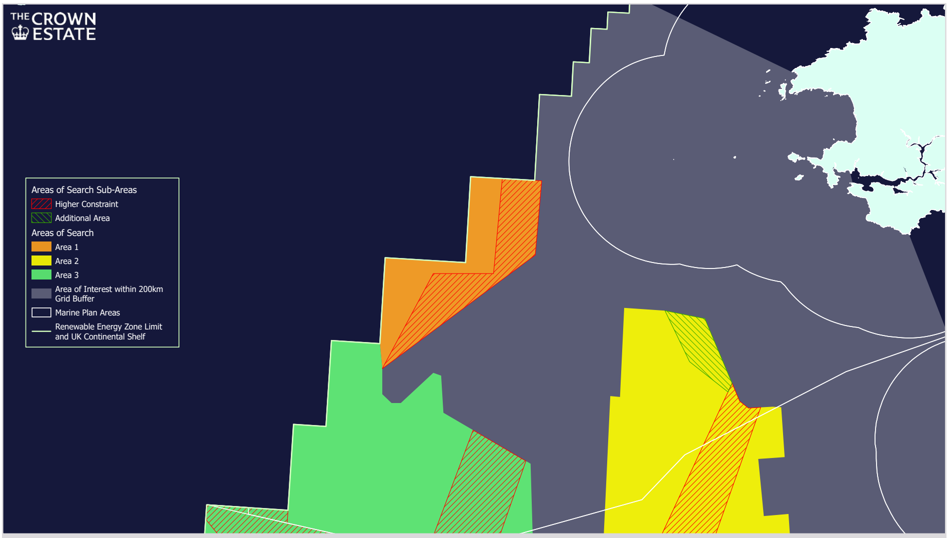


Figure 17: Floating Offshore Wind AoS 1

Interaction	Nature of interaction	Comment
Fisheries	Intersection with an area known to be used for fishing, specifically, Nephrops (langoustine).	The southern part of the hatched area within Area 1 represents the potential risk to fishing activity identified. We have engaged with fisheries stakeholders to understand the interaction in more detail. Further engagement has helped to refine Area 1.
Navigation	The AoS is within close proximity to a known Traffic Separation Scheme (TSS) to the North East of the AoS.	The northern part of the hatched area has been flagged as a potential risk. Sufficient distance between the TSS and any identified projects is required. We have engaged with navigational stakeholders to help characterise the route and to understand safety implications within the area. Further engagement has helped to understand the potential for bringing forward PDAs in Area 1.
Proximity to Exclusive Economic Zone (EEZ) boundary	The AoS aligns to the EEZ boundary.	Interactions across the border need to be sufficiently understood and a potential buffer distance applied to the boundary within which projects should not be located. Engagement with the Irish Government has been undertaken. We continued this when refining the AoS to PDAs.
Cables	The AoS has 5 active telecommunications cables running through it.	We have engaged with ESCA to inform them of our spatial design methodology. Further engagement has helped to build a deeper understanding of the interactions associated with existing cables and floating offshore wind development to enable identification of PDAs that minimise the narrowing of corridors for future cables.

Table 1: Interactions and risks flagged through the identification of floating offshore wind AoS 1

3.2 AREA 2

Figure 18 shows Area 2 of the identified AoS. Table 2 outlines some of the initial risks flagged through the analysis and bilateral engagement on AoS, as well as describing the reasoning behind an addition to the area. Area 2 is approximately 2,077km² in size.

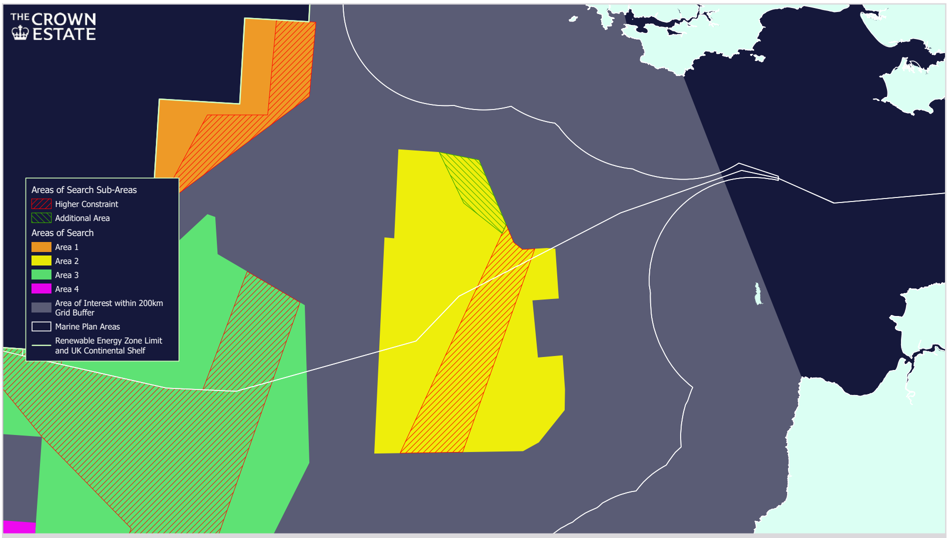


Figure 18: Floating Offshore Wind AoS 2

Interaction	Nature of interaction	Comment
Environmental	Intersection with an area potentially foraged by Lesser Black Back Gull.	The Crown Estate is carrying out a more detailed analysis of the interaction to ascertain the risk to the species ahead of the Plan-Level HRA.
Navigation	A known navigation channel that feeds into Milford Haven port intersects the AoS.	The channel is represented by the red hatched area in Figure 18. We have engaged with navigational stakeholders to help characterise the route and to understand safety implications within the Area. Further engagement has helped to refine Area 2.
Civil Aviation	Civil radar interference in the north of AoS 2.	We engaged with civil aviation experts to understand the potential impact of floating wind farms on civil aviation radar, and in particular the impact of including the green hatched area at this stage in spatial design. It was determined that inclusion was prudent until spatial refinement began to narrow down and identify PDAs.
Cables	The AoS has 7 active telecommunications cables running through it.	We have engaged with ESCA to inform them of our spatial design methodology. Further engagement has helped to build a deeper understanding of the interactions associated with existing cables and floating offshore wind development to enable identification of PDAs that minimise the narrowing of corridors for future cables.

Table 2: Interactions and risks flagged through the identification of floating offshore wind AoS 2

3.3 AREA 3

Figure 19 shows Area 3 of the identified AoS and Table 3 outlines some of the initial risks flagged through the analysis and bilateral engagement on AoS. Area 3 is approximately 4,075km² in size.

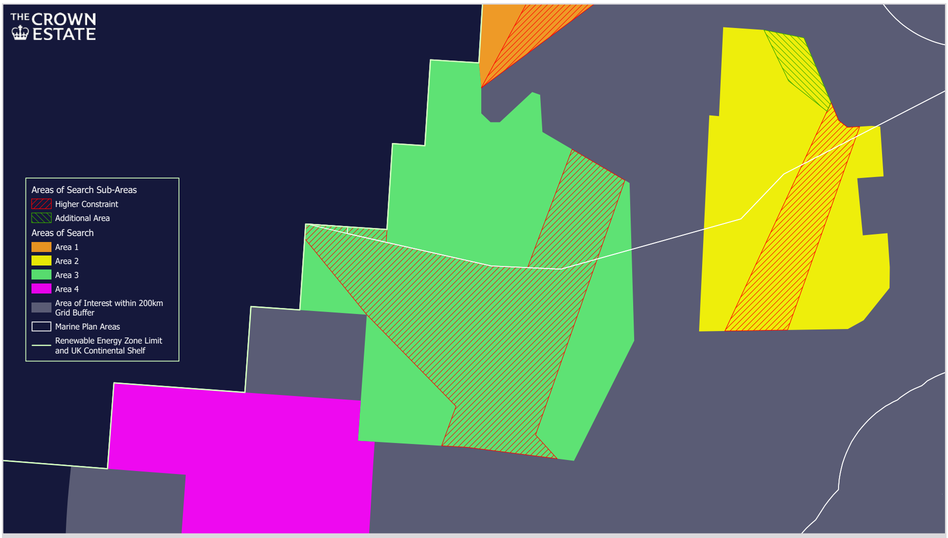


Figure 19: Floating Offshore Wind AoS 3

Interaction	Nature of interaction	Comment
Fisheries	The AoS sits just to the South of an area known to be used for fishing, specifically Nephrops (langoustine).	We have engaged with fisheries stakeholders to understand the interaction in more detail. Further engagement has helped to refine Area 3.
Navigation	Two navigation channels intersect the AoS. One extends north to south of the Eastern side of the AoS. The second transects diagonally South East to North West in the southern part of the AoS.	The identified navigation safety risks are located within the hatched area in Figure 19. We have engaged with navigational stakeholders to help characterise the route and to understand safety implications within the Area. Further engagement has helped to refine Area 3.
Environmental	The AoS surrounds the South of Celtic Deep MCZ.	The identified MCZ is located within the hatched area in Figure 19. Further understanding was sought on the features of the MCZ in respect of its potential to co-locate with floating offshore wind development. We engaged further with Statutory Nature Conservation Bodies as well as environmental NGOs to assess consideration of the MCZ in refinement.
Environmental	Intersection with an area potentially foraged by Lesser Black Back Gull.	The Crown Estate carried out a more detailed analysis of the interaction to ascertain the risk to the species ahead of the Plan-Level HRA.
Proximity to EEZ boundary	The AoS aligns to the EEZ boundary.	Interactions across the border need to be sufficiently understood and a potential buffer distance applied to the boundary within which projects should not be located. Engagement with the Irish Government has been undertaken. We sought to continue this engagement when refining the AoS to PDAs.
Cables	The AoS has 9 active telecommunications cables running through it.	We have engaged with ESCA to inform them of our spatial design methodology. Further engagement has helped to build a deeper understanding of the interactions associated with existing cables and floating offshore wind development to enable identification of PDAs that minimise the narrowing of corridors for future cables.

Table 3: Interactions and risks flagged through the identification of floating offshore wind AoS 3

3.4 AREA 4

Figure 20 shows Area 4 of the identified AoS and Table 4 outlines some of the initial risks flagged through the analysis and initial engagement. Although no hatched areas of higher risk were identified during bilateral engagement on AoS, a number of cables cross the area for which we subsequently engaged further on and any additional risks were accounted for through further spatial refinement and the identification of PDAs. Area 4 is approximately 3,297km² in size.

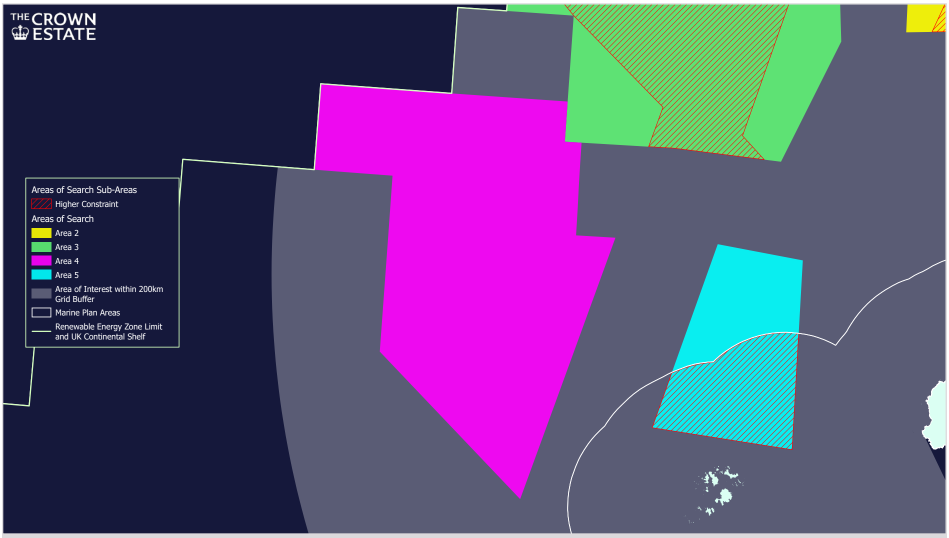


Figure 20: Floating Offshore Wind AoS 4

Interaction	Nature of interaction	Comment
Cables	The AoS has 9 active telecommunications cables running through it.	We have engaged with ESCA to inform them of our spatial design methodology. Further engagement has helped to build a deeper understanding of the interactions associated with existing cables and floating offshore wind development to enable identification of PDAs that minimise the narrowing of corridors for future cables.
Proximity to EEZ boundary	The AoS aligns to the EEZ boundary.	Interactions across the border need to be sufficiently understood and a potential buffer distance applied to the boundary within which projects should not be located. Engagement with the Irish Government has been undertaken. We continued this when refining the AoS to PDAs.

Table 4: Interactions and risks flagged through the identification of floating offshore wind AoS 4

3.5 AREA 5

Figure 21 shows Area 5 of the identified AoS and Table 5 outlines some of the initial risks flagged through the analysis and bilateral engagement on AoS. Area 5 is approximately 1,009km² in size.

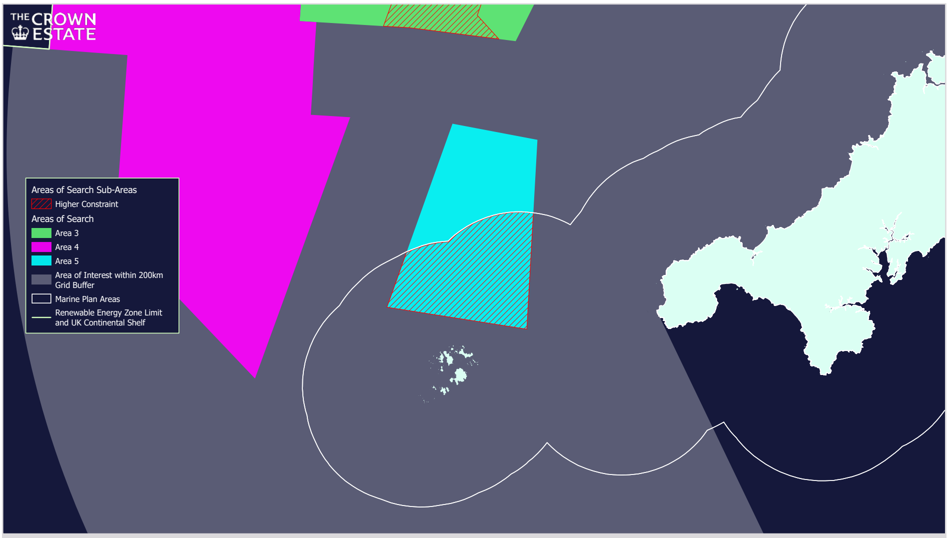


Figure 21: Floating Offshore Wind AoS 5

Interaction	Nature of interaction	Comment
Fisheries	Intersection of the AoS with an area known to be used for fishing.	The area of higher risk is identified within the red hatched area in Figure 21. We engaged with fisheries stakeholders to understand the interaction in more detail. Further engagement has helped to refine Area 5.
Visibility from protected landscapes	The AoS is identified as having potential visibility constraint in in relation to landscape designations, specifically from the Isles of Scilly.	The area of higher risk is identified within the red hatched area in Figure 21. We are aware of the risk associated with visual impact in the southern portion of Area 5. Further engagement took place with vested parties to ensure this consideration was drawn into spatial refinement.
Cables	The AoS has 2 active telecommunications cables running through it.	We have engaged with ESCA to inform them of our spatial design methodology. Further engagement has helped to build a deeper understanding of the interactions associated with existing cables and floating offshore wind development to enable identification of PDAs that minimise the narrowing of corridors for future cables.

Table 5: Interactions and risks flagged through the identification of floating offshore wind AoS 5

4. Spatial Refinement

4.1 OVERVIEW

The next phase of spatial design for floating offshore wind in the Celtic Sea region was spatial refinement. During the process, a series of smaller Refined Areas of Search (RAoS) were identified within the five broad AoS through detailed stakeholder engagement. Please see our [Summary Stakeholder Report] for more details.

A number of potential Project Development Areas (PDAs) were then identified within the RAoS and further bilateral engagement supported the identification of a final set of PDAs, representing the concluding step in the spatial design process. Figure 22 shows the three final PDAs in the context of the refinement process from AoS to PDAs. The PDAs sit within RAoS A and B.

The following sections will cover the definition of Refined Areas of Search through to PDAs.

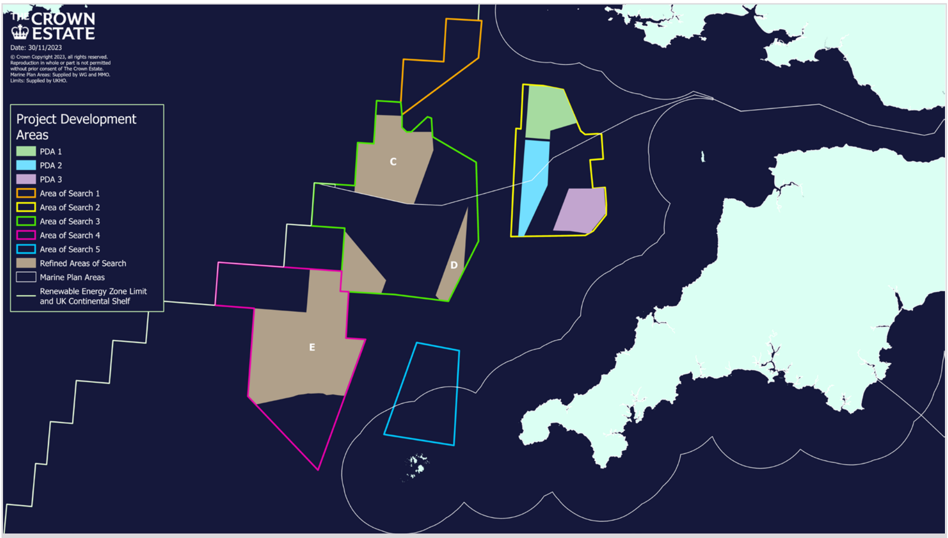


Figure 22: Three final PDAs within the context of the refinement process from AoS

4.2 REFINED AREAS OF SEARCH (RAOS)

[Figure 23] shows the five RAoS that were identified through the spatial refinement process. The five RAoS (Areas A to E located within AoS 2 to 4) represent just over 4,600km² of seabed. The refinement of the AoS has been undertaken through building on our initial targeted bilateral engagement between February and June of 2022, by reviewing feedback received from stakeholders via our AoS questionnaire in July 2022, and from further targeted bilateral engagement held since summer 2022.

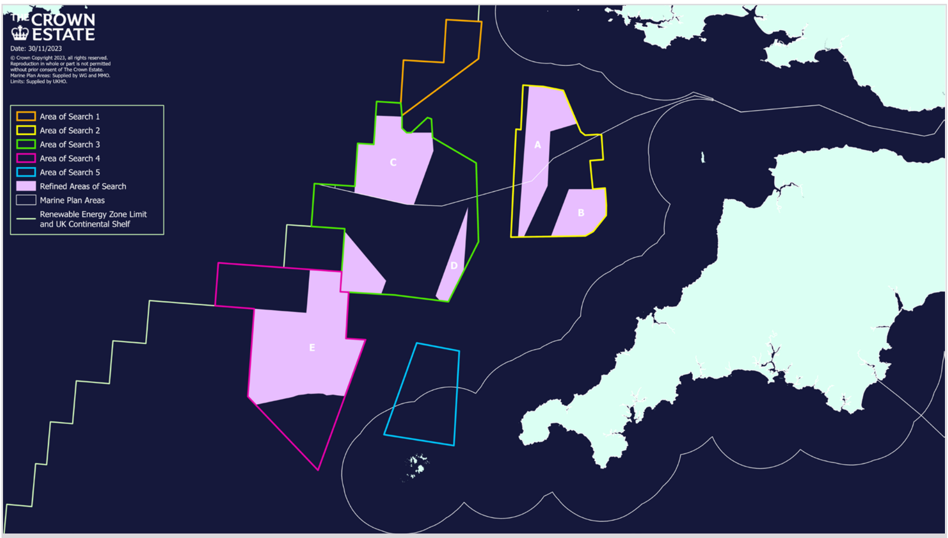


Figure 23: Five RAoS identified through the spatial refinement process

4.2.1 MARKET AND STAKEHOLDER QUESTIONNAIRE

In July 2022, directly after the announcement of our initial AoS, we sought to further engage with stakeholders to seek additional feedback on the five broad AoS, and the related constraints within these locations. The findings of this engagement were sought to further inform the spatial design and to support refinement of the AoS into smaller RAoS and subsequent PDAs. Specific details of the feedback and the actions taken forward as a result can be found in our Summary Stakeholder Report.

4.2.2 BILATERAL ENGAGEMENT

From July to September of 2022, additional targeted engagement on specific topics was carried out to identify RAoS within the AoS. Topics for targeted engagement included those already discussed with sector representatives in:

- Defence
- Navigation
- Civil Aviation
- Fisheries
- Environmental
- Cables

4.2.3 REMOVING AREAS OF SEARCH 1 AND 5

AoS 1 and 5 shown in Figure 24 were removed during the identification of RAoS. Throughout the process of refining AoS, we have sought to deliver PDAs that developers can be confident are most optimal for rapid deployment at current time to deliver on our ambition of up to 4.5GW of floating offshore wind in the Celtic Sea by 2035. The following subsections detail the reasoning behind the removal of AoS 1 and 5.

Area of Search 1

AoS 1 was removed on multiple grounds. Factors included a combination of fishing, environmental, navigation and subsea telecom cable interactions. The area intersects with a high intensity fishing ground for Nephrops (Langoustine). Environmentally, the area intersected with Tidal Front Mixing data provided by stakeholders in targeted engagement. The evidenced data suggests indications of higher instances of biodiversity in areas subject to increased mixing. From a navigation perspective, two major routes from TSS's East and West of the Isles of Scilly converge into a single TSS west of Pembrokeshire. The routes are in close proximity and feedback provided showed that development within the far north east of AoS 1 has the potential to displace commercial shipping activity. In combination, the outlined factors indicated that other areas were more preferable to larger GW scale development.

Area of Search 5

When considering Area 5, it was evident that there was potential for visual sensitivity in the southern portion of the area. Through our continued work with key stakeholders and consideration of the broad range of feedback, we deemed it appropriate to remove Area 5 due to a combination of constraints including visual sensitivity and fisheries.

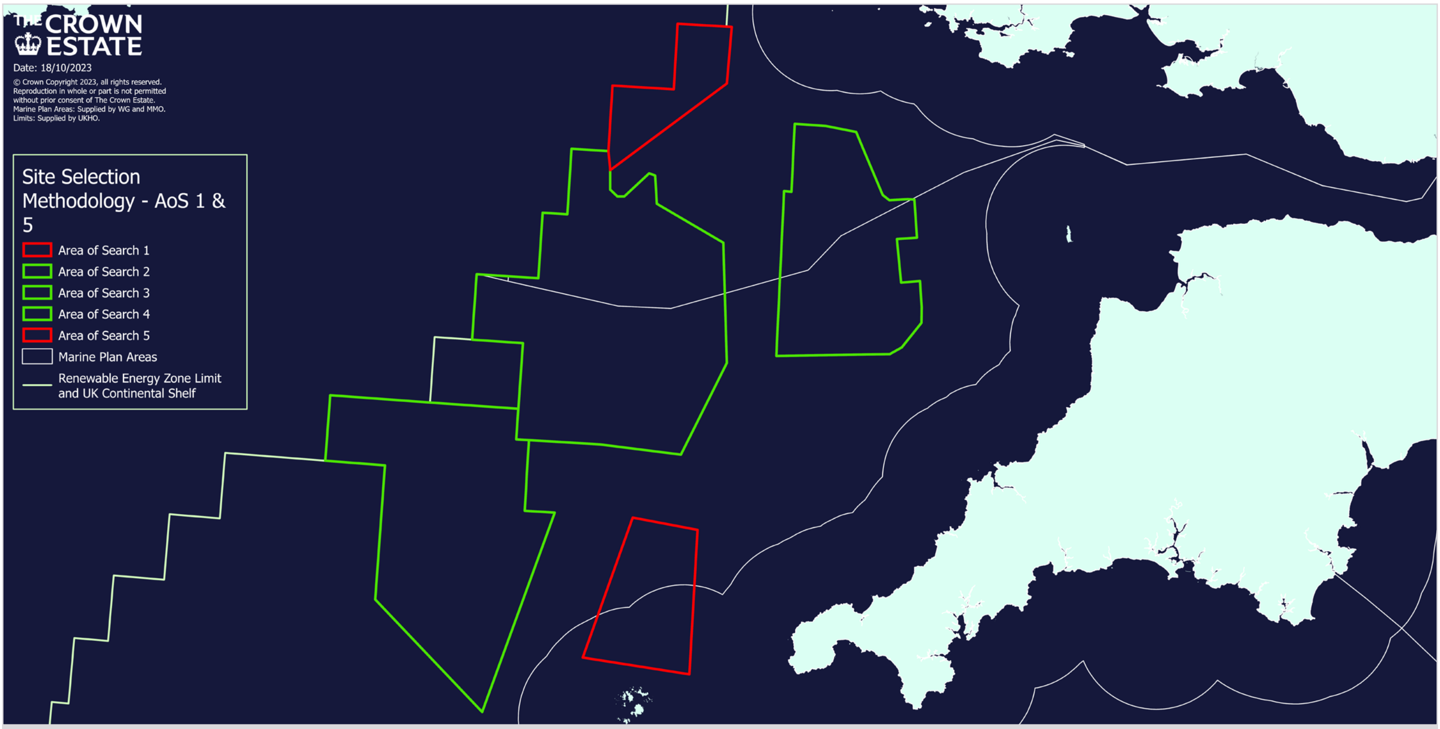


Figure 24: AoS 1 and 5 removed during the spatial refinement process

4.2.4 REFINED AREA OF SEARCH - A

Figure 25 shows RAoS A, and Table 6 outlines actions undertaken to aid refinement within AoS 2. RAoS A is approximately 810 km² in size.

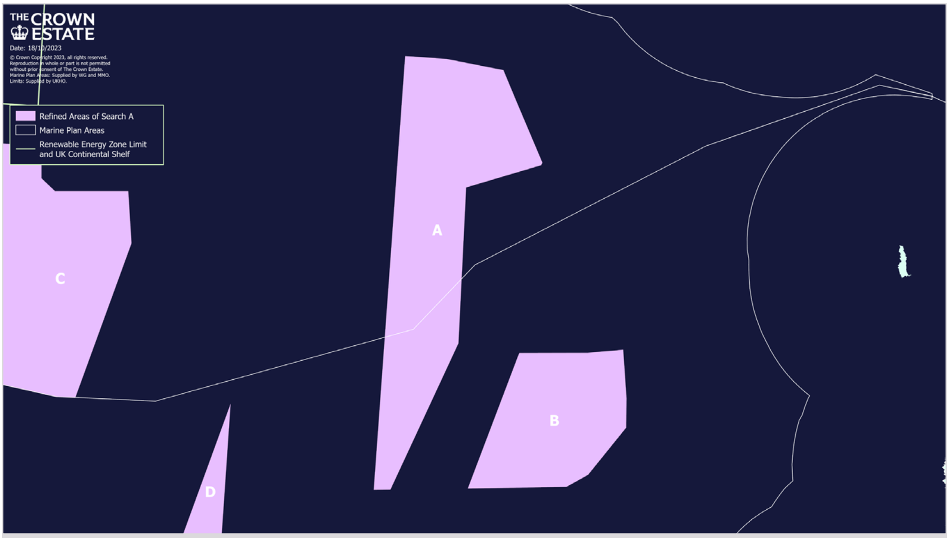


Figure 25: RAoS A

Interaction	Nature of interaction	Comment
Navigation	Alignment of the area east of the major shipping route extending between TSS's east of the Isles of Scilly and west of Pembrokeshire. Alignment of the area away from a less dense route extending into and out of Milford Haven.	Engagement with navigation stakeholders highlighted a requirement for greater space between the major route and a possible development. Please note this was extended to 2NM in final PDA 1 and 2 refinement. Previously identified constraint by navigation stakeholders, highlighted in AoS development was actioned and removed.
Fishing	Extension away from known static gear fishing activity east of the area	Targeted engagement with fishing representatives highlighted the extensive static gear fishing activity being undertaken within certain regions of AoS 2.
Civil Aviation	Civil radar interference intersects with Refined Area of Search A.	We have engaged with civil aviation experts to understand the potential impacts of floating wind farms on civil aviation radar. Suitable mitigation has been assessed as likely to be available.

Table 6: Actions taken to aid refinement within AoS 2, resulting in RAoS A

4.2.5 REFINED AREA OF SEARCH - B

Figure 26 shows RAoS B, and Table 7 outlines actions undertaken to aid refinement within AoS 2. RAoS B is approximately 371 km² in size.

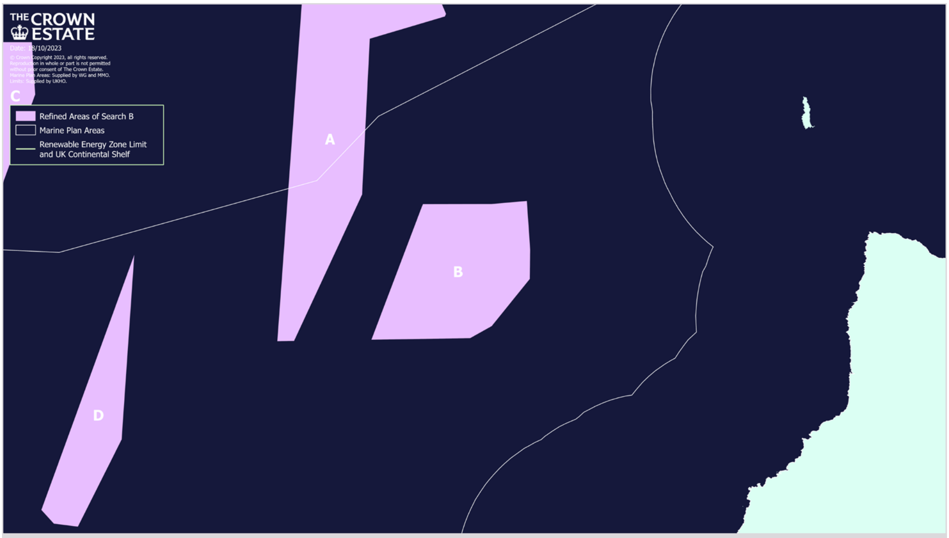


Figure 26: RAoS B

Interaction	Nature of interaction	Comment
Navigation	Alignment of the area away from a less dense route extending into and out of Milford Haven.	Previously identified constraint by navigational stakeholders, highlighted in AoS development was actioned and removed.
Fishing	Extension away from known static gear fishing activity north of the area	Targeted engagement with fishing representatives highlighted the extensive static gear fishing activity being undertaken within certain regions of AoS 2.

Table 7: Actions taken to aid refinement within AoS 2, resulting in RAoS B

4.2.6 REFINED AREA OF SEARCH - C

Figure 27 shows RAoS C, and Table 8 outlines actions undertaken to aid refinement within AoS 3. RAoS C is approximately 953km² in size.

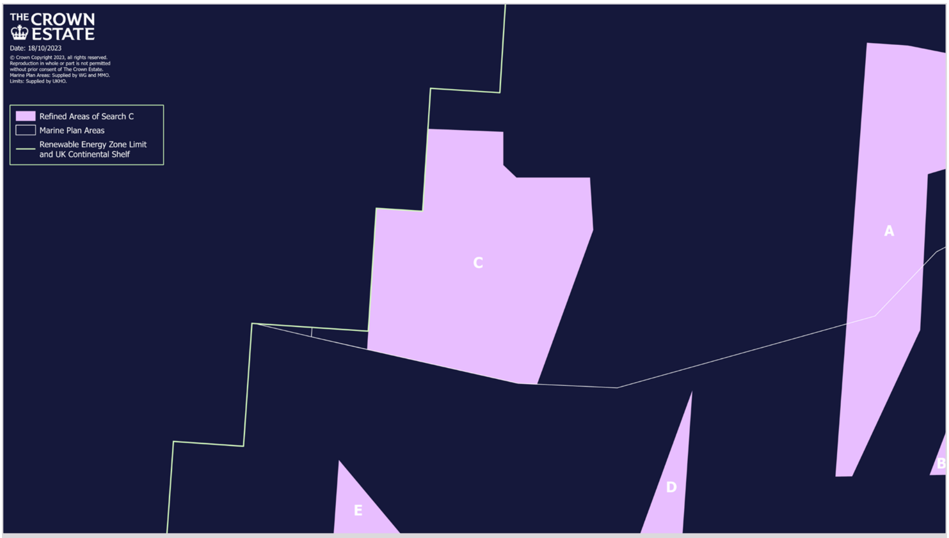


Figure 27: RAoS C

Interaction	Nature of interaction	Comment
Navigation	Alignment of the area west of the major route extending between TSS's west of the Isles of Scilly and west of Pembrokeshire.	Previously identified constraint by navigational stakeholders, highlighted in AoS development was actioned and removed.
Fishing	Extension away from known fishing activity to the north and east of the area.	Targeted engagement with fishing representatives highlighted extensive fishing activity being undertaken within certain regions of AoS 3.
Environment	To not intersect with South of Celtic Deep MCZ.	Previously identified constraint by environmental stakeholders, highlighted in AoS development was actioned and removed.

Table 8: Actions taken to aid refinement within AoS 3, resulting in RAoS C

4.2.7 REFINED AREA OF SEARCH - D

Figure 28 shows RAoS D, and Table 9 outlines actions undertaken to aid refinement within AoS 3. RAoS D is approximately 281km² in size.

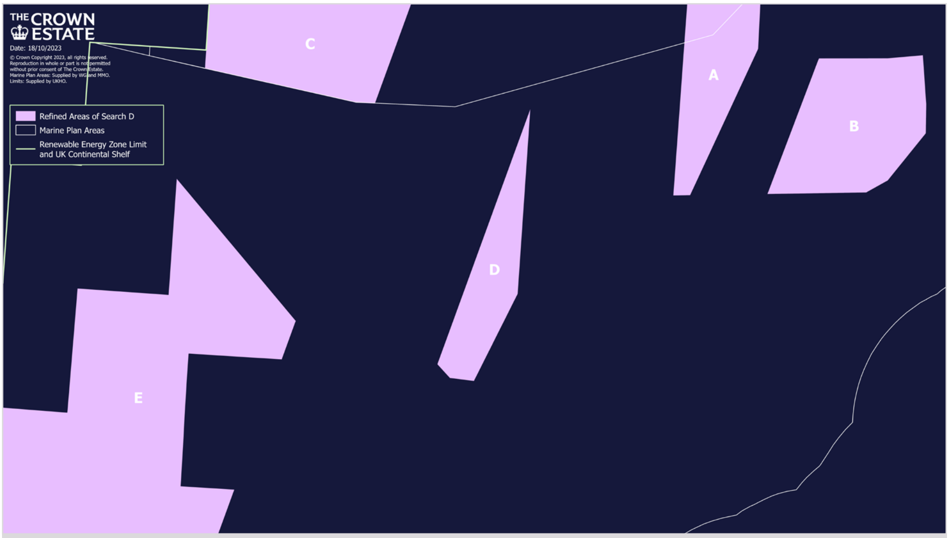


Figure 28: RAoS D

Interaction	Nature of interaction	Comment
Navigation	Alignment of the area east and west of the major route extending between TSS's east and west of the Isles of Scilly and west of Pembrokeshire.	Previously identified constraint by navigational stakeholders, highlighted in AoS de-velopment was actioned and removed.
Fishing	Extension away from known fishing activity to the south east of the area.	Targeted engagement with fishing representatives highlighted extensive fishing activity being undertaken within certain regions of AoS 3.

Table 9: Actions taken to aid refinement within AoS 3, resulting in RAoS D

4.2.8 REFINED AREA OF SEARCH - E

Figure 29 shows RAoS E, and Table 10 outlines actions undertaken to aid refinement within AoS 3 and 4. RAoS E is approximately 2,220km² in size.

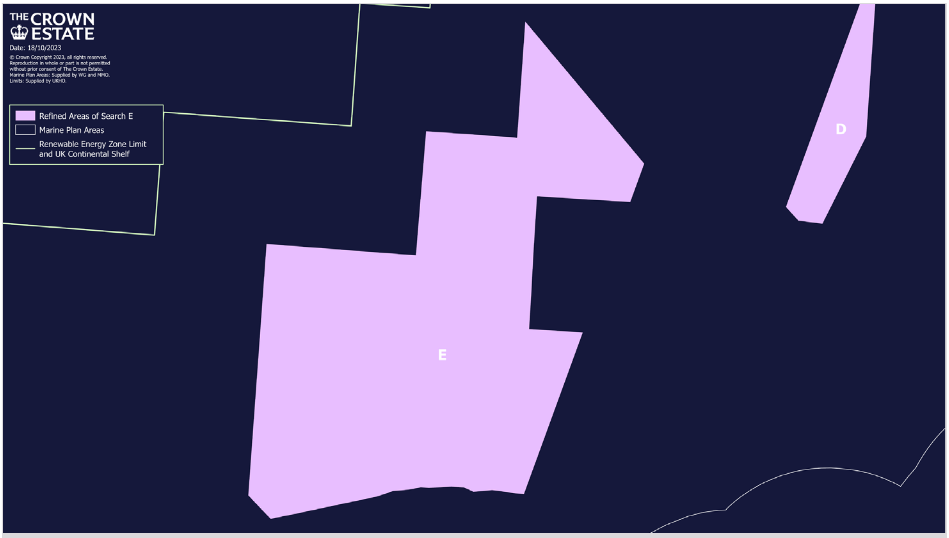


Figure 29: RAoS E

Interaction	Nature of interaction	Comment
Fishing	Extension away from known fishing activity to the north west and south of the area.	Targeted engagement with fishing representatives highlighted extensive fishing activity being undertaken within certain regions of AoS 3 and 4.
Cables	Alignment of the RAoS to buffer away from a cable route to the far south of the area.	Targeted engagement with ESCA has yielded specific actions throughout the spatial design process including consideration of appropriate buffers.

Table 10: Actions taken to aid refinement within AoS 3 and 4, resulting in RAoS E

4.3 PROJECT DEVELOPMENT AREAS

4.3.1 SPATIAL CONSIDERATIONS IN THE CELTIC SEA

As part of its work, The Crown Estate has continuously engaged a wide range of stakeholders, including governments, industry and the full range of seabed users. This has focused on a number of important issues, including the spatial work to identify broad AoS, with the aim of refining these into PDAs to be made available to market via tender.

This engagement has helped highlight that the Celtic Sea is subject to many competing demands and that there are a number of spatial considerations and policy drivers that the UK Government has worked to resolve, supported by The Crown Estate.

As a result of these constraints, we have focused our attention on delivering PDAs within two of the RAoS (A and B).

4.3.2 MINDED-TO SCENARIO

In July 2023 The Crown Estate published a minded-to scenario (Figure 30) for Offshore Wind Leasing Round 5. The scenario included 4 PDAs totalling up to 4GW in potential capacity. As part of the update, a series of questions were provided to market participants. Specific technical and spatial feedback from the market outlined the importance of ensuring there is spatial flexibility to meet the potential capacity from the round. As a result of the feedback, the scenario was amended to deliver a three PDA scenario detailed in Section 4.3.4 and our Round 5 press release.

4.3.3 FINAL PDA SCENARIO

The spatial design for the three PDAs was agreed with UK Government and developed through close engagement with other seabed users and in response to market feedback. **Figure 31** shows the final PDA scenario for Offshore Wind Leasing Round 5. The spatial design represents three distinct PDAs within the Celtic Sea. Each PDA will be made available for a capacity of up to 1.5GW each, resulting in a leasing round delivering up to 4.5GW.

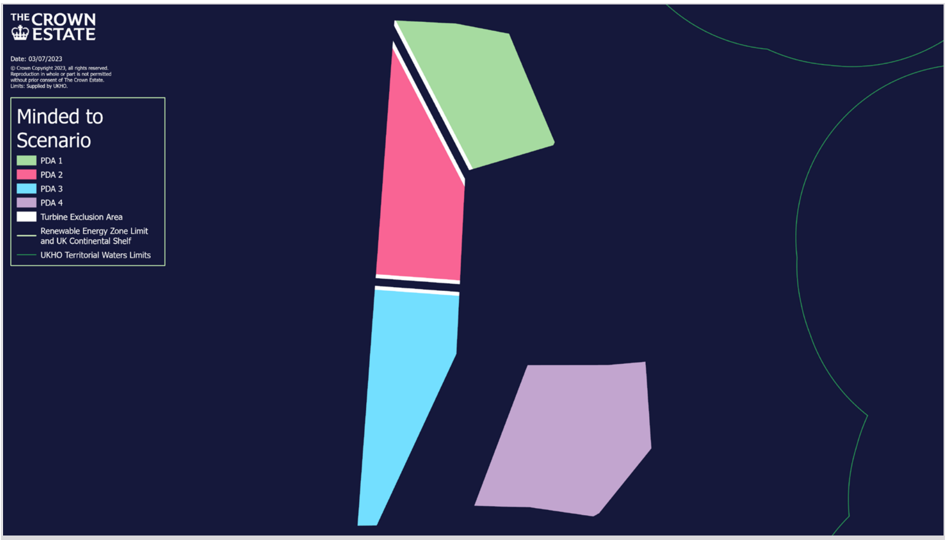


Figure 30: Minded to PDA scenario published in July 2023

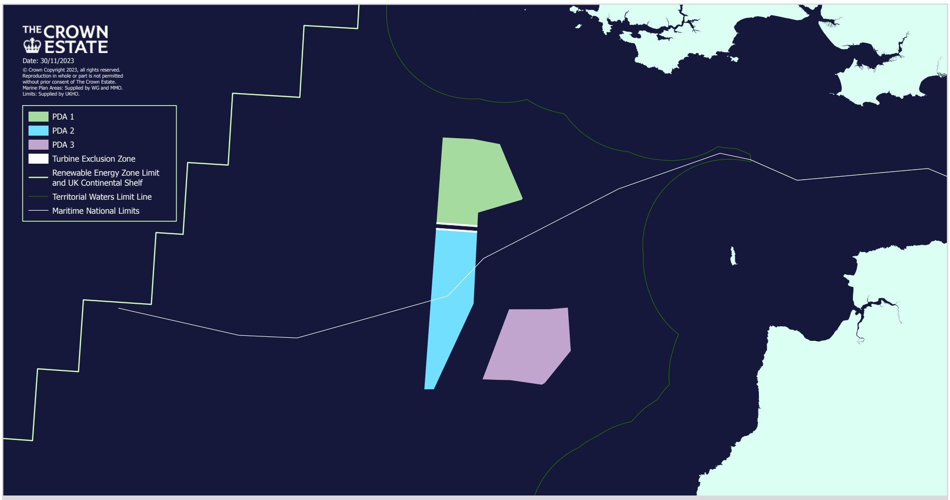


Figure 31: Final PDAs

Each PDA's respective size is detailed here:

- PDA 1 - 369 km²
- PDA 2 - 358 km²
- PDA 3 - 334 km²

Within PDAs 1 and 2 there is a Turbine Exclusion Zone (TEZ) which is designed to ensure separation of turbines on the boundary of a PDA which may be immediately adjacent to the boundary of another PDA. It is an area within which foundation anchors can be installed, but in which the turbine cannot be located. This is to ensure there is always a 2km distance between centre-points of turbines (including allowing for maximum excursion of the foundation on its moorings) in neighbouring PDAs.

The next section details the final refinement steps taken to identify three PDAs within RAoS A and B. Considerable characterisation and refinement of the RAoS had already been undertaken as part of the spatial refinement process to date, resulting in minimal spatial changes within the RAoS.

4.3.4 PDA 1

Figure 32 shows PDA 1, and Table 11 outlines actions undertaken to aid refinement within RAoS A.

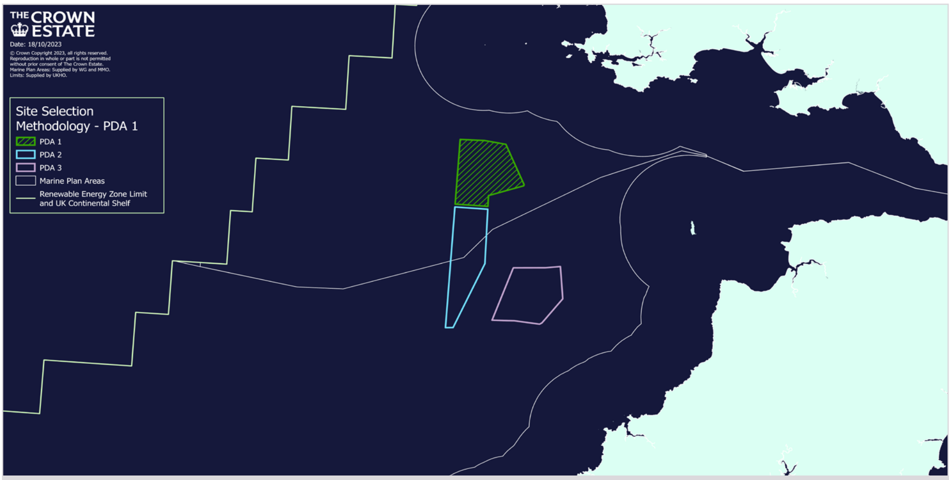


Figure 32: PDA 1

Interaction	Nature of interaction	Comment
Navigation	Ensure a 2 NM buffer between the western PDA boundary and the major navigation route that extends from the east of the Isles of Scilly TSS to the TSS west of Pembrokeshire	Final engagement with navigation stakeholders yielded taking a precautionary approach to ensure navigational safety was as far as possible, built into PDA identification. The guidance on distance used is found in the Marine Coastguard Authorities, Marine Guidance Note 654.
Environment	Ensure a 500m buffer to the Skomer, Stokholm and the seas of Pembrokeshire SPA	A precautionary buffer taken after engagement with SNCB's.
Civil Aviation	Civil radar interference intersects with PDA 1.	We have engaged with civil aviation experts to understand the potential impacts of floating wind farms on civil aviation radar. Suitable mitigation has been assessed as likely to be available. Specific details should be assessed at project level.

Table 11: Actions undertaken to aid refinement within RAoS A, resulting in PDA 1

4.3.5 PDA 2

Figure 33 shows PDA 2, and Table 11 outlines actions undertaken to aid refinement within RAoS A.

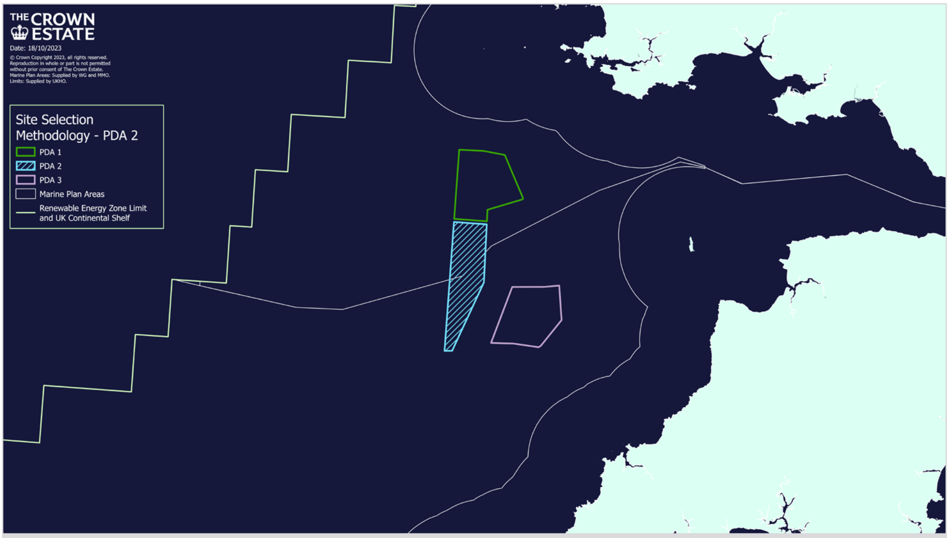


Figure 33: PDA 2

Interaction	Nature of interaction	Comment
Navigation	Ensure a 2 NM buffer between the western PDA boundary and the major navigation route that extends from the east of the Isles of Scilly TSS to the TSS west of Pembrokeshire	Final engagement with navigation stakeholders yielded taking a precautionary approach to ensure navigational safety was as far as possible, built into PDA identification. The guidance on distance used is found in the Marine Coastguard Authorities, Marine Guidance Note 654.

Table 12: Actions undertaken to aid refinement within RAoS A, resulting in PDA 2

4.3.6 PDA 3

Figure 34 shows PDA 3, and Table 13 outlines actions undertaken to aid refinement within RAoS B.

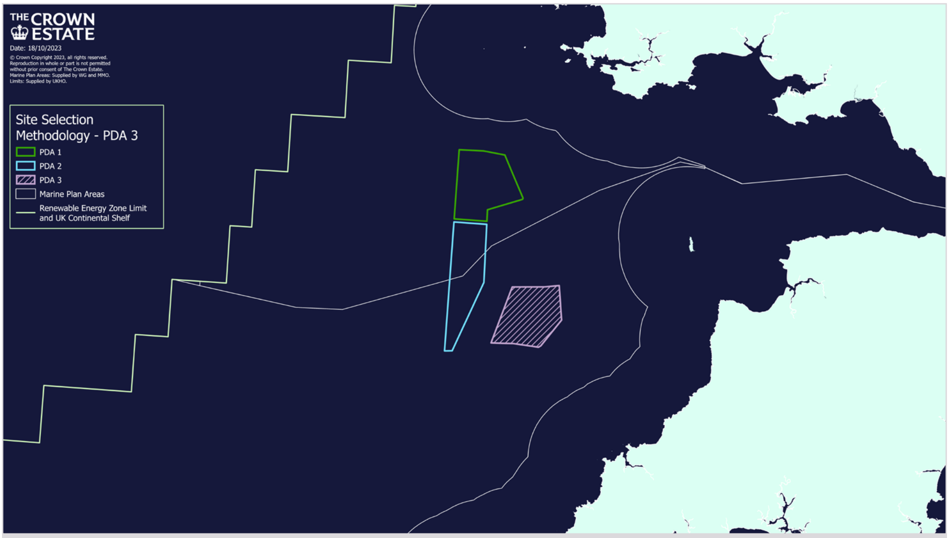


Figure 34: PDA 3

Interaction	Nature of interaction	Comment
Navigation	No specific action taken for PDA 3.	No specific comments.
Environment	Ensure a 500m buffer to the Bristol Channel Approaches SAC and the Bristol MCZ	A precautionary buffer taken after engagement with SNCB's
Cables	Ensure subsea cable buffer of 250m to the south of the PDA.	Targeted engagement with ESCA has outlined specific actions throughout the spatial design process including consideration of appropriate buffers.

Table 13: Actions undertaken to aid refinement within RAoS B, resulting in PDA 3

4.4 ELECTRICITY NETWORK

National Grid Electricity System Operator (ESO) and National Grid Electricity Transmission (NGET) have been engaged throughout the spatial design process. As part of the Pathway to 2030 workstream of the Offshore Transmission Network Review (OTNR) being delivered by National Grid ESO, Round 5, and the evolution of PDA selection and leasing round capacity, has been included and considered within the scopes of the Holistic Network Design (HND), and follow-up exercise (HNDFUE) for the Celtic Sea region. The output of the HNDFUE for the Celtic Sea will be a recommended offshore electricity transmission network design to connect the final PDAs to onshore grid substations. More information about the ongoing process can be found here on National Grid ESO's website.

4.5 TELECOMMUNICATIONS CABLES

Subsea telecoms cables represent critical connectivity and resilience to communication for the United Kingdom. The Celtic Sea holds routes that connect North America, Europe and Africa. Our engagement with the industry association, the European Subsea Cables Association (ESCA) has taken place throughout the spatial design process and has aided in how existing and future cables are considered in the design process.

As part of the engagement, we undertook an assessment of the service and operation dates for the cables running through the region. The assessment utilised industry knowledge with ESCA, as well as targeted engagement with specific owners.

The result of the assessment alongside the continued engagement on cables throughout the process has led to well characterised and understood cable interactions within the PDAs. Please refer to our PDA Characterisation Reports for more details.

4.6 ENGINEERING

The Crown Estate has undertaken a spatial analysis of Levelised Cost of Energy (LCOE) and engineering risk, utilising our Technical Advisor's proprietary offshore wind software capability 'SCALE'. Due to the high commercial sensitivity of this material, the analysis outputs are not presented to bidders. However, each PDA Characterisation Report contains a summary of the key physical input parameters which informed the engineering risk assessment.

LCOE analysis involves processing spatial input data and running a series of techno-economic models to calculate the cost to develop, construct, operate and decommission an offshore wind farm project. Our analysis revealed that PDAs 1 to 3 span an area of relatively low LCOE, benefitting from proximity to shore and less extreme metocean conditions, as compared to the rest of the Celtic Sea Area of Interest.

The engineering risk assessment picked up technical spatial considerations that are less readily captured in LCOE analysis. This considered risks associated with design optionality, installation and operation such as extreme wave height and depth to bedrock. PDAs 1 to 3 were found to span areas of significant but mitigable engineering risk and the risk rating is relatively low compared to the Celtic Sea Area of Interest in general.

5. Next steps

The final spatial design for offshore wind leasing Round 5 has now concluded. The PDAs will feed into the tender process for Round 5, subject to the Plan-Level HRA Conformity Check. More details can be found in Section 5.1.

5.1 HRA DETAILS

Following confirmation of the three PDAs, the technical work on HRA will continue to progress, with the process anticipated to conclude in early 2024.

To support delivery of our Plan-level HRA, we are continuing to engage with and consult our independently overseen HRA Expert Working Group. This incorporates consultation with the relevant UK statutory marine planning authorities, statutory nature conservation bodies and relevant non-governmental organisations. As our marine environment becomes increasingly busy, our up-front and strategic approach to plan-level HRA, to discharge our statutory obligations under the Habitat Regulations, supports us in ensuring that we deliver against our ambitions regarding nature and biodiversity whilst de-risking and accelerating the tender process.

5.2 ADDITIONAL DOCUMENTATION

In addition to the final methodology, further documentation including Project Development Area Characterisation Reports, a Summary Stakeholder Report and a Peer-Review of the spatial design approach are encouraged to be read in conjunction with this methodology report. Further details are set out in the following sections.

5.2.1 PROJECT DEVELOPMENT AREA CHARACTERISATION REPORTS

Spatial Design for Offshore Wind Leasing Round 5 has sought to identify the most suitable locations within the Celtic Sea to enable the first commercial scale Floating Offshore Wind offering. Three PDAs have been characterised against the various users and activities in the region in combination with a high level assessment of cost and technical risk. They represent locations close to onshore grid infrastructure and with low levels of constraint following extensive stakeholder engagement and spatial analysis.

The reports outline key PDA information, considerations and links to external guidance. This is achieved by the characterisation of each PDA against sections including Environment, Navigation, Sub-sea Telecoms, Fishing, Civil Aviation, Defence, Marine Plans and any legacy seabed uses (disposal sites). The reports also contain a summary of a Technical/Engineering assessment for each PDA.

5.2.2 SUMMARY STAKEHOLDER REPORT

The Summary Stakeholder Feedback Report sets out how The Crown Estate has engaged with statutory and non-statutory stakeholders throughout the development of the spatial design of Offshore Wind Leasing Round 5. It provides details of the engagement activities carried out to inform the design of the spatial areas made available to the market for tender, summarises the feedback that was received, and sets out how The Crown Estate addressed and made regard to feedback from various stakeholder groups.

5.2.3 PEER-REVIEW

An independent peer-review of the spatial design approach for Offshore Leasing Round 5 has been completed by independent consultants. The work was undertaken to assess and validate that the approach is fit for purpose, building on the spatial design completed for Offshore Wind Leasing Round 4. The detailed report can be found on our document library.

5.2.4 GIS STORY MAP

To help bring the spatial design to life further, we have created a GIS Story Map to visualise the process from spatial analysis to the final PDAs in an accessible and shorter format. The Story Map can be found here.

6. Glossary

AfLs	Agreements for Lease
AHP	Analytic Hierarchy Process
AIS	Automatic Identification System
AONB	Area of Outstanding Natural Beauty
AoS	Large areas of sea space identified in the Celtic Sea region, presented in this report following detailed spatial modelling and stakeholder engagement, within which smaller Project Development Areas (PDAs) will be located.
CCUS	Carbon Capture Utilisation and Storage
DEFRA	Department for Environment, Food and Rural Affairs
DEM	Digital Elevation Model
EEZ	Exclusive Economic Zone
ESCA	European Subsea Cables Association
GIS	Geographic Information System
HRA	Habitats Regulations Assessment
HS	Historic Scotland
HVAC	High-Voltage Alternating Current
HVDC	High-Voltage Direct Current
IMO	International Maritime Organisation
JNCC	Joint Nature Conservation Committee
KRAs	Key Resource Areas
MaRS	Marine Resource System
MCA	Maritime Coastguard Agency
MCZ	Marine Conservative Zone
MHW	Mean High Water
MoD	Ministry of Defence
NATS	National Air Traffic Services
NE	Natural England
NFFO	National Federation of Fisherman's Organisations
NGESO	National Grid Electricity System Operator
NGET	National Grid Electricity Transmission
NGO	Non-Governmental Organisation
NIEA	Northern Ireland Environment Agency
NRW	Natural Resources Wales
NS	Nature Scot
NSTA	North Sea Transition Authority
NM	Nautical Mile
OTNR	Offshore Transmission Network Review
OWEC	Offshore Wind Evidence and Change Programme
PDAs	Smaller areas of sea space identified through further stakeholder engagement, environmental and technical analysis, within which an individual floating offshore wind project could be developed. These areas will be offered up to tender.
PIANC	Permanent International Association of Navigation Congresses
RAoS	Smaller areas of sea space, within AoS, identified through further stakeholder engagement, environmental and technical analysis
TSS	Traffic Separation Scheme
WFA	Welsh Fishermen's Association

Appendix 1 - Data audit and pre-processing

In advance of completing the weighted analysis of soft constraints (see Section 2.2.3), a review of all data holdings including third party and asset data was undertaken to ensure that appropriate and up to date information was used.

Two new datasets were also created or adapted for inclusion in this model:

The Visibility from Sensitive Receptors data layer was produced to identify areas of sea surface that are highly visible from terrestrial sensitive receptors (i.e. Areas of Outstanding Natural Beauty (AONBs), National Parks, Heritage Coasts and World Heritage sites).

The below steps were followed to create this layer:

1. Several spatial datasets[8] containing information on the location of landscape designations were merged and dissolved to create one combined sensitive receptor layer.
2. The combined sensitive receptor layer was clipped to areas falling within 40km of the coastline. The value of 40km is cited by Everoze as the maximum view distance that should be used to inform offshore wind leasing.
3. Observer points were then extracted by overlaying a digital elevation model (DEM) of the UK with the combined sensitive receptor layer (within 40km of the coastline). These observer points represent discrete areas within sensitive receptor sites and contain information on the elevation at each point.
4. The observer points were then used to perform a geodesic viewshed analysis. This generated a raster dataset identifying areas of the sea surface which are highly visible from these sensitive receptor areas.

The spawning and nursery grounds layer was created by combining the separate Cefas high intensity spawning and nursery grounds species counts[9] together to provide an overview of which areas are most used by different species for both spawning and nursery.

[8] AONBs (Natural England (NE), Natural Resources Wales (NRW), Northern Ireland Environment Agency (NIEA)); Heritage Coast (NE, NRW); National Parks (NE, NRW, NatureScot (NS)); World Heritage (Historic England (HE), Cadw, NIEA); Scheduled Monuments (HE, Cadw, NIEA)

[9] Ellis, J.R., Milligan, S.P., Readdy, L., Taylor, N. and Brown, M.J. (2012). Spawning and nursery grounds of selected fish species in UK waters. Cefas Lowestoft, 147: 56 pp

Appendix 2 - Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a structured technique for dealing with complex decisions developed by mathematician Thomas L. Saaty in 1977[10]. AHP provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements; relating those elements to overall goals; and, for evaluating alternative solutions.

The theory behind AHP states that it is generally only possible to compare the significance of inputs across seven criteria at a time and therefore uses a tree structure to define mini multi criteria analysis calculations that feed up into a more complex analysis. The methodology ensures that a robust, traceable, repeatable and defendable prioritisation is undertaken.

Criteria representing soft constraints are organised into themes and subthemes. These are then structured into a hierarchy, grouping similar criteria together. This allows the relative barriers to development of each data layer to be defined in a coherent, structured format with statistical rigor applied to how the input criteria will impact on the final output. It also has the benefit of breaking models down for stakeholders. This allows focussed discussions about the relative importance of similar assessment criteria and clearer incorporation of stakeholder views into analysis. As a result, a more transparent modelling methodology is utilised.

To achieve this, the datasets in Appendix 4 were grouped into four tiers representing the chosen themes and subthemes (See Figure 22). Below outlines what each tier of the model represents:

Tier 1 - Tier 1 represents the high-level themes which all the criteria (or data layers) are grouped into at the first stage of analysis. The themes identified are economic, environmental, and social. These themes are weighted against each other at the top of the hierarchy and the overall weightings dictate the relative influence the sub-criteria beneath them. For example, if the economic theme is weighted significantly higher than the social theme, then the criteria and data in the social theme will have a lower influence on the output than those in the economic theme. This is controlled as all weightings in each branch of the tree must add up to 1. Detail on the pairwise comparisons, which fed into the weightings, can be found further down in this appendix.

Tier 2 - Tier 2 represents sub-themes that have been added to accommodate the large number of criteria that form under each of the themes in Tier 1. The theory behind AHP states that it is only possible to compare the significance of inputs across up to seven criteria at a time before the individual input of each criteria becomes insignificant. We therefore add sub-themes to limit the number of datasets that are being compared with one another at each level in the tree.

The Tier 2 sub-themes in each branch are weighted against each other and dictate the relative influence the sub-criteria beneath them can have on the overall model. Example subthemes include navigation & shipping, subsurface activity and environmental criteria which allow for the categorising of data or assessment criteria.

Tier 3 - Lastly, criteria and individual data layers sit within Tier 3 under the separate groupings for each Tier 2 heading. For example, all the navigation criteria sit under the "navigation and shipping" subtheme and all the historic criteria sit under the historic sub-theme. The criteria in each of these Tier 3 groups are data layers and are weighted against each other to establish which present the highest risk to development.

Tier 4 - Tier 4 represent datasets that are continuous across the Area of Interest (e.g. raster datasets). These require categorising within the datasets to establish relative importance of different levels a specific activity (e.g. fishing intensity).

Four of the datasets included within the model are continuous and therefore represent Tier 4. These datasets required additional processing to permit inclusion within the model. This additional processing work relates to: Navigation AIS Density; Fisheries AIS Density; Recreational Yachting AIS Density; Visibility from Sensitive Receptors.

First they were split into classes of intensity. The methods utilised to classify these intensity intervals for each dataset are outlined in Table 6. We then defined the levels of influence the higher intensity of activity should have over lower classes in the final output based on the pairwise comparison result of their Tier 3 parent.

[10] Saaty, T.L. 1977. A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology 15 (3)

Dataset	Classification Method
Navigation AIS Density	The data was split into classes using an equal interval approach and weighted linearly[11]
Fisheries AIS Density	The data was split into classes using an equal interval approach and weighted linearly
Recreational Yachting AIS Density	The data was split into classes using an equal interval approach and weighted linearly
Visibility from Sensitive Receptors	Classified using a quantile method[12] and weighted so that areas of high visibility from landscape designations are weighted significantly higher than lower classification groups.

Table 6: A summary of how the continuous datasets were classified to create groupings of intensity levels that were then weighted in Tier 4 using AHP

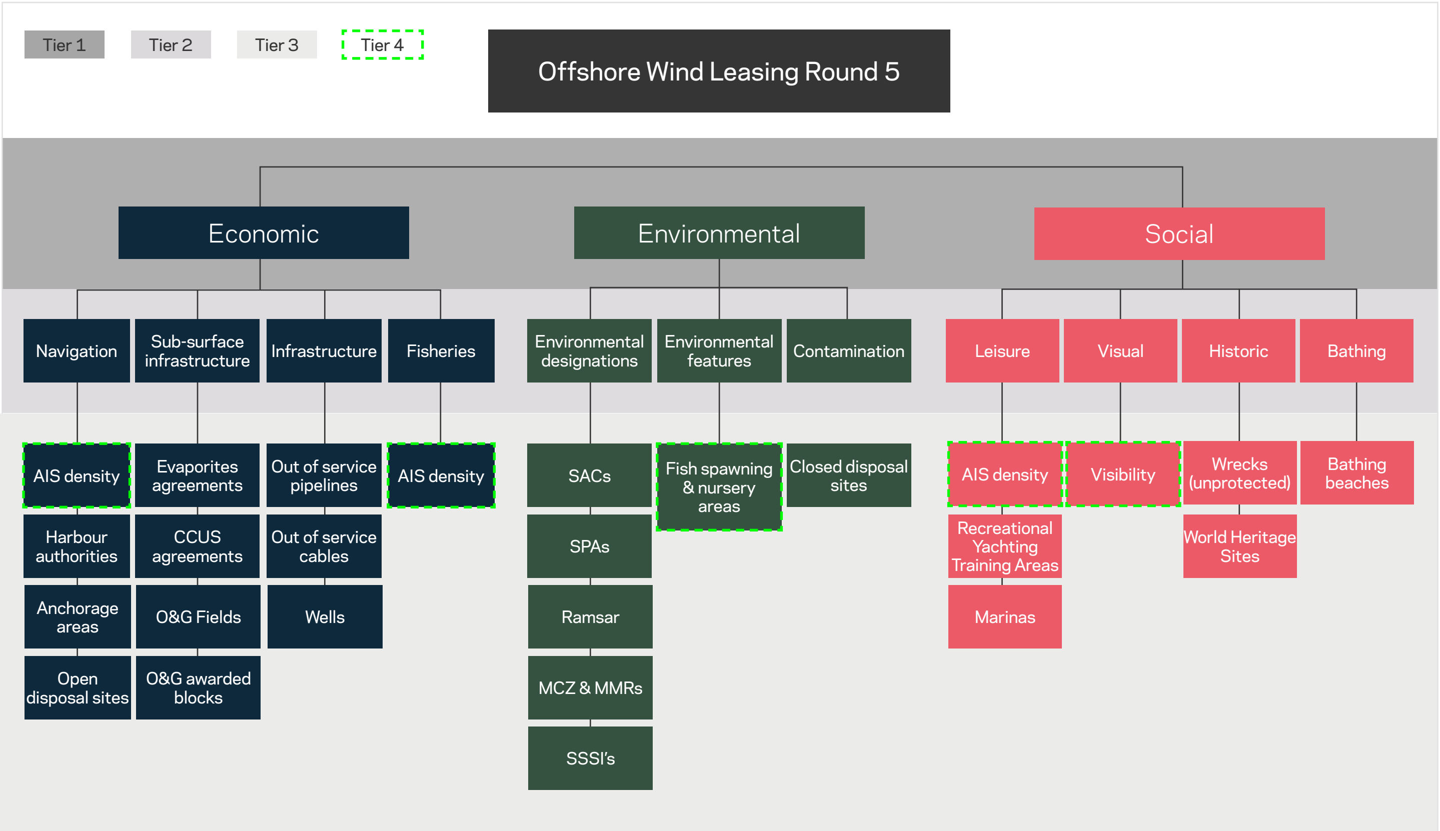


Figure 22: Final AHP model structure for Offshore Wind Leasing Round 5 where datasets are grouped into themes and subthemes across four tiers.

[11] Equal interval classification: this method splits the data into equal intervals based on the range of data i.e. if there are classes over a data range of 0-1, breaks would occur at 0.2, 0.4, 0.6, 0.8 and 1. This method takes no account of the distribution of data across the range so could result in 90 per cent of data displayed as one class.

[12] Quantile Classification: This method defines breaks at points which ensure there is an equal number of features within each class. This ensures an even distribution of the data across each class but means that the break points will be at non-uniform points throughout the data.

PAIRWISE COMPARISONS

Pairwise Comparisons is the process by which two criteria are compared to establish relative importance to one another. We ran the pairwise comparisons process with stakeholders for Tiers one to three in the model using Spice Logic software[13] within breakout groups at a workshop in February 2022. The aim of this was to seek stakeholder expertise and acquire input to the comparisons proposed for floating offshore wind leasing from key stakeholders. These comparisons informed the final restriction model weightings alongside feedback received through bilateral engagement.

A pairwise comparison between each relevant themed criteria or data in each tier was conducted using the scale within Figure 23. Using the Environment and Social themes in Tier 1 as an example, the top scale shows that a score of 1 means that the two criteria are of equal risk to development and as you as you increase the scale on the left, the level of importance of the Environment theme increases. Essentially, where a criteria drops down on one side of the scales, this is indicating that it would have a heavier weighting in the model (or pose a higher risk to the development of floating offshore wind) than the other criteria. A score of 3 means that the Environment theme poses moderately more risk to the development of floating offshore wind, 5 poses a strong risk in comparison, 7, a very strong risk and 9 extremely more risk when compared with the other theme.

Figure 24 shows a worked example of the weights that are applied to the Navigation & Shipping sub-theme criteria. In this example, harbour authority areas are being compared on the left with other navigation criteria on the right. It was concluded that the development of floating offshore wind poses highest risk to the density of shipping traffic criterion which has the made the top scale drop down to the right, with harbour authority areas identified as the next most constraining as the next two scales show that harbour authority areas have more weight, dropping down to the left. Anchorage areas are constrained in location to where suitable technical conditions are found, for example, shelter, appropriate seabed type and proximity to ports. It was considered that these presented a lower level of risk to development than the two other criteria as it was deemed that suitable alternative locations could be sought if proposals were brought forward in these areas.

Disposal sites were deemed to be the lowest risk to development as they are easiest to re-locate. The outcome of the weighting is shown in the bar chart. In this example, the pairwise comparison has resulted in the shipping density data having the highest relative priority and the disposal sites representing the lowest.

As each pairwise comparison was worked through, a consistency score was generated, ensuring the statistical robustness of the analysis. A full list of the final pairwise comparisons, which fed into the weightings, can be found in Tables 7 to 21. This lists the user defined pairwise scores and includes explanations for the scoring of each tier and criteria.

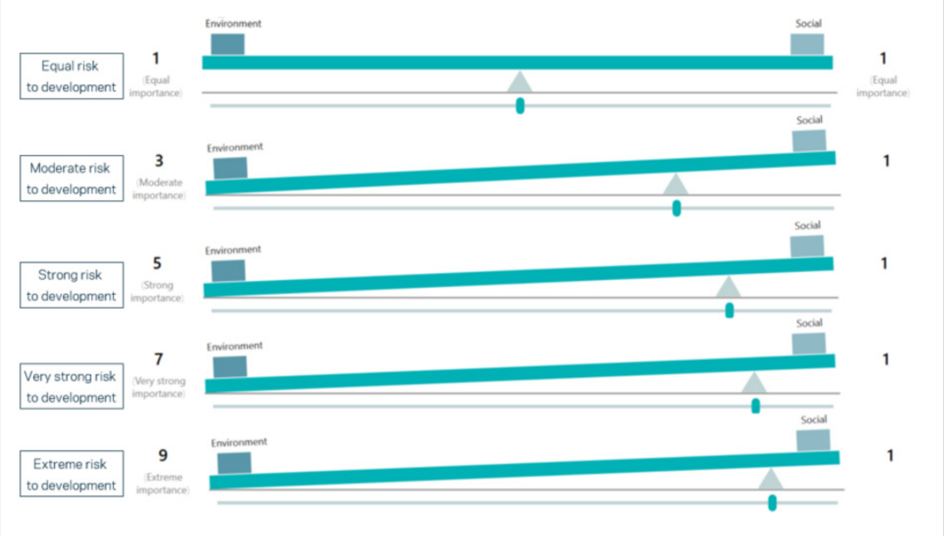


Figure 23: Pairwise comparison scale

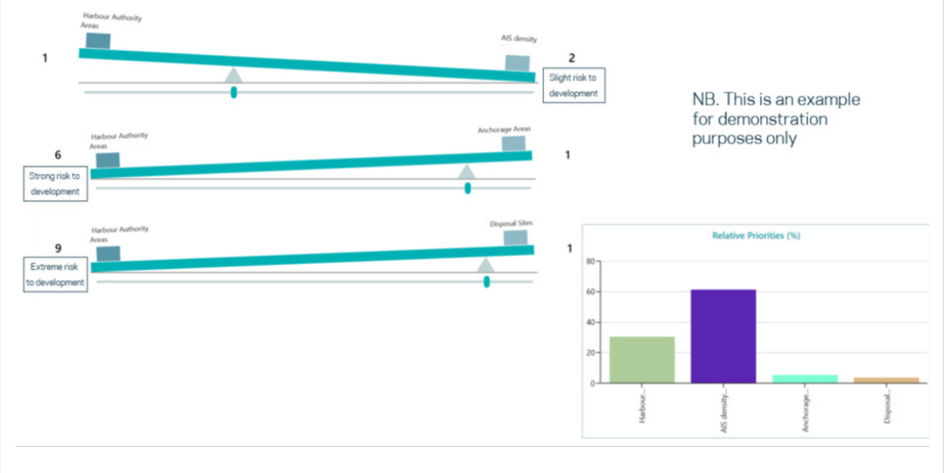


Figure 24: Worked example of pairwise comparisons and relative weightings

[13] https://www.spicelogic.com/Products/ahp-software-30

PAIRWISE COMPARISON OUTPUT

TIER 1

In the pairwise comparison within Table 7, Economic and Environmental were weighted equally, with a lower weighting given to Social. There were mixed views for Tier 1 during the marine stakeholder workshop in February 2022, and not all stakeholder groups were able to reach consensus, or have the opportunity to engage at this tier level due to limited time. As such, a decision was taken based on the feedback received to lower the social theme in line with previous offshore wind leasing weighting. For Economic and Environmental themes, both have significant amounts of data that detail constraint to development well.

The social theme was weighted at a slightly lower level due to the contents of the theme being a subset of true social constraint e.g. there is no consideration of economic typologies of coastal communities that may be impacted (positively or negatively) by development.

Model Name	Tier 2 ID	Global Weight	Pairwise Comparisons		
			1-Economic	2-Environmental	3-Social
1-Economic	1	0.4	1.00	1.00	2.00
2-Environmental	2	0.4	1.00	1.00	2.00
3-Social	3	0.2	0.50	0.50	1.00

Table 7: Pairwise scores assigned to each theme that makes up Tier 1

TIER 2

In the Economic theme pairwise comparison within Table 8 Fisheries and Navigation & Shipping were weighted highest against other sub-themes within the group. Stakeholder discussion within the Economic sub-themes yielded consensus that Navigation & Shipping alongside Fisheries should be weighted highest. Subsurface and Infrastructure were identified in multiple groups to be weighted the lowest within the group.

Model Name	Tier 3 ID	Group Name	Pairwise Comparisons			
			Navigation & Shipping	Subsurface	Fisheries	Infrastructure
1-Economic	1a	Navigation & Shipping	1.00	2.00	1.00	5.00
1-Economic	1b	Subsurface	0.50	1.00	0.50	2.00
1-Economic	1c	Fisheries	1.00	2.00	1.00	5.00
1-Economic	1e	Infrastructure	0.20	0.50	0.20	1.00

Table 8: Pairwise scores for each subtheme in Tier 2 that constitutes the Economic theme

In the environmental theme pairwise comparison in Table 9, Environmental Designations were weighted highest against other sub-themes within the group. In the marine stakeholder workshop there was wide consensus that Environmental Designations be weighted the highest in this tier due to the known interactions with offshore wind development, and Contamination Risk was agreed to be weighted the lowest against all others within that group. A mobile species sub-theme was engaged on at the marine stakeholder workshop. However, there was concern about weighting individual species above, or below one another. In addition, confidence about effectively modelling their distribution was also low. As such, the sub-theme was removed from the tiered hierarchy. It should be noted that mobile species are being considered during spatial refinement either through the Plan-Level HRA or through the review of additional data and evidence that has been made available to us following engagement at the marine stakeholder workshop.

Model Name	Tier 3 ID	Group Name	Pairwise Comparisons		
			Environmental Designations	Contamination	Fish Spawning and Nursery Grounds
2-Environmental	2a	Environmental Designations	1	8	3
2-Environmental	2b	Contamination Risk	0.125	1	1
2-Environmental	2c	Fish Spawning and Nursery Grounds	0.333	1	1

Table 9: Pairwise scores for each subtheme in Tier 2 that constitutes the Environmental theme

In the Social theme pairwise comparison in Table 10 Leisure Craft and Visual were weighted highest against other sub-themes within the group. Engagement at the marine stakeholder workshop indicated broad agreement on the weightings. The Historic Environment sub-theme was originally included under the Environmental theme but following feedback from stakeholders that this more appropriately sat under the Social theme it was moved.

Model Name	Tier 3 ID	Group Name	Pairwise Comparisons			
			Leisure Craft	Visual	Bathing & Diving	Historic Environment
3-Social	3a	Leisure Craft	1	1	6	1
3-Social	3b	Visual	1	1	6	1
3-Social	3c	Bathing & Diving	0.166	0.166	1	0.5
3-Social	3d	Historic Environment	1	1	2	1

Table 10: Pairwise scores for each subtheme in Tier 2 that constitutes the Social theme

TIER 3

Table 11 shows the pairwise comparisons for the Navigation & Shipping sub-theme. Navigation AIS Density was weighted highest against other datasets within the group. In the marine stakeholder workshop it was noted that the other datasets (namely Harbour Authority Areas and Anchorage Areas) were less likely to interact with floating wind development and as such, are weighted lower.

Model Name	Group Name	Pairwise Comparisons			
		Harbour Authority Areas	Navigation AIS Density	Anchorage Areas	Open Disposal Sites
1a- Navigation & Shipping	Harbour Authority Areas	1.00	0.50	2.00	2.00
1a- Navigation & Shipping	Navigation AIS Density	2.00	1.00	5.00	9.00
1a- Navigation & Shipping	Anchorage Areas	0.50	0.20	1.00	2.00
1a- Navigation & Shipping	Open Disposal Sites	0.50	0.11	0.50	1.00

Table 11: Pairwise scores for each data layer in Tier 3 that constitutes the Navigation & Shipping sub-theme

Table 12 shows the pairwise comparisons for the Subsurface sub-theme. Evaporites Agreements, CCUS Agreements and O&G Fields were weighted equally within the group with a lower weighting given to O&G Awarded Blocks. In the marine stakeholder workshop there was broad agreement of the weightings with limited discussion on amending them.

Model Name	Group Name	Pairwise Comparisons			
		Evaporites Agreements	CCUS Agreements	O&G Fields	O&G Awarded Blocks
1b- Subsurface	Evaporites Agreements	1.00	1.00	1.00	3.00
1b- Subsurface	CCUS Agreements	1.00	1.00	1.00	3.00
1b- Subsurface	O&G Fields	1.00	1.00	1.00	3.00
1b- Subsurface	O&G Awarded Blocks	0.33	0.33	0.33	1.00

Table 12: Pairwise scores for each data layer in Tier 3 that constitutes the Subsurface sub-theme

Only one dataset was included within the fisheries sub-theme (Table 13) and therefore no pairwise comparisons were required within the group.

Model Name	Group Name	Pairwise Comparisons
		Fisheries AIS Density
1c-Fisheries	Fisheries AIS Density	1.00

Table 13: Pairwise scores for each data layer in Tier 3 that constitutes the Fisheries sub-theme

The pairwise comparison in Table 14 represents the scores from the Infrastructure theme. Plugged and Abandoned Wells were weighted highest against other datasets within the group. This was emphasised in the marine stakeholder workshop where it was commented that there would be limited potential for such structures to be moved. Feedback also included that out of service cables were deemed as having the lowest weight as there was no risk of contamination unlike out of service pipelines.

Model Name	Group Name	Pairwise Comparisons		
		Plugged and Abandoned Wells	Out of Service Pipelines	Out of Service Cables
1e-Infrastructure	Plugged and Abandoned Wells	1.00	7.00	8.00
1e-Infrastructure	Out of Service Pipelines	0.14	1.00	3.00
1e-Infrastructure	Out of Service Cables	0.13	0.33	1.00

Table 14: Pairwise scores for each data layer in Tier 3 that constitutes the Infrastructure sub-theme

Table 15 shows the pairwise comparisons for all datasets within the Environmental Designations sub-theme. All datasets were weighted equally with the exception of SSSIs, which has a lower weighting. This was generally agreed to be appropriate in the marine stakeholder workshop due to the strength of the legislation associated with SSSI protection when compared to other designations. Notably MCZs were considered by stakeholders to be of the same weight as other designations that have historically been perceived as providing a higher level of protection.

Model Name	Tier 3 ID	Group Name	Pairwise Comparisons				
			SPAs	SACs	Ramsars	MCZs & MNRs	SSSIs
2a-Environmental Designations	2ai	SPAs (European)	1.00	1.00	1.00	1.00	8.00
2a-Environmental Designations	2aii	SACs (European)	1.00	1.00	1.00	1.00	8.00
2a-Environmental Designations	2aiii	Ramsars (European)	1.00	1.00	1.00	1.00	8.00
2a-Environmental Designations	2aiv	MCZs & MNRs	1.00	1.00	1.00	1.00	8.00
2a-Environmental Designations	2av	SSSIs	0.13	0.13	0.13	0.13	1.00

Table 15: Pairwise scores for each data layer in Tier 3 that constitutes the Environmental Designations sub-theme

Only one dataset was included within the Contamination Risk sub-theme (Table 16) and therefore no pairwise comparisons were required within the group.

Model Name	Group Name	Pairwise Comparisons
		Closed Disposal Sites
2b-Contamination Risk	Closed Disposal Sites	1.00

Table 16: Pairwise scores for each data layer in Tier 3 that constitutes the Contamination Risk sub-theme

Only one dataset was included within the Environmental Features sub-theme (Table 17) and therefore no pairwise comparisons were required within the group.

Model Name	Group Name	Pairwise Comparisons
		Fish Spawning and Nursery Grounds
2c-Fish Spawning and Nursery Grounds	Fish Spawning and Nursery Grounds	1.00

Table 17: Pairwise scores for each data layer in Tier 3 that constitutes the Environmental Features sub-theme

The pairwise comparisons within the Leisure Craft sub-theme are shown in Table 18. Recreational Yachting AIS density was weighted higher than all other datasets within the group as it provides a true reflection of the routes leisure craft are using. Consensus on the pairwise scorings was reached at the marine stakeholder workshop.

Model Name	Group Name	Pairwise Comparisons		
		Recreational Yachting AIS intensity	Marinas	Recreational Yachting Training Areas
3a-Leisure Craft	Recreational Yachting AIS density	1.00	3.00	3.00
3a-Leisure Craft	Marinas	0.33	1.00	1.00
3a-Leisure Craft	Recreational Yachting Training Areas	0.33	1.00	1.00

Table 18: Pairwise scores for each data layer in Tier 3 that constitutes the Leisure Craft sub-theme

Only one dataset was included within the fisheries sub-theme (Table 19) and therefore no pairwise comparisons were required within the group.

Model Name	Group Name	Pairwise Comparisons
		Visibility from Sensitive Receptors
3b-Visual	Visibility from Sensitive Receptors	1.00

Table 19: Pairwise scores for each data layer in Tier 3 that constitutes the Visual sub-theme

Table 20 provides the pairwise comparisons for the Bathing & Diving sub-theme. Diving Sites were weighted higher than Bathing Beaches as there was greater risk of a negative interaction, particularly as beaches would be located significantly farther away than floating offshore wind developments. Consensus on the pairwise scoring was reached at the marine stakeholder workshop.

Model Name	Group Name	Pairwise Comparisons	
		Diving Sites	Bathing Beaches
3c-Bathing & Diving	Diving Sites	1.00	2.00
3c-Bathing & Diving	Bathing Beaches	0.50	1.00

Table 20: Pairwise scores for each data layer in Tier 3 that constitutes the Bathing & Diving sub-theme

The pairwise comparisons for the Historic Environment sub-theme are provided in Table 21. World Heritage Sites were weighted higher than Wrecks-unprotected due to their protected status. Consensus was reached on pairwise scorings at the marine stakeholder workshop.

Model Name	Group Name	Pairwise Comparisons	
		World Heritage Sites	Wrecks - unprotected
3d-Historic Environment	World Heritage Sites	1.00	7.00
3d-Historic Environment	Wrecks - unprotected	0.14	1.00

Table 21: Pairwise scores for each data layer in Tier 3 that constitutes the Historic Environment sub-theme

PROCESS OF AHP

Following the pairwise comparisons process, the scores require converting into data weightings and input into the tree structure of grouped criteria. AHP is conducted by calculating and combining the weights within each tier as it builds up within the model. The step-by-step procedure to complete AHP and calculate the local weightings is as follows:

1. Define the criteria that will be used in the analysis and arrange these into a tiered structure where comparable criteria are together in groups of up to seven. The structure outlined for this process is shown in Figure 22.
2. Assess the criteria in each Criteria Group against each other using a pairwise comparison. In this case, the usual 'importance' scoring terminology defined by Saaty is replaced by 'risk to development'. The scale used and presented visually in Figure 23 was:

1	Equal risk to development
3	Criteria A moderately more of a risk to development than Criteria B
5	Criteria A strongly more of a development risk than Criteria B
7	Criteria A very strongly more of a development risk than Criteria B
9	Criteria A extremely more of a development risk than Criteria B

3. Populate a reciprocal matrix with the pairwise scores for the top half and 1/ the pairwise score on the bottom half. This should then be decimalised (see Step 4).
4. Square the matrix using a dot product function (see outputs in Tables 7 to 20).
5. Sum each of the rows of each of the criteria.
6. Normalise these so that they total one. This will result in what is termed a Priority Eigen Vector (PEV), or Local Weight. The normalisation formula for a three by three matrix where X, Y and Z are the summed rows would be:

$$PEV_x = \frac{X}{(X+Y+Z)}$$

7. Repeat from step four until the PEVs do not change.
8. These PEVs form the local weights for the AHP structure.

This process has been summarised in Figure 25.

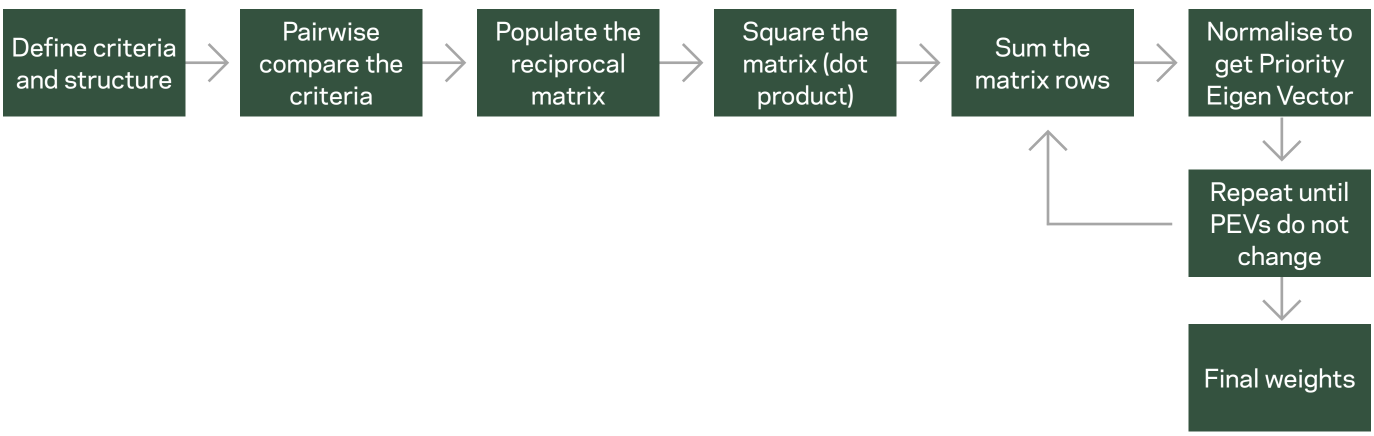


Figure 25: Diagram of procedure to define PEV for criteria and themes

A rigorous consistency test is used to ensure the assessment applied in the pairwise comparison is statistically and logically robust[14]. This uses the following formula[15] (**see below**).

The consistency ratio should always be below 0.1 to ensure that the local weights are statistically robust.

APPLYING AHP TO A STRUCTURE

There are two methods of combining the Local Weights within tiers of the wider structure to produce combined results, referred to from here on as Global Weights. These are the standard AHP method as proposed by Saaty (1977) and an approach termed B-G modified, proposed by Belton Gear in 1982[16].

STANDARD APPROACH TO CREATE GLOBAL WEIGHTS

The standard approach takes the weighting of each criteria and multiplies it by the covering weight (referred from here on as Parent Weight) in the tier above. This is demonstrated in Figure 26. This means that the sum of all the Criteria Group Global Weights will equal the parent Global Weight.

There are two key issues associated with this approach:

- To achieve the full weight of any given criteria all of the corresponding spatial data in the sub-Criteria Group must spatially overlap. This is often impossible as criteria are spatially explicit, for example closed or open disposal sites, meaning that criteria would be unintentionally under weighted in this approach. For example the data representing 1.1.1, 1.1.2 and 1.1.3 would need to fully spatially overlap in order to achieve the weight of criteria 1.1
- As more criteria are added to a Criteria Group the influence of each individual criteria in that group is diluted. This is due to the sum of the Global Weights being equal to the parent Global Weight. This can be seen in the Criteria Group 1.3.1 – 1.3.4 Where the individual criteria have less Global Weight than those in 1.2.1 and 1.2.2, despite having a higher parent Global Weight (in 1.3)

B-G APPROACH TO CREATE GLOBAL WEIGHTS

The B-G modified approach gives the full parent weight to the highest weighted criteria in the sub Criteria Group. The remaining criteria in the sub Criteria Group are weighted proportionately to the highest local weight within the group. This avoids the issues noted above but adds a layer of complexity to the calculations that may be harder to explain to stakeholders. A demonstration of the calculation of global weights using the B-G modified approach is shown in Figure 27.

The formula used is:

$$T3_w = \left({}^{T3_x}/_{T3_{max}}\right) * T2_w$$

where:

$T3_w$ = *The Tier three weight for each criteria*

$T3_x$ = *The Eigen Vector weight multiplied by* $T2_w$

$T3_{max}$ = *The maximum* $T3_x$ *in each Tier 3 group*

$T2_w$ = *The Tier 2 covering weight*

$$CI = \frac{(\lambda max - n)}{(n-1)}$$

Where:

CI = *Consistancy Index*

λ = sum of PEV $*$ sum of columns for each criteria: e.g. {PEV for criteria A $*$ sum column criteria A} + {PEV for criteria B $*$ sum column criteria B}etc.

n = Number of columns in the matrix

$$CR = {}^{CI}/_{RI}$$

Where:

CR = *the Consistency ratio which should be* $< 10\%$

[14] Saaty, T.L., (1977). A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology 15 (3)
[15] RI= Randomness Index which is pre-defined and available in a set lookup table
[16] V. Belton, T. Gear (1982), On a shortcoming of Saaty's method of analytic hierarchies, Omega, 11 (3), pp. 226-230

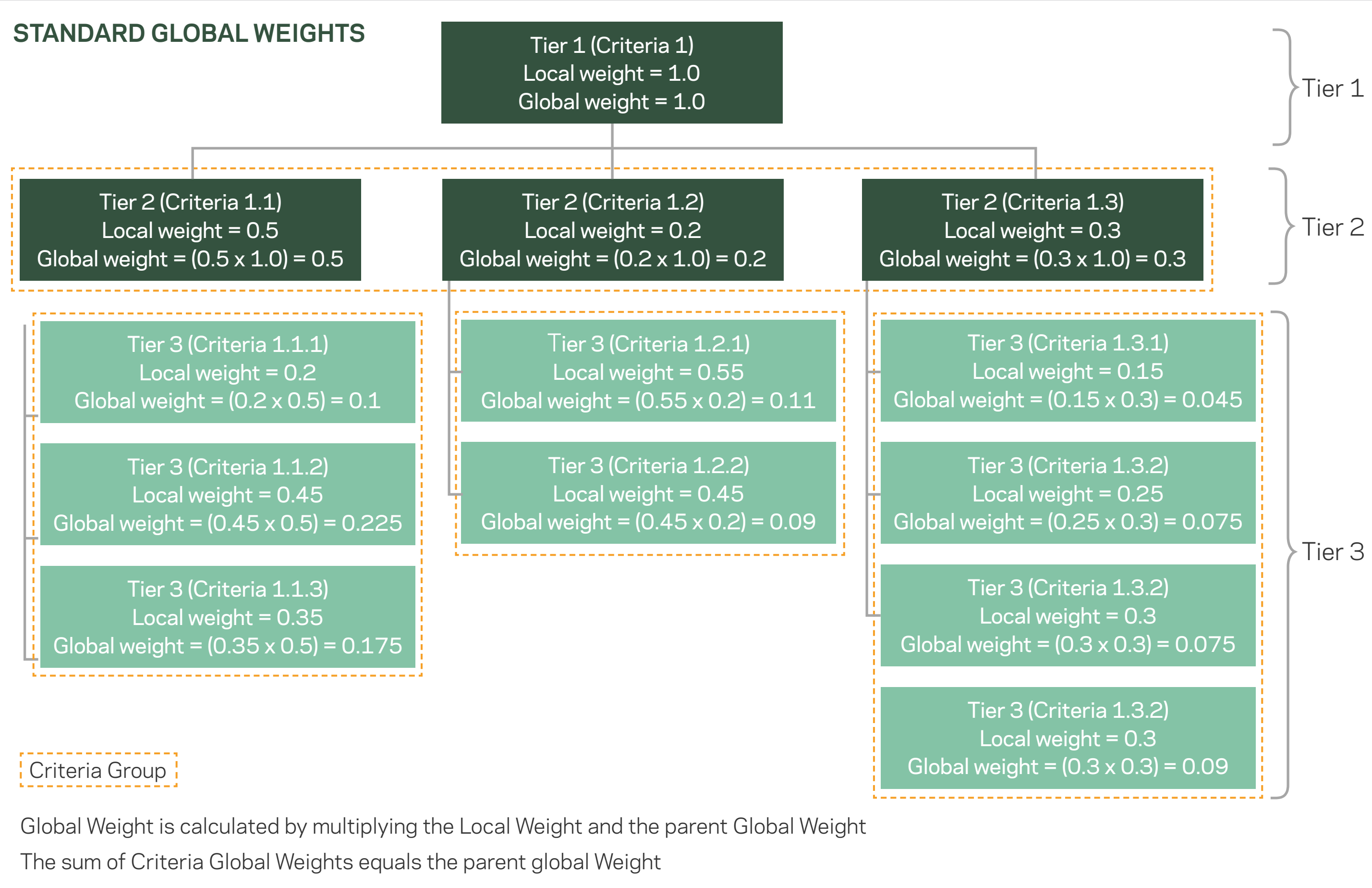
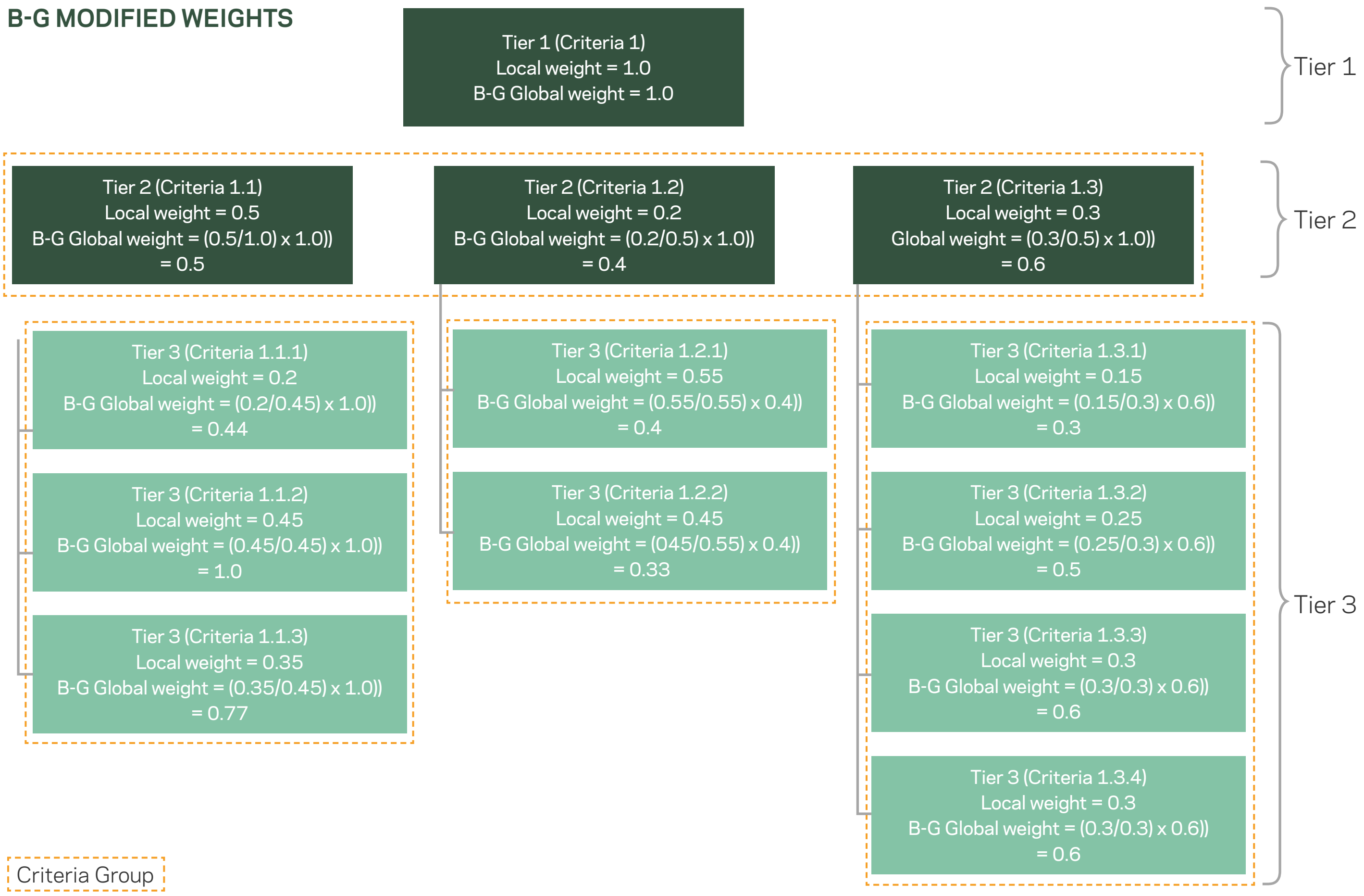


Figure 26: Example hierarchy demonstrating the standard approach to global weighting



B-G Global Weight is calculated by dividing the local weight by the maximum local weight within that criteria group, then multiplying by the paent B-G Global Weight

The sum of Criteria Group B-G Global Weights does not equal the parent B-G Global Weight

The max B-G Global Weight within any Tier will always be 1

Figure 27: Example hierarchy demonstrating the B-G modified approach to global weighting

After running test models and comparing standard AHP outputs against B-G modified outputs, the B-G modified approach was deemed most appropriate. This is because the B-G modified approach better preserves the criteria weights when using spatial datasets, therefore the floating offshore wind model more accurately represents the agreed weighting of each criteria.

Figure 28 presents the final relative weightings of all data layers included within the model.

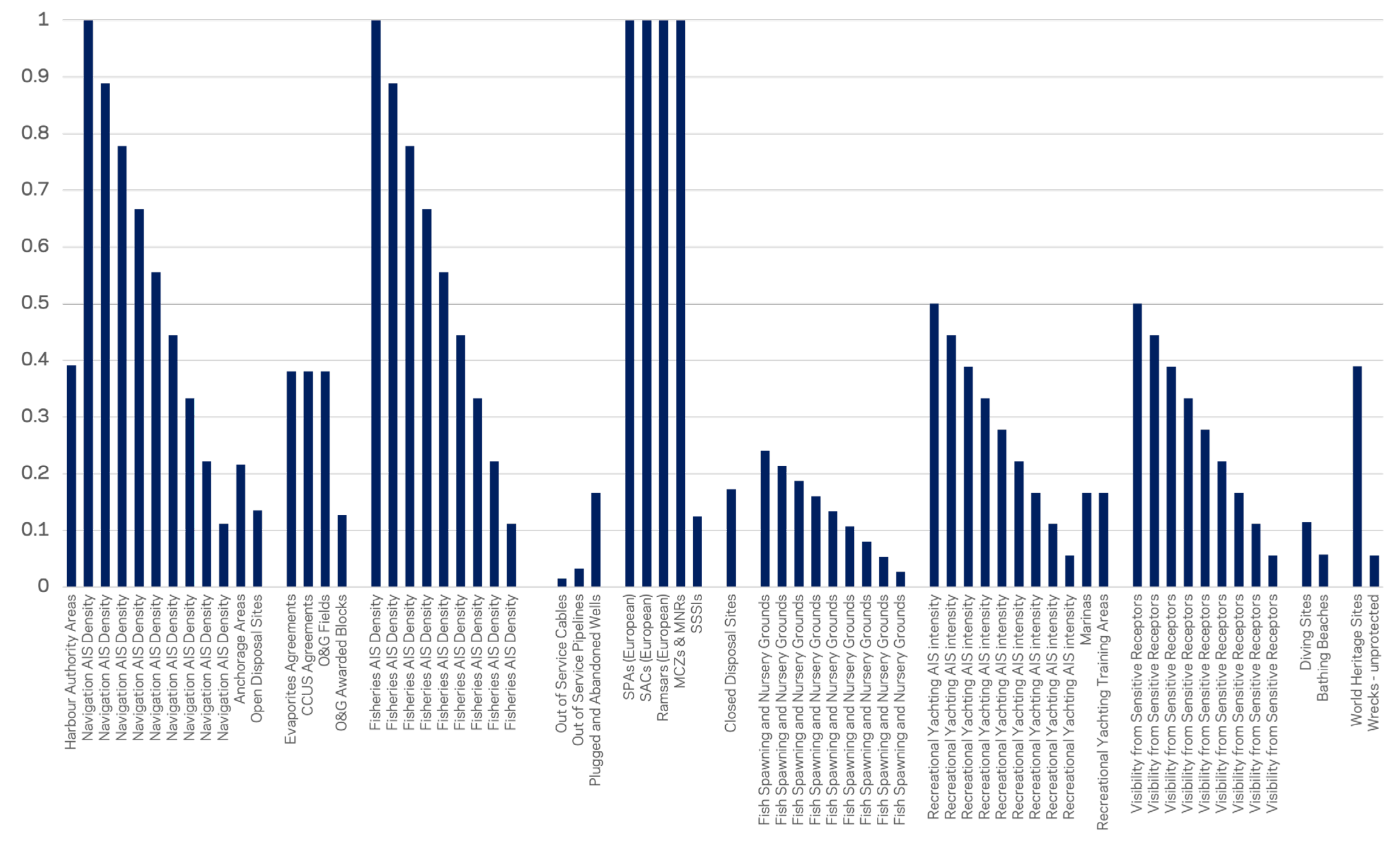


Figure 28: Final relative data weightings within the Restrictions Model

Appendix 3 - Exclusions model data

Dataset	Source Organisation	Buffer	Justification	Presence	Checked for updates
Protected Wrecks Exclusion Zones	English Heritage, CADW, Historic Scotland, Northern Ireland Government		Legislative protection		Apr-22
EDF — UK Nuclear Power Stations	EDF	1NM	Safety grounds	Not present in Area of Interest	Apr-22
MMO — MCMS Navigational Dredging	Marine Management Organisation		Navigational conservation and maintenance	Not present in Area of Interest	Apr-22
The Crown Estate — Cables Agreements	The Crown Estate		Current legal agreement potentially including existing infrastructure		Apr-22
The Crown Estate — Infrastructure Oil and Gas Agreements	The Crown Estate		Current legal agreement potentially including existing infrastructure	Not present in Area of Interest	Apr-22
The Crown Estate — Meteorological Equipment Agreements	The Crown Estate		Current legal agreement potentially including existing infrastructure	Not present in Area of Interest	Apr-22
The Crown Estate — Minerals and Aggregates Agreements	The Crown Estate		Current legal agreement potentially including existing infrastructure	Not present in Area of Interest	Apr-22
The Crown Estate — Minerals Capital and Navigation Agreements	The Crown Estate		Current legal agreement potentially including existing infrastructure	Not present in Area of Interest	Apr-22
The Crown Estate — Natural Gas Storage Agreements	The Crown Estate		Current legal agreement potentially including existing infrastructure	Not present in Area of Interest	Apr-22
The Crown Estate — Wave Agreements	The Crown Estate		Current legal agreement potentially including existing infrastructure		Apr-22
The Crown Estate — Wind Agreements	The Crown Estate		Current legal agreement potentially including existing infrastructure		Apr-22
The Crown Estate — Pipelines Agreements	The Crown Estate		Current legal agreement potentially including existing infrastructure	Not present in Area of Interest	Apr-22
The Crown Estate — Tidal Stream Agreements	The Crown Estate		Current legal agreement potentially including existing infrastructure		Apr-22
The Crown Estate — Aquaculture Agreements	The Crown Estate		Current legal agreement potentially including existing infrastructure		Apr-22
The Crown Estate — Outfall Leases	The Crown Estate	250m	Current legal agreement potentially including existing infrastructure. Buffer tested during engagement.		Apr-22
Active Cables Infrastructure	The Crown Estate	250m	Current legal agreement potentially including existing infrastructure. Buffer tested during engagement		Apr-22
Active Pipelines Infrastructure	The Crown Estate	250m	Current legal agreement potentially including existing infrastructure. Buffer tested during engagement	Not present in Area of Interest	Apr-22
Traffic Separations Schemes (International Maritime Organisation)	UK Hydrographic Office	1.77NM	Safety grounds – Permanent International Association of Navigation Congresses (PIANC) report on interactions between maritime navigation and offshore wind farms[17]		Apr-22
Platform Helicopter Safety Zones	NSTA		Safety grounds	Not present in Area of Interest	Apr-22

Table 22: A list of all development exclusions used in the Exclusions Model to identify Feasible Areas

[17] www.pianc.org/publications/marcom/marcom-wg-161-interaction-between-offshore-wind-farms-and-maritime-navigation-1

Appendix 4 - Restriction model data

Dataset	Source Organisation	Buffer	Presence	Checked for updates
Harbour Authority Areas	UK Hydrographic Office			Apr-22
Navigation AIS Density	EMODnet			Apr-22
Anchorage Areas	UK Hydrographic Office			Apr-22
Open Disposal Sites*	Cefas			Apr-22
The Crown Estate — Evaporites Agreements	The Crown Estate			Apr-22
The Crown Estate — CCUS Agreements	The Crown Estate		Not present in Area of Interest	Apr-22
Hydrocarbon Fields	North Sea Transition Authority			Apr-22
Hydrocarbon Awarded Blocks	North Sea Transition Authority			Apr-22
Fisheries AIS Density	EMODnet			Apr-22
Out of Service Cables Infrastructure	The Crown Estate	250m		Apr-22
Out of Service Pipelines Infrastructure	The Crown Estate	250m	Not present in Area of Interest	Apr-22
Plugged and Abandoned Wells	North Sea Transition Authority	250m		Apr-22
SPAs (European)	JNCC, NE, NRW, SNH, NIEA			Apr-22
SACs (European)	JNCC, NE, NRW, SNH, NIEA			Apr-22
Ramsars (European)	JNCC, NE, NRW, SNH, NIEA			Apr-22
MCZs & MNRs	JNCC, NE, NRW, SNH, NIEA			Apr-22
SSSIs	JNCC, NE, NRW, SNH, NIEA			Apr-22
Closed Disposal Sites[18]*	Cefas			Apr-22
Fish Spawning and Nursery Grounds	Cefas			Apr-22
Recreational Yachting AIS intensity	EMODnet			Apr-22
Marinas	Royal Yachting Association	1NM		Apr-22
Recreational Yachting Training Areas	Royal Yachting Association			Apr-22
Visibility from Sensitive Receptors	The Crown Estate			Apr-22
Bathing Beaches	MCS	1NM		Apr-22
World Heritage Sites	EH, CADW			Apr-22
Wrecks - unprotected	UK Hydrographic Office	50m		Apr-22

Table 23: A list of all development risks used in the Restrictions Model to identify Practical Areas

[18] The source of this data layer is the Cefas UK Disposal Site Layer which has been filtered to determine the operational status of each disposal site