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Scoping 'Areas of Search' Study for offshore wind energy in Scottish Waters, 2018.

marine scotland science

Scoping ‘Areas of Search’ Study for offshore wind energy in Scottish Waters, 2018.

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Executive summary

Around Scotland, there exists the potential to extract significant energy resources in the form of renewable offshore wind energy generation. Any expansion of offshore wind energy generation in Scottish waters requires the application of marine spatial planning, at a national, regional and local scale, to identify areas that may be suitable for the development of offshore wind projects.

As the first stage of the sectoral marine planning process for offshore wind, this scientific study identifies the initial Areas of Search, which are then subject to a process of consultation and assessment, in order to become Final Plan Options. These Options, once adopted, will outline the spatial footprint within which any future commercial scale offshore wind development (over 100 MW) should take place, in Scotland. This report describes the process to identify Areas of Search that contain the best resource and overall suitability for future development.

Identifying Areas of Search required a multi-criteria analysis to be completed. This analysis brings together multiple geospatial data layers, which depict both opportunity (such as average wind speed or existing grid connections) and constraint (such as fishing activity, shipping traffic or environmental sensitivities) into spatial analysis software where they can be combined and presented as one national map. The full list of data used in this analysis is contained within the report.

Each spatial dataset included in the analysis is standardised in terms of resolution (grid cell size), spatial extent and classifications (high, medium or low level of constraint). Each dataset is then given a “weight” value which determines how much influence those data will have in the resulting output. The chosen relative weights are based upon previously published information where available. Where information is not available the most up to date knowledge is applied. The analysis produces a map highlighting areas around Scotland where there is both available wind resource and lower levels of spatial constraint.

Spatial data that describes locations where no development should be considered, such as areas where existing offshore infrastructure (oil and gas or renewables) is already in place, were combined into a separate “exclusion” data set. This exclusion dataset was then used to remove areas from the multi-criteria analysis output.

The resulting output from these processes produces a map where broad areas of potential opportunity can be discerned. The map shows varying degrees of constraint that are generally higher in areas close to shore. Areas of decreasing constraint begin to appear as distance from the shore increases. Although water depth generally increases with distance from shore this was not considered as a hard constraint as the study includes the potential for floating wind technology, which is theoretically not limited by depth. From this output, six Areas of Search were identified

For these six broad Areas of Search, a single issue analysis was then applied in order to refine the Areas of Search further. This process allows individual spatial constraints to further influence the Areas of Search by specifically avoiding a spatial constraint, at a local level, that may not be clear in the national multi-criteria process. Data used at this stage

included individual species fishing activity, combined shipping routes and marine nature protection designations.

This refinement process resulted in the selection of 24 distinct Areas of Search that will be taken forward in the sectoral marine planning process and presented, through consultation, to relevant stakeholders for comment and review. Figure 1 shows the initial broad Areas of Search and the resulting refined Areas of Search that have been drawn once the spatial extent of the single issue activities has been considered. Table 1 lists the refined Areas of Search and the Scottish Offshore Renewable Energy Regions (SORER) that they predominantly occupy.

Table 1: This table lists the refined AoS and the SORER area that they predominantly occupy.

AoS name	SORER occupied
E1	East
E2	East
E3	East
N1	North
N2	North
N3	North
N4	North
N5	North
N6	North
N7	North
N8	North
NE1	North East
NE2	North East
NE3	North East
NE4	North East
NE5	North East
NE6	North East
NE7	North East
NW1	North West
NW2	North West
NW3	North West
W1	West
W2	West
W3	West

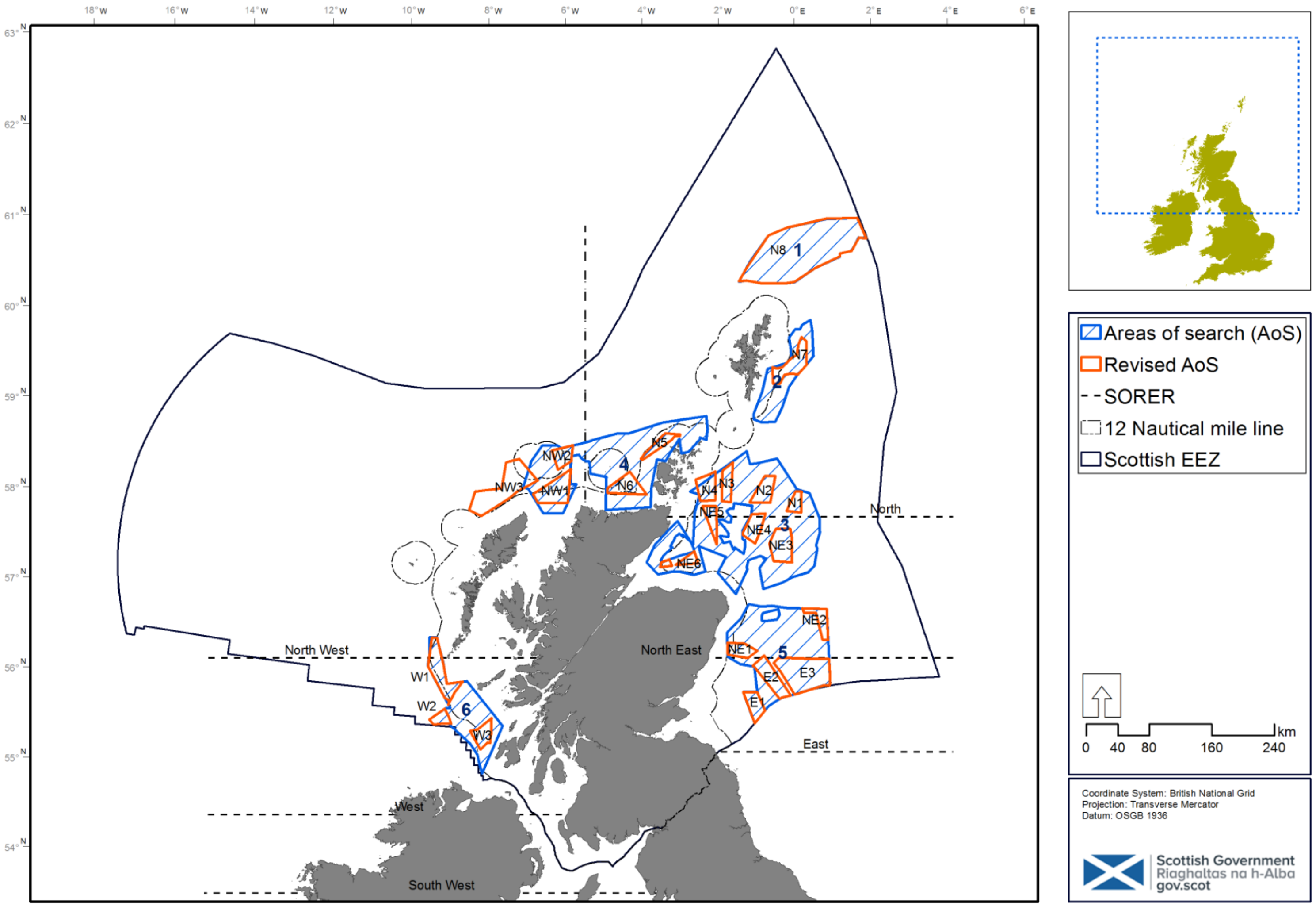

Figure 1: Areas of search resulting from selecting broad sites of minimised constraint from the multi-criteria analysis output. These have been further refined to ensure a minimised level of interaction with existing activities and users by considering the spatial extent of shipping traffic, fishing, designated nature protection areas . © Crown copyright and database rights (2018) OS (100024655).

1 Introduction

1.1 Potential for offshore wind in Scotland

Within Scottish Waters (includes territorial waters and Exclusive Economic zone (EEZ)) there exists a great deal of potential offshore wind resources that could be used to generate energy using offshore wind turbines. Maximising this offshore renewable resource requires the identification of potential development locations and careful selection of areas through a scientific scoping process. This process must take into account the many uses of the sea that potential new developments may interact with. Interactions can be industrial, cultural or environmental.

This study uses Geographic Information System (GIS) data to visualise the many uses of Scottish waters, combine them into a single output and identify areas where potential exists to recommend further development. The selected areas are within the Scottish Offshore Renewable Energy Regions (SORER). Some areas can cover more than one SORER. Section 4 contextualises the identified areas at a broad scale (east, west and north coasts, Orkney and Shetland) and details which SORER they are within. Figure 2 shows the SORER limits.

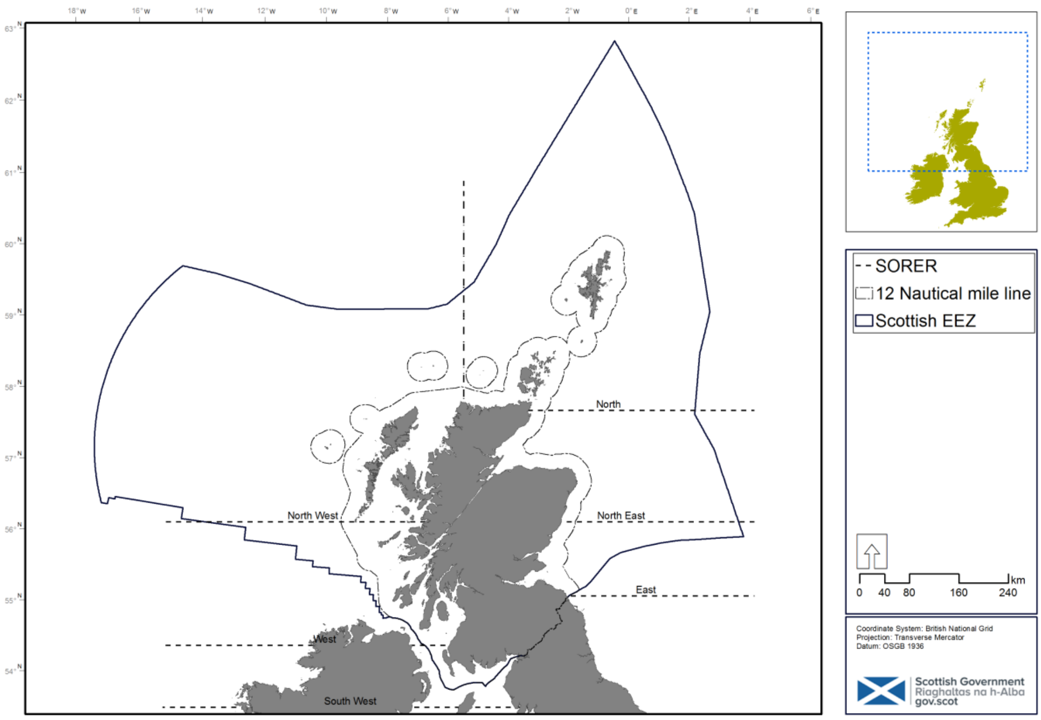

Figure 2: SORER limits. © Crown copyright and database rights (2018) OS (100024655).

The activities and existing infrastructure included in this study have been categorised into two groups: those where there is no compatibility with offshore development and those that show a range of constraint towards offshore development. These two groups were each represented using GIS outputs.

The study does not seek to identify specific areas for development but to take the first step in the sectoral planning process by identifying broad areas within which it would be logistically realistic to host development of new commercial offshore wind arrays. The Areas of Search (AoS) shown are not proposed as sites to be developed in their entirety. They provide the starting point from which optimum locations for offshore wind energy production can be identified and Plan Options produced.

Currently the majority of offshore wind farms have been built using conventional fixed bottom substructure technology. The maximum depth considered economically and technically feasible for these to be installed is approximately up to 60 m of depth (The Carbon Trust, 2015). This depth requirement significantly limits the amount of seabed space that can be exploited. New technology like floating wind turbines attached to the seabed by chains and anchors can potentially open up new areas of sea as they are theoretically not limited by depth.

The full range of water depths have been considered in this study. The depth data used was measured using the lowest astronomical tide as its reference. The depths included range from shore depths to the maximum depths within Scottish waters, At present the maximum depth considered for offshore deployment is 800 m as expressed by Statoil in reference to their Hywind technology (Statoil, 2015).Construction and deployment prices of floating foundations may eventually compete with those of fixed bottom technologies (The Carbon Trust, 2015), if floating wind sees a similarly rapid cost reduction to that which has taken placed in the fixed foundation wind industry.

The large scale potential for offshore wind has been investigated recently by BVG Associates (2017). This work involved multi-criteria analysis based principally on economically attractive potential using levelised cost of energy as the main metric. The study focused on areas that can be expected to allow construction and operation under an acceptably profitable threshold. The North Sea and parts of the west and north coast were identified as having potential for wind technology to be used to exploit wind resources in deeper water. Floating wind technologies were included as a possible technical solution.

The BVG Associates (2017) report recognises Scotland’s offshore wind potential from the economic perspective. This scoping report aims to identify it from the planning perspective.

1.2 The Scottish Sectoral plan for offshore wind: Scoping study 2011

In 2011 Marine Scotland published a Scoping Study for Offshore Wind Farm Development in Scottish Waters (Davies and Watret, 2011) that applied spatial multi-criteria analysis to investigate the most suitable locations for offshore wind farms out to 200 nautical miles (NM). This scoping study was undertaken in conjunction with the Crown Estate (TCE) using their Marine Resource System (MaRS) asset management tool. The scoping study used a suite of GIS layers provided by Marine Scotland (MS) and TCE.

Three types of output model were created:

- A technical model, this described spatially the resource to be exploited and the technical feasibility to do so

- An exclusion model which collected the features that were deemed incompatible with offshore wind development and removed their known footprint from the output
- A constraint model which gave the combined degree of interaction to be encountered and was generated by combining three themed restriction models

The large number of layers of spatial information that were used for the combined constraint model output benefited from being grouped into three themes based on their conceptual similarity: environmental, industrial and socio-economic. This combination of the restriction, exclusion and technical output models was the basis from which the spatial selection of AoS were made. Figure 3 shows the combined constraint output taken forward to be used to select the most suitable areas.

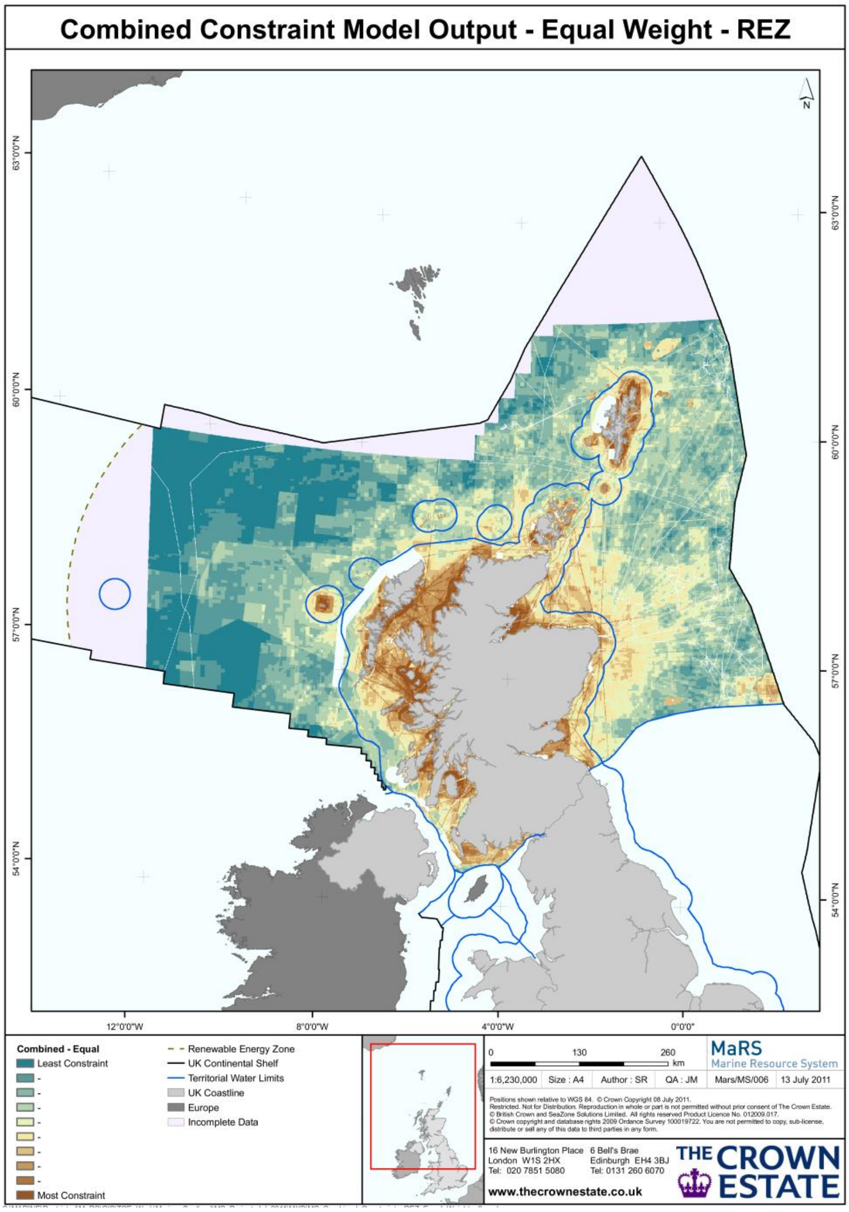

Figure 3: Results of the MaRS multi-criteria analysis study for the offshore wind scoping study of 2011. Combined output from the three themes (environmental, industrial and socio-cultural) weighted equally for the three themes. © Crown Copyright 2011.

By identifying the broad scale locations that present minimised constraint a set of broad AoS were drawn that brought together the most suitable areas These AoS provided the starting point for the consultation and assessment process which were used to refine these areas in to Draft Plan Options. Scottish Ministers' consulted on these options in 2013

1.3 Updating the offshore wind scoping study for 2018

The processes undertaken to create the new AoS for offshore wind in Scottish waters are described below. A feature of the sectoral marine planning process is the integrated opportunity provided through consultation that allows new or more recent data to be considered at these early stages. This document contains an account of the scientific modelling process undertaken and information taken into account in order to inform the identification of potential plan options.

The technological changes in the offshore wind industry now allow further offshore developments to be considered. Floating technology allows the potential to deploy in areas previously considered unsuitable on engineering grounds. The first step to identify new AoS locations is to apply multi-criteria analysis using relevant spatial data layers and considerations. This study collates 20 data sets and uses them to investigate potential areas of opportunity and constraint. For guidance and confirmation on what aspects were more relevant to identify the Pre-statutory Consultation – Draft Analysis Report (Marine Scotland, 2013b) was referred to and the more recurring themes and issues were included. This document summarised the discussions and issues raised by consultees during the pre-statutory consultation period on the sectoral marine plans for offshore wind, wave and tidal that took place in 2013.

The three themes applied in Davies & Watret (2011) are also used in this analysis as they are helpful for describing sets of layers collectively, hence the groupings of data types into industrial, environmental or socio-cultural continues in this work. To these the technical theme, which describes the resource to be exploited and the suitable conditions for development, has been added also.

Most of the layers applied in this study were also included in Davies & Watret (2011). Some of the layers used have been updated since then and some improved layers have been added. Similar relative weighting values as the scoping study of 2011 have been applied to this analysis as many of the considerations remain pertinent. Table 1 provides a comparison of the layers and weightings from Davies & Watret (2011) and those used in this study.

Data improvements to the layers used in Davies & Watret (2011) allows for a more spatially detailed analysis and a better representation of where offshore wind development opportunity exists. Examples of new and improved GIS layers are those that describe: coastal tourism density, shipping density, and combined fishing activity.

2 Models generated for the scoping study 2018

This study was undertaken to identify the areas of opportunity and constraint based on a number of spatial information layers that have been shown to be important in previous studies. Two models were created to do this. Combining these two models provides a visualisation of where cumulative obstacles to new developments exist. Technical aspects such as resource availability and bathymetry were included directly into the constraint model. The exclusion model was created separately and then used to remove features incompatible with offshore wind development.

The models were presented using the Scottish renewable EEZ as the output extent.

2.1 Exclusion Model

A number of offshore activities and features are not compatible with offshore wind developments. The spatial footprint of these activities has been removed from the spatial calculations to avoid taking forward locations that should not be selected for development.

These activities and structures are not included in the outputs other than as a gap in the resulting output surface. The features considered incompatible are listed below.

- Existing offshore energy leases: Crown Estate Scotland is the authority that grants lease agreements for developments in Scottish waters. It is not possible to plan for developments within existing lease sites hence these have been removed from the calculations
- Hydrocarbon activity and infrastructure: The east coast of Scotland hosts the bulk of the oil and gas installations in Scottish waters. There are a number close to the shore although the majority are concentrated west of the eastern EEZ limit far offshore. It is not recommended that offshore wind developments are developed within oil and gas industry zones
- Aquaculture: Aquaculture is a highly important industry in Scotland in terms of employment and revenue. Currently the Scottish government has plans to expand both the finfish and shellfish production by 50% and 100% respectively. locations leased to aquaculture farming are considered incompatible with offshore wind developments, unless offshore wind is used as a power source for the aquaculture sites themselves
- IMO Routeing (excluding Areas to be Avoided (ATBAs)), offshore shipping traffic control zones
- Offshore dumping zones either closed or open
- Mapped ship anchorages, mostly found in bays, firths, voes and embayments

This model is based upon that used in the offshore wind scoping study of 2011, Davies and Watret (2011), with the application of a number of updates:

- A number of offshore energy leases sites have changed
- A number of the wind leases in the west have been discontinued and additional wind leases have been granted in the east and north coasts
- Cables and pipelines have been updated using the KIS-ORCA data set

- Hydrocarbon facilities have been updated using data from the UK Oil and Gas authority
- Disposal sites have also been updated with information provided by the Centre for Fisheries and Aquatic Science

These changes have been incorporated into the exclusion layer to ensure it is up to date. The outline of the Scottish coastline is also removed to ensure the multi-criteria calculations do not get applied to land.

Figure 4 shows the exclusion model.

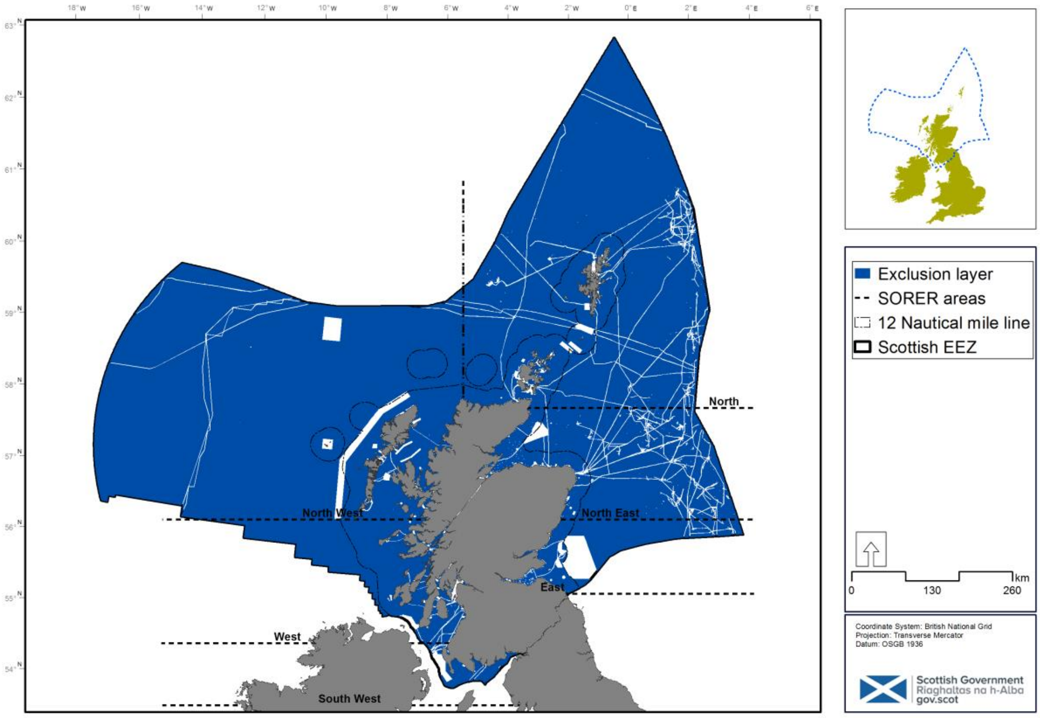

Figure 4: Exclusion model as generated using combined spatial layers that are considered incompatible with offshore wind developments. © Crown copyright and database rights (2018) OS (100024655).

2.2 Constraint model

In order to visualise where broad areas appropriate for development are located, the constraint model is produced by overlaying GIS layers. The layers included are those considered relevant to the selection process for sites of low impact on environmental, socio-cultural or industrial factors that could indicate minimised consenting and licensing risk.

Data layers to be included were collected and standardised in extent, resolution and geographic coordinate system. The inclusion criteria for the constraint model were broad scale relevance to the siting of offshore wind farms. Data layers considered directly relevant to the consenting process and the construction and operation of any potential developments were included in the analysis.

3 Methodology

A single mapped output identifying the strongest areas of constraint and opportunity within Scottish waters serves as a guide for planning the most appropriate areas of search for the development of offshore wind. This multi-criteria spatial output helps select broad areas that minimise interaction with the existing uses of the sea. GIS techniques provide a method to generate such an output and to manipulate the relative influence of its component layers.

The layers of relevant spatial information were collected and standardised to:

- Coordinate reference system (WGS 84): this ensures all the layers are spatially compatible
- Geographical extent (Scottish waters by using the Scottish renewables EEZ): this makes all layers overlap within the same spatial extent
- Grid square (pixel) size: all layers, if not already, were converted to raster and the grid square size selected for all was the same
- Number of range classes: for ease of comparability each layer was reclassified into a maximum of three classes: high level of constraint, medium level of constraint or minimal level of constraint. This was done for quantitative layers, for example depth in the bathymetry layer and where possible for categorical layers, for example type of seabed substrate. Some layers only present one class as there is no differentiation in their values, for example the radar interference layer or the helicopter routes

3.1 Reclassification of layers to three classes

The classification of the layers into a maximum of three classes serves to make these different sources of spatial information standardised to the same scale so they are comparable in value. It is important to select appropriate cut-off value points when selecting three classes as the resulting divisions have to remain representative of each layer’s data values. The classification into three classes was done on an individual layer basis as the process cannot be applied in the same manner to all layers.

For layers like bathymetry the classification process is straightforward as they can be divided into known accessibility depths. For quantitative layers that are composed of a range of numerical values the statistical functions of the ArcGIS GIS system were applied to find the most suitable values to use for class separation. The resulting outputs were checked visually to ensure that all parts of the value distribution were being represented. Section 8.2 describes the layers used and the method applied for reclassification.

3.2 Overlay procedure

Once standardised into a maximum of three classes the layers are added together using a GIS overlaying tool that sums each layer’s grid square values. Since all the layers have been standardised to be drawn in exactly the same location the grid squares line up and can be added together. The relative weighting between layers is included at this time by the GIS operator.

This cumulative value per grid square is what results in the overall weight layer that can then be interpreted as showing the variation in constraint over the study area.

This multi-criteria analysis output can then be used as a guiding template to select broad areas that fall within an acceptable level of constraint. These broad areas can then be refined into discrete options that minimise constraint and maximise opportunity. Section 6 describes the process undertaken to refine these broad areas of higher opportunity into smaller AoS from which the final Plan Options will be produced. The level of constraint will affect the ease of licensing and consenting of any one option. An area that displays low constraint translates into a site that is likely to go through the consenting and licensing phase with fewer objections. The opposite is true for a heavily constrained site.

The content of the spatial layers of information was separated into four data type categories:

- Environmental aspects: nature designated sites, species density, seabird collision vulnerability
- Industrial activities and features: helicopter transit lines, shipping density, fishing intensity
- Socio-cultural content: sea-based leisure activities
- Technical aspects: distance from substations and cable landings, depth, wind resource

These four data categories have been combined together to form an overall expression of the relative degree of constraint and opportunity for new offshore wind energy developments. The level of influence of each layer on the final output was guided by the relative weightings between layers used in Davies and Watret (2011).

3.3 Relative influence of layers

In order to create a reliable multi-criteria output the relative weights between layers need to be set so that those that are more relevant and important to the outcome have the greatest influence and help identify the higher constraint. Davies and Watret, (2011) used a relative set of weightings and scores that has been reviewed and revised for this study. Weightings were applied to each layer as a whole. In this study the maximum score that any layer's class can reach is 3 (high), the minimum is 1 (low).The maximum weighting of any layer is 10. The layer overlaying tool multiplies the layer weighting by each of the classification scores to generate the overall constraint output.

The weighting and scoring value range is different compared to the 2011 scoping study but the relative difference in overall influence between layers has been maintained. This ensures that the considerations that were appropriate for the 2011 offshore wind scoping study are included into the update. Table 1 shows the layers that have been used in the scoping update of 2018, the equivalent layer that was used in (Davies and Watret, 2011) has been included as a comparison.

Table 2: GIS layers of spatial information used in the updated scoping study and the scoping study (Davies and Watret, 2011)

Data Theme	Layers used in Scoping Study for Offshore Wind Farm Development in Scottish Waters 2011	Weightings applied	Maximum score	Potential maximum influence
Environmental	Cetacean density (JNCC) Atlas of Cetacean distribution in north-west European waters (2003) Reid, J.B., Evans, P.G.H., & Northridge, S.P.	900	164	147600
Environmental	Nature protection designated areas (MPA, SAC, SPA, SSSI, RAMSAR)	1000	100	100000
Environmental	Seabird distribution during breeding season (ESAS density surfaces, 2010)	1000	182	182000
Environmental	Seabird distribution during winter season. Data used from ESAS (2010).	1000	182	182000
Environmental	Nursery areas for commercial fish species Coull et al. (1998)	400	73	29200
Environmental	Spawning areas for commercial fish species, Coull et al. (1998)	400	73	29200
Environmental	not included	-	-	-
Environmental	not included	-	-	-
Industrial	AIS shipping Anatec (2010)	1000	182	182000
Industrial	Static and mobile fishing ground classified by distance banding from the shore	1000/600	182/109	182000/65400
Industrial	Helicopter routes (National air traffic services, NATS)	600	100	60000
Industrial	Military exercise (PEXA) from GIS provider and classified into risk levels after consultation with MOD	1000	180	180000
Industrial	Radar interference at 140 m (NATS)	600	100	60000
Socio-economic	RYA routes and sailing areas (RYA 2010)	300	30	9000
Technical	Bathymetry (Trudepth, 2010)	Not addressed in constraint model	Not addressed in constraint model	Not addressed in constraint model
Technical	Distance from shore (land buffered)	300	100	30000
Technical	not included	-	-	-
Technical	not included	-	-	-
Technical	not included	-	-	-
Technical	Wind (ABPMer Renewables atlas)	1000	182	182000

Data Theme	Layers used in offshore wind Scoping update 2018	Relative weightings (taken from Scoping study 2011) (1-10)	Maximum score	Potential maximum influence
Environmental	Cetacean density (JNCC) Atlas of Cetacean distribution in north-west European waters (2003) Reid, J.B., Evans, P.G.H., & Northridge, S.P.	9	3	27
Environmental	Collected protected areas (MPA, SAC, SPA, SSSI, RAMSAR, draft offshore SPA) 2018	10	3	30
Environmental	Seabird distribution during breeding season (ESAS density surfaces, 2010). Vulnerability indices from Furness and Wade (2012)	10	3	30
Environmental	Seabird distribution during winter season. Data used from ESAS (2010). Vulnerability indices from Furness and Wade (2012)	10	3	30
Environmental	Amalgamated nursery areas for 13 commercial species (Aires et al., 2016)	3	3	9
Environmental	Spawning areas for commercial fish species, Coull et al. (1998)	3	3	9
Environmental	Spawning update for cod (Gonzalez-Irusta & Wright 2015)	3	3	9
Environmental	Spawning update for haddock (Gonzalez-Irusta & Wright 2016)	3	3	9
Industrial	AIS shipping ABPMer (2015)	10	3	30
Industrial	Fishing (Amalgamated VMS and Scotmap)	10	3	30
Industrial	Helicopter routes (National air traffic services, NATS)	6	3	18
Industrial	Military exercise (PEXA) from GIS provider and classified into risk levels after consultation with MOD	10	2	20
Industrial	Radar interference at 200 m (NATS)	6	1	6
Socio-economic	All tourism intensity (tourism survey scotland 2015)	9	3	27
Technical	Bathymetry (Ocean wise, 2018)	5	3	15
Technical	Distance from electrical substations	3	3	9
Technical	Distance from key cable landings	3	3	9
Technical	Sediment (Ocean wise)	5	3	15
Technical	Slope (Ocean wise)	3	3	9
Technical	Wind (ABPMer Renewables atlas)	10	3	30

3.4 Data

The data layers that have been applied to the multi-criteria analysis reflect the variety of interactions with potential to overlap with any new offshore wind developments. The most up to date available data have been used. When updates were not available GIS layers have been taken from those used in previous work such as Davies and Watret (2011).

The data can be broadly divided into four categories in terms of the type of activity or user of the sea the data represents.

Environmental data sets:

- Seabird collision risk breeding season
- Seabird collision risk overwintering season
- Cetacean overall density
- Fish life history sensitivity
    - Early life stages of fish (0-group aggregation probability)
    - Spawning haddock
    - Spawning cod
    - Spawning of other commercial species (CEFAS, 1998)
- Nature protection designations, an amalgamated layer of all the nature protection designations, includes:
    - RAMSAR wetland sites
    - Coastal SSSI (selected at 1 km from the sea)
    - marine SPA
    - marine SAC and offshore SAC
    - nature conservation MPAs
    - draft offshore SPA

Industrial data sets:

- Fishing value for Scottish VMS and non-VMS vessels (2007-2011)
- Shipping density and routes
- Aviation
    - Radar interference potential
    - Helicopter routes
- Military exercise areas

Socio-cultural data sets:

- All sea-based leisure activities

Technical data sets:

- Bathymetry
    - Depth
    - Slope
- Wind resource
- Distance from electrical substations
- Sediment

The full complement of layers included in this scoping study are listed in Section 3.5.

3.5 Description of layers used to create the constraint model

The following sections describe the layers that have been used for the constraint output in this scoping study.

3.5.1 Resource

For this study the annual average wind speed in ms^{-1} at 100 m height was used. The offshore environment, from a distance of 20 km from the Scottish shore, displayed an average annual wind speed that was suitable for generating energy from wind turbines as it exceeded 9 ms^{-1}. Turbines can begin rotation from a wind velocity of 4 ms^{-1} (Sinden, 2007), however a higher and more constant wind speed will generate more electricity and economic benefit.

The average annual wind speed at 100 m in height was selected from the ABPMer UK Renewables (ABPMer, 2018) and two classes proved sufficient to describe this resource layer within the model.

The wind resource data layer was reclassified into two categories, those higher or equal to 9 ms^{-1} in wind speed were given the lowest constraint and wind speeds lower than 9 ms^{-1} were given the medium constraint value. Average annual wind speeds of 8 ms^{-1} or more cover the vast majority of Scottish waters extent according to the ABPMer resource layer.

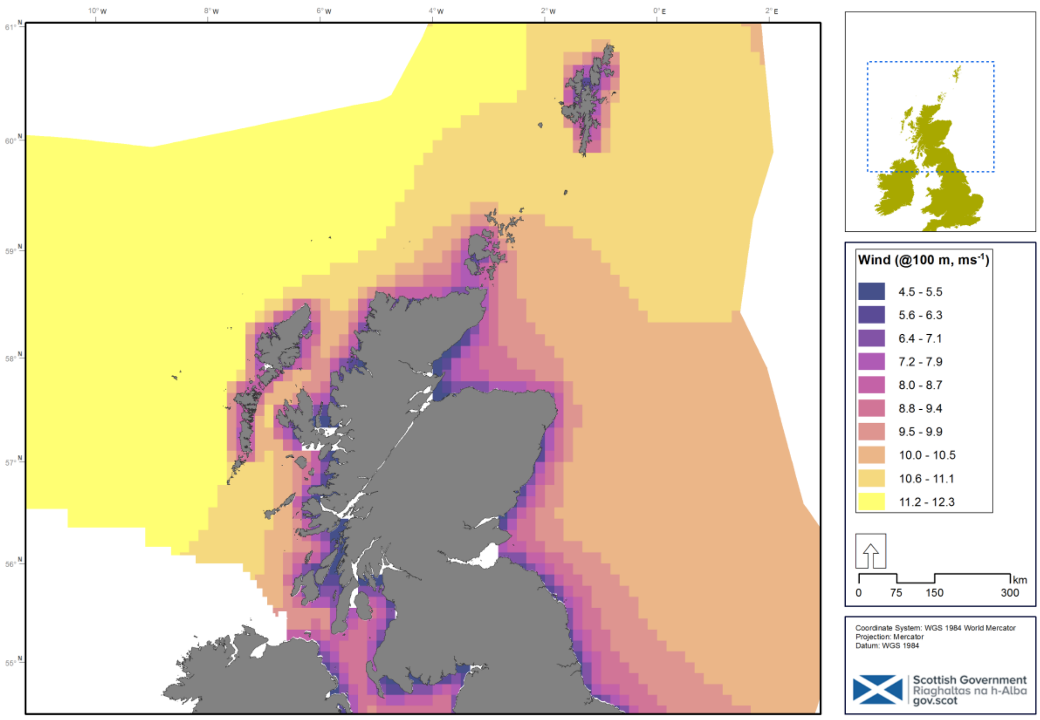

Figure 5: Wind resource in Scottish waters. Wind speed data were taken from ABPMer Renewables Atlas website. © Crown copyright and database rights (2018) OS (100024655). Atlas of UK Marine Renewable Energy Resources. 2008. ABPmer. December 2017. Reproduced from http://www.renewables-atlas.info/ © Crown Copyright.

3.5.2 Grid connection

Offshore wind technologies often require an electrical grid connection to demonstrate the full commercial generation cycle. More distance from shore generally equates to more cost. In this scoping study two indicators of grid potential have been included, both based on distance: distance from electrical substations and distance from key cable landings.

Alternative uses for the electricity generated at sea may become commercially available and be integrated into the chain of supply. Should battery or an alternative storage technology mature sufficiently in the near future it may form part of the offshore wind supply chain.

These layers were generated using the *Euclidean distance* function in ArcGIS and the three classes used were based on the distance from the key cable landing or substation. Figure 6 shows the distance bandings from the application of this distance tool before the layer was reclassified into three classes. The distances applied to the three classes were 0-50 (low constraint), 50-100 (medium constraint) and more than 100 km (high constraint).

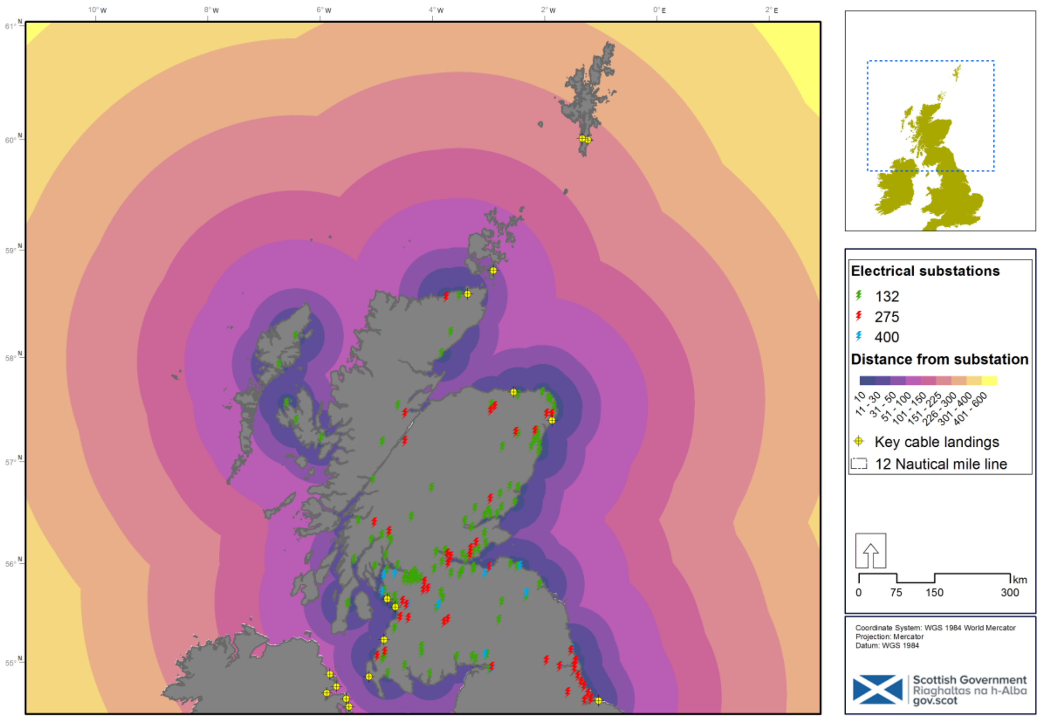

Figure 6: Distance bandings created from electrical substations. Substation spatial information has been taken from National grid. Important cable landings have also been included. The Key cable landings layer was created and classified in the same manner. © Crown copyright and database rights (2018) OS (100024655).

3.5.3 Depth

Offshore wind industry forecasts (Haslett, 2016) have expressed that from 50 m in depth the difference in cost becomes noticeable between fixed and floating foundations. In waters deeper than 50 m the versatility of floating foundations becomes a strong asset. Fixed foundations, mostly monopile type structures with a smaller percentage of jacket type structures, are a more technically developed approach and in waters between 30 and 50 m are the most mature foundation. The cost decrease in the energy generated by this technology has decreased quicker than forecasted in recent years (The Crown Estate, 2012). Based on this price reduction in the seabed fixed technologies some industry forecasts point towards a similar rapid decrease in floating wind technologies (Haslett, 2016) towards 2050.

Bathymetry can also be considered a broad scale distance from shore proxy as mostly the large areas of deeper water are further away from the coast. Figures 7 and 8 show the bathymetry as a continuous layer and subdivided by depth ranges to allow visualisation of the relative amount of area at 60 m, 60-100 m and over 100 m.

This layer was classified categorically using depths up to 0-200 as the least constraining class, depths of 200-700 and the medium and depths over 700 m were classed as highly constrained. The lower constraint depths of 0-200 cover the majority of the North Sea and west coast up till the western shelf edge. All current technologies can be accommodated within this depth range. Although the classified layer used in the multi-criteria analysis started at 0 m the shallowest any development is expected to be built at is 20 m.

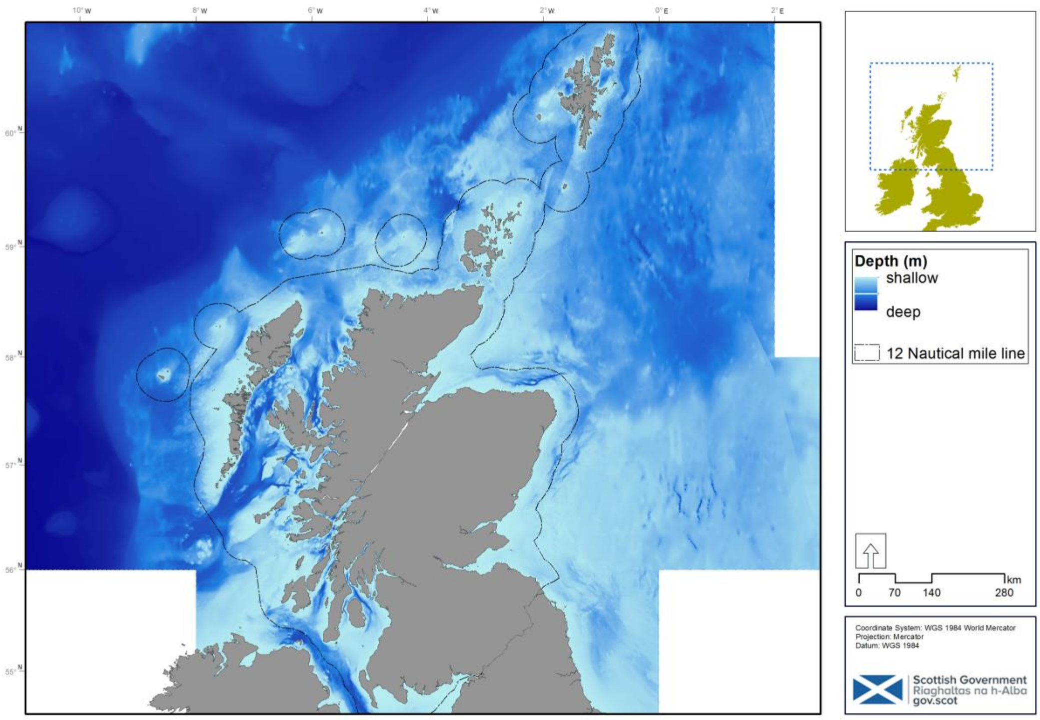

Figure 7: Bathymetry of Scottish waters. © Crown copyright and database rights (2018) OS (100024655). © Crown Copyright, 2018. All rights reserved. License No. EK001-20140401.

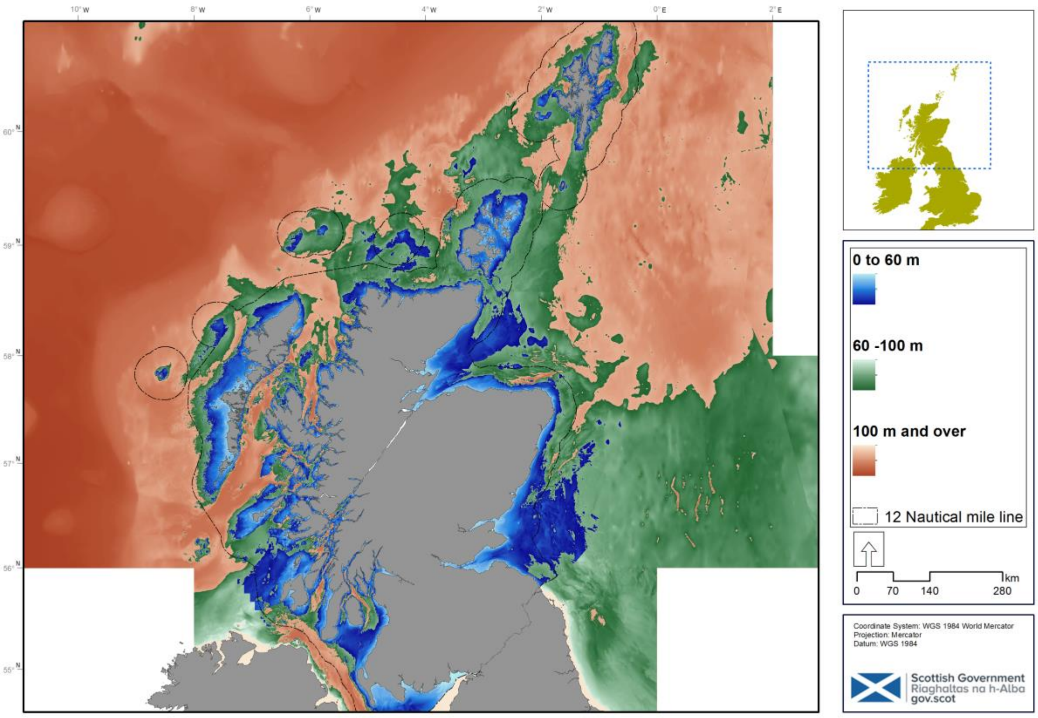

Figure 8: Bathymetry of Scottish waters separated into depth bandings to help visualisation of the relative area at each depth range. © Crown copyright and database rights (2018) OS (100024655). © Crown Copyright, 2018. All rights reserved. License No. EK001-20140401.

3.5.4 Sediment type

Floating wind technology seabed attachments can use a number of types. (Haslett, 2016). The anchoring methodology eventually chosen will depend on the sediment type and will likely require soft sediments deep enough for penetration to work effectively. Mud, sand or gravel substrates were considered appropriate, rocky sea beds were considered to be more constrained. The layer used, however, only provides information on the type of sediment and not on the depth of sediment at any location. The sediment depth would be a requirement to be investigated at specific locations once they have been chosen.

This layer was classified categorically. The four classifications were converted to two by amalgamating the muddy, gravelly and sandy substrates into one class as the lowest constraint and classifying rocky substrates as the highest constraint.

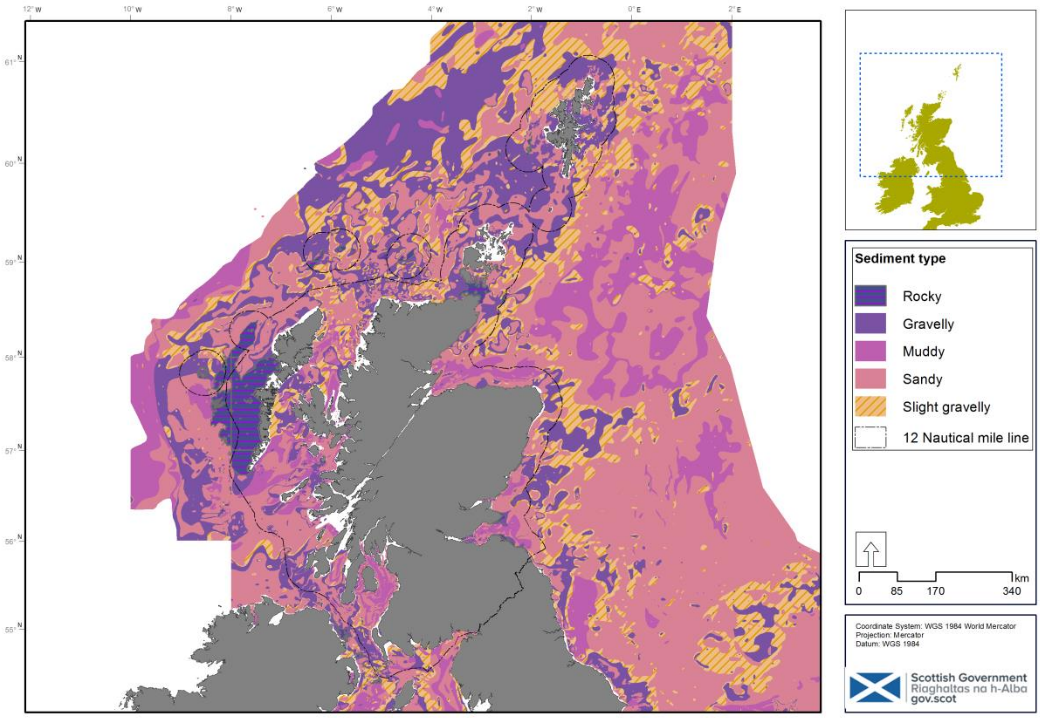

Figure 9: Sediment types on Scottish waters. Data from British Geological Survey. © Crown copyright and database rights (2018) OS (100024655). © Crown Copyright, 2018. All rights reserved. License No. EK001-20140401.

3.5.5 Nature protected areas

These are designated by the Scottish Government under European directives, or through national nature conservation legislation. Their constraint was considered on an individual basis. European designated sites were given a high constraint (3), national and regional designated sites were given a medium constraint level (2). Not yet fully designated protected areas such as draft offshore Special Protected Areas (SPA) and the Marine Protected Areas (MPA) areas of search have been included but have been given a medium constraint level (2) as they may not go to full designation but should be included in the analysis. For the multi-criteria analysis all nature designated areas were joined together to form one layer and this layer was given the highest possible weighting. Many of these designated areas overlap directly so to avoid counting any of them more than once all the layers were merged together to form one single spatial footprint.

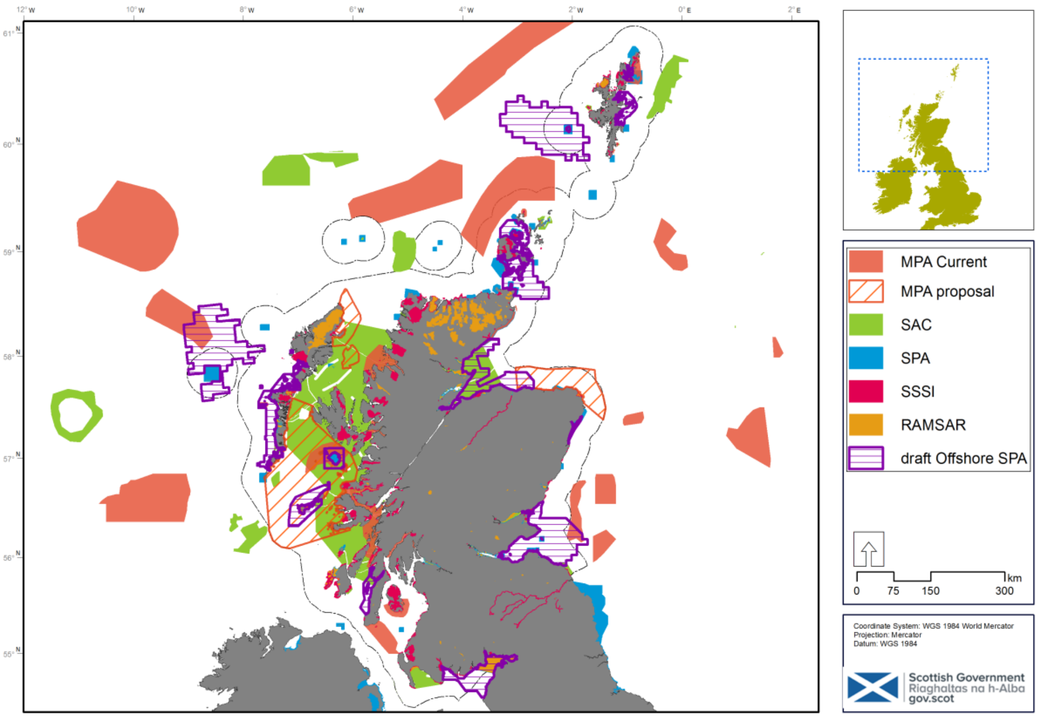

Figure 10: All of the offshore and coastal nature protected designations that have been included into the multi-criteria analysis. © Crown copyright and database rights (2018) OS (100024655). © Crown copyright. All rights reserved. Joint Nature Conservation Committee Support Co 2018.

3.5.6 Fishing activity

There is a varied and flexible fishing industry working in Scotland. Boats of different sizes exploit different areas at different times of year. Some are more predictable than others as their quarry is specific to a particular type of substrate, for example scallops or trawled nephrops. Others, for example squid or herring, are more variable in the locations where the fishery is prosecuted.

With the advent of Automatic Information Systems (AIS), foreign vessel activity can also be plotted, although it was not included in this study.

This is an important industry in Scotland from an economic and social point of view and it is essential to include its footprint into the spatial analysis. Fishing can be considered a heritage activity as well as an industry as its significance spreads through generations in more senses than the purely economic. It is important to assess both the areas that are currently fished and to investigate those that may be fished in the future as patterns do change and the fishing industry will adapt by returning to historically fished zones or discovering new ones.

The layer used for this scoping study included Vessel Monitoring System (VMS) data as well as outputs from the Scotmap project. Since Scotmap did not cover the entirety of the Scottish inshore fleet, landings as reported by statistical square extent were incorporated into the layer to ensure as complete a representation as possible. This layer scales the VMS and the Scotmap output to the same economic value range so that all fisheries in Scotland can be looked at together on a monetary value basis.

The fishing layer was reclassified into three classes by applying the quantile classification and selecting three classes. The resulting low medium and high classes gave a suitable reflection of the range of values in this layer.

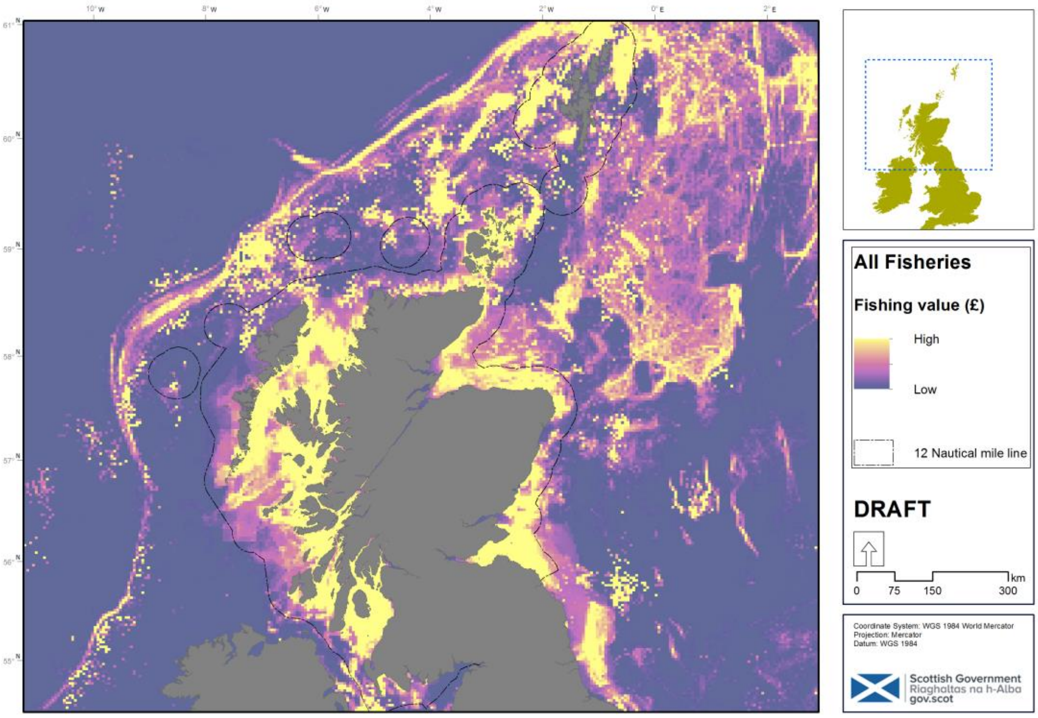

Figure 11: Fishing activity by monetary value including data from VMS and from Scotmap as well as supplementary landings information for the inshore fishing data. The data period mapped was 2007-2011. © Crown copyright and database rights (2018) OS (100024655).

3.5.7 Sea and coast based leisure activities

The use of sea and coastal areas by the Scottish population has to be considered when developing any infrastructure in our waters. Spatial data can help to visualise preliminary areas of conflict and to help identify suitable locations that do not interfere with these important socio-cultural locations. The Scottish Marine Recreation and Tourism Survey (LUC, 2016) has helped to answer questions on the locations where various coastal and sea-based activities happen. Results from the responses provided for this voluntary survey have been used to visualise the density, amount of users per unit area, of the activities recorded around the coast and inshore waters. The layer used to summarise all activities has been included in the constraint model.

Data sets under this theme can often be the hardest to categorise into measurable and comparable outputs as what they represent is often not as tangible or quantifiable as other layers. However, outputs from the Scottish Marine Recreation and Tourism Survey (LUC, 2016) have allowed spatial data on human leisure interactions to be added to these analyses. This has improved greatly the description of leisure activities around the cost and has added a quantitative element to these maps. The previously used data were based on static points and gave no sense of relative amount of use. However, this data should not be considered exhaustive or unbiased.

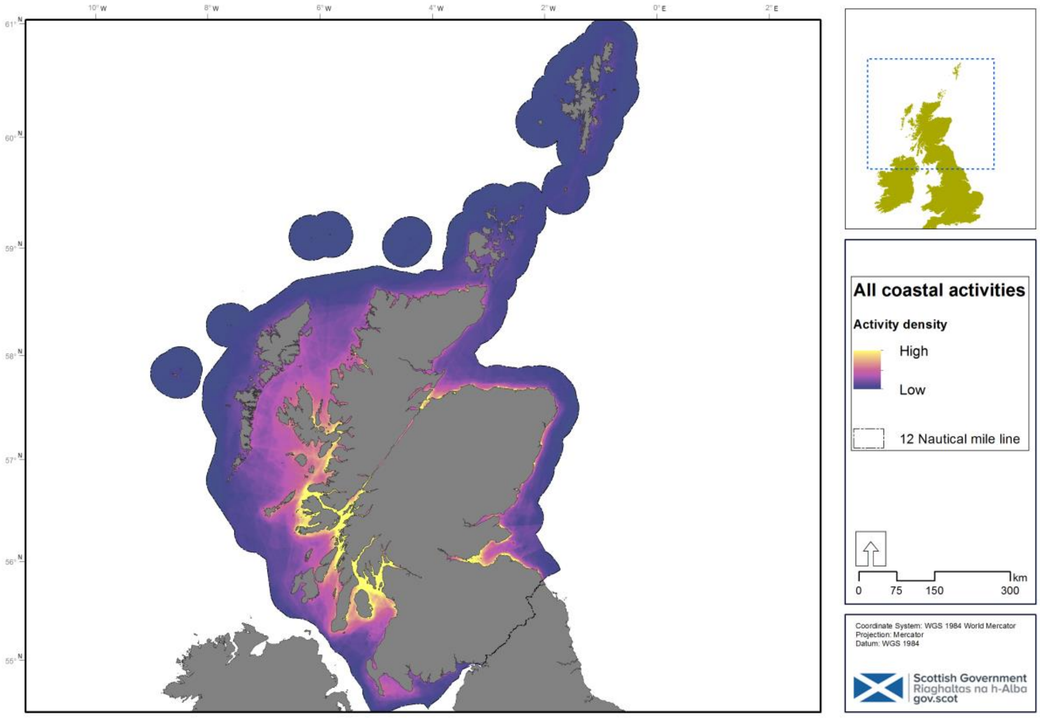

Figure 12: Combined coast and sea-based activities density map taken from the Scottish Marine Recreation and Tourism Survey (2016). © Crown copyright and database rights (2018) OS (100024655).

3.5.8 Military exercise areas

Information about military operations is kept confidential. However, the broad scale areas shown on the map below identify areas used for offshore military exercise purposes. Military operations are not constant in time or location, but for planning purposes they must be taken into account. Once more specific locations are identified, consultation with the Ministry of Defence (MOD) will help to establish if any exercises undertaken in the chosen area are likely to be incompatible with offshore developments.

Areas where operations are undertaken at high altitudes were removed as these do not overlap with the footprint of offshore wind sites. This layer has been classified into two classes using the metadata provided by the MOD with this layer and based on the level of risk.

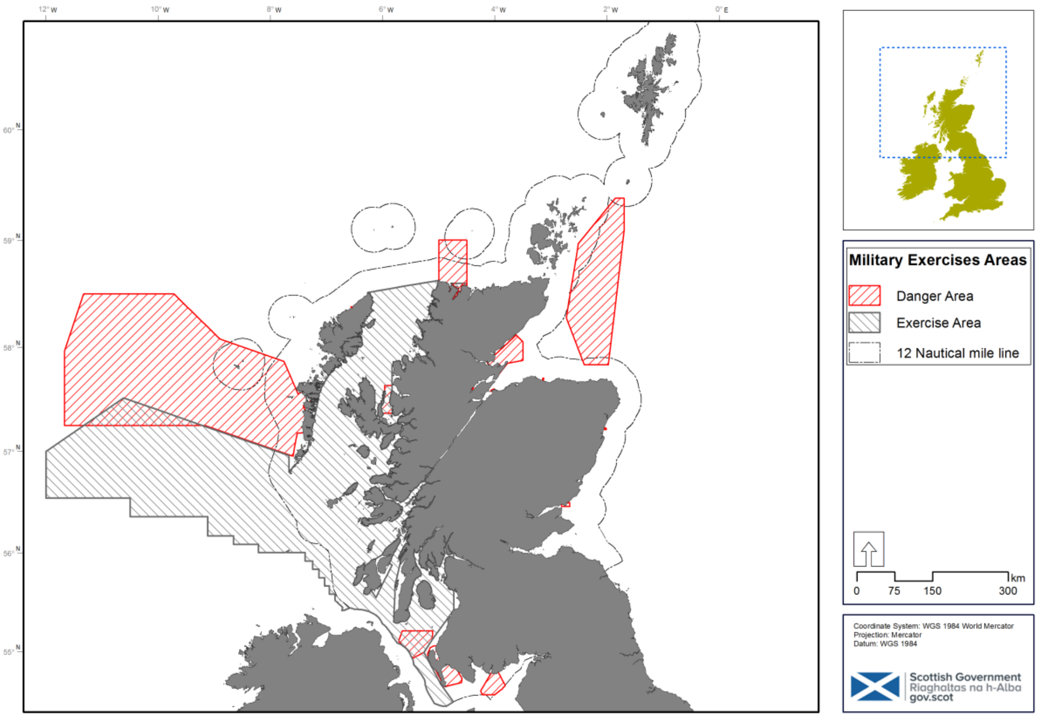

Figure 13: Military exercise areas. © Crown copyright and database rights (2018) OS (100024655). © Crown Copyright, 2018. All rights reserved. License No. EK001-20140401. Not to be used for Navigation.

3.5.9 Shipping

Scotland has busy shipping lanes used by cargo vessels, oil tankers and, predominantly in the east coast, the support vessels for the oil and gas industry. Decoded and processed AIS data is available from online sources and has been used in this assessment. Figure 14 shows the density of all vessels for the first week of each month of 2015.

AIS data is available from sources like the Maritime and Coastguard Agency who can provide it to government organisations. Coastal based radar received AIS data from 2015 has been processed and made available online by ABPMer.

This layer was classified into three classes by using the quantile classification technique to investigate the distribution. The data values are highly skewed with less data in the higher density values, the quantile distribution exaggerated the spread to the higher values. The middle (medium) value was increased to 200 vessels per week as otherwise the shipping layer exaggerated the extent of high density shipping presence. At these custom breaks the three classes take in the main routes without spreading out too much in the highest class value.

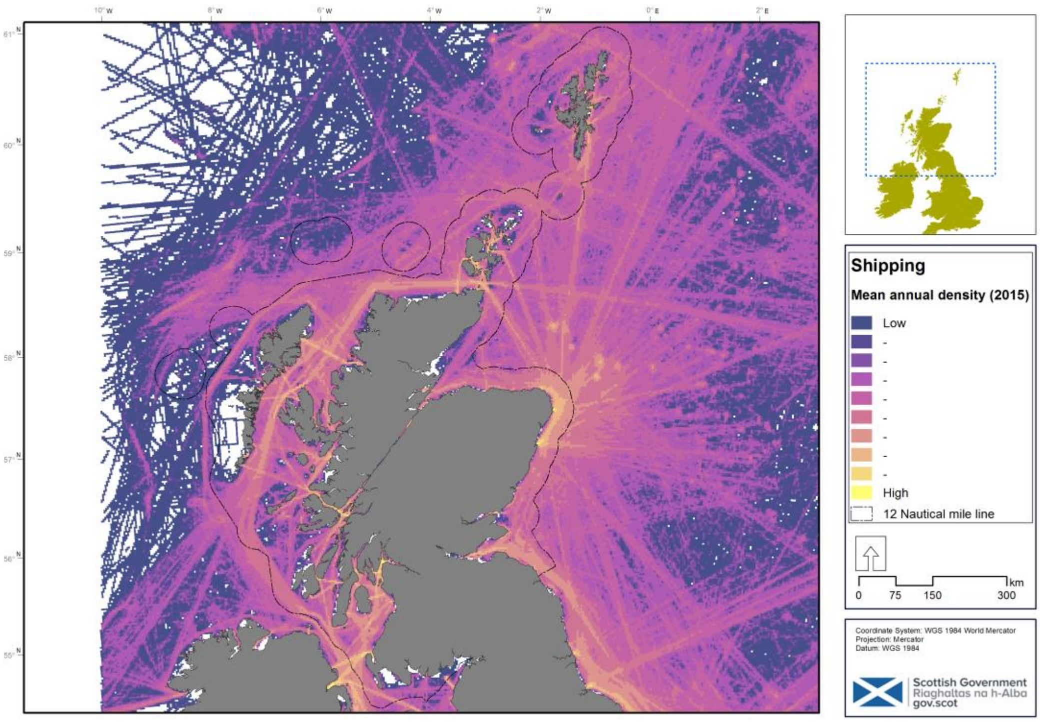

Figure 14: Annual mean shipping density as calculated by ABPMer for the year 2015. © Crown copyright and database rights (2018) OS (100024655). © ABPMer copyright (2018) http://www.abpmer.net/downloads/default.asp?location=ArcGIS_Online&request=2015_AIS.

3.5.10 Aviation

The spatial extent of potential interference between offshore wind turbines and Civil Aviation Authority radar is represented using the National Air Traffic Services (NATS) provided GIS layers. These give an indicative guide and identify areas where a developer should consult with NATS to investigate the importance of overlaps between any likely interference and the planned development. The probable interference layer up till 200 m height was chosen given that increasing wind turbine sizes are likely to reach this elevation. The data can be downloaded from the NATS self-assessment site (NATS, 2018). These maps describe areas where the height of the turbines could present a potential interference hazard to primary surveillance radars operated or used by NATS En-Route. Helicopter routes were also provided by NATS as a map of helicopter main routes showing the Northern North Sea Offshore safety area. The lines of this map were digitized to convert the image to a usable GIS format.

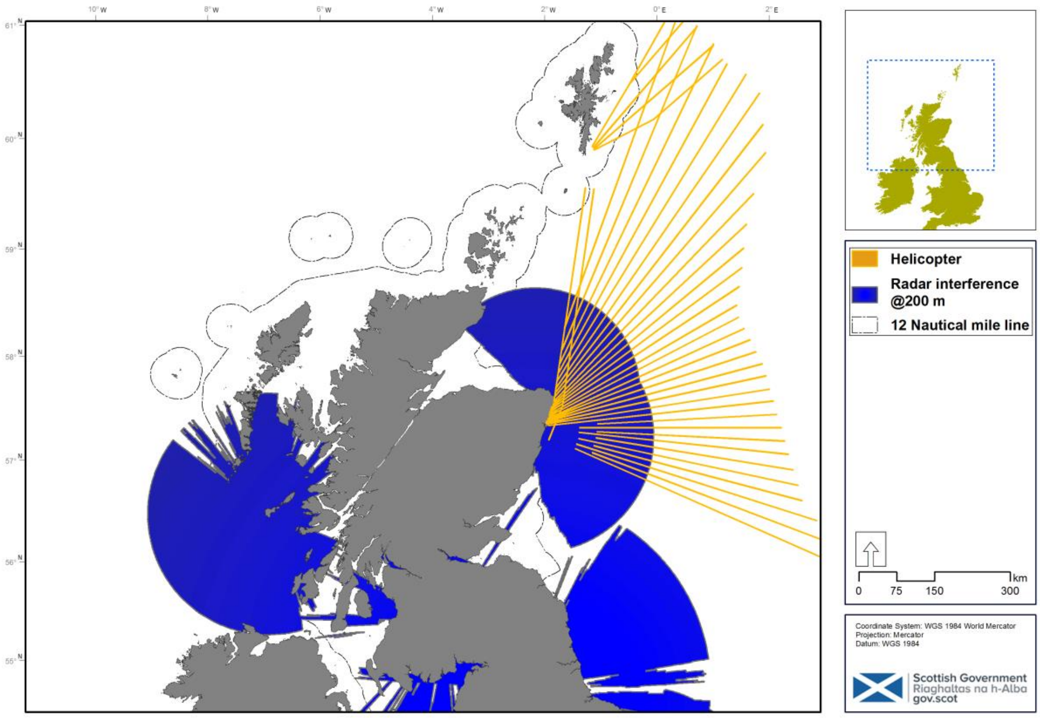

Figure 15: Radar interference taken from the NATS self-assessment website and helicopter flight routes to oil and gas locations. © Crown copyright and database rights (2018) OS (100024655) © NATS copyright (2018) https://www.nats.aero/services/information/wind-farms/self-assessment-maps/.

3.5.11 Seabirds and cetaceans

The construction process of offshore wind farms can generate a number of impacts which marine mammals may be sensitive to. Principally during the construction period as the percussive noise of some installation methods such as piling has been shown to affect marine mammals (Southall *et al.*, 2007). For seabirds the potential collision, displacement and barrier effects can have an impact on seabird populations over the lifespan of the development. The layers used to represent constraint generated from seabirds, expressed as vulnerability to collision with offshore wind farms were created using a combination of data sources. The overall seabird density was taken from the European seabirds at sea survey data (ESAS). Two seabird layers were generated, one for the breeding season and one for the overwintering seabirds. Initially these layers were created for the scoping study of 2011 and they show an overall density of all recorded species. Each of these species' distribution layers are then combined with a factor based on their vulnerability to wind energy based on the seabirds' physical characteristics. The creation of these vulnerability factors is documented in Furness *et al.* (2012).

The seabird vulnerability layers were classified into three classes by examining the distribution of the vulnerability values. The range of values for both the seabird layers were skewed highly over a huge range towards the lower values, so for both these layers it was considered appropriate to choose the class breaks based on a modified natural breaks classification. This provided a more balanced distribution between the three classes and did not overwhelm the inshore areas with higher constraint values than were warranted.

The cetacean layer used was created by combining surveyed densities of the most common cetacean species as collected into a series of data sets by Reid, Evans and Northridge (2003). This layer's value distribution was also skewed towards the lower values. A set of classes that did not overstate the high class and balanced out the mid and low classes was arrived at manually.

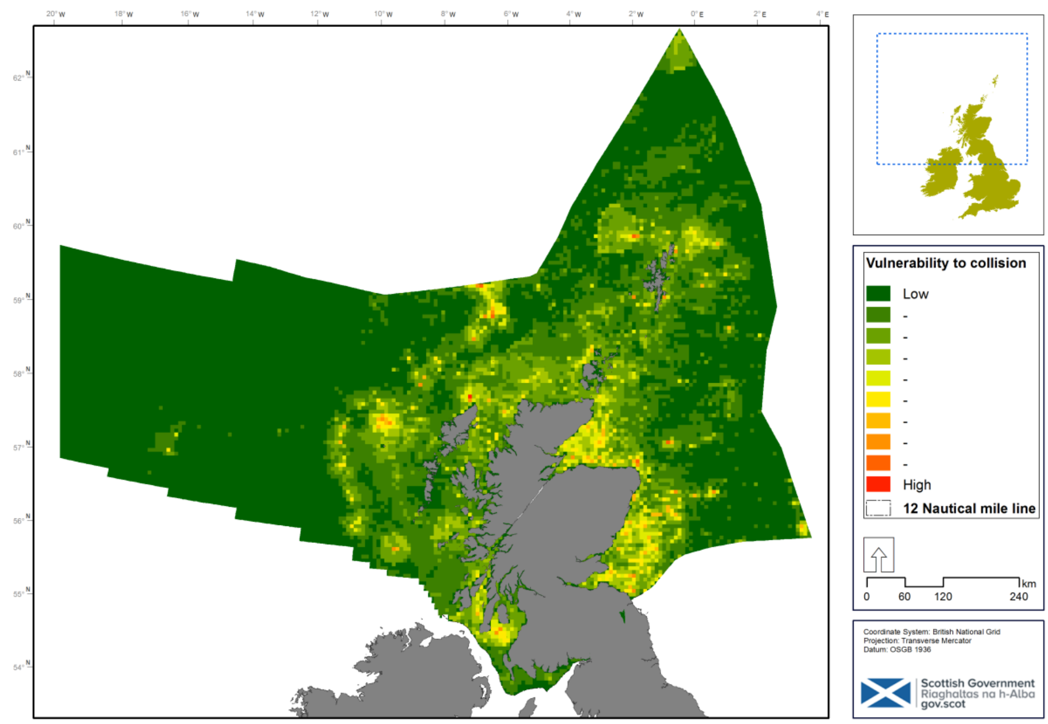

Figure 16: Vulnerability to collision of seabirds during the breeding season. © Crown copyright and database rights (2018) OS (100024655).

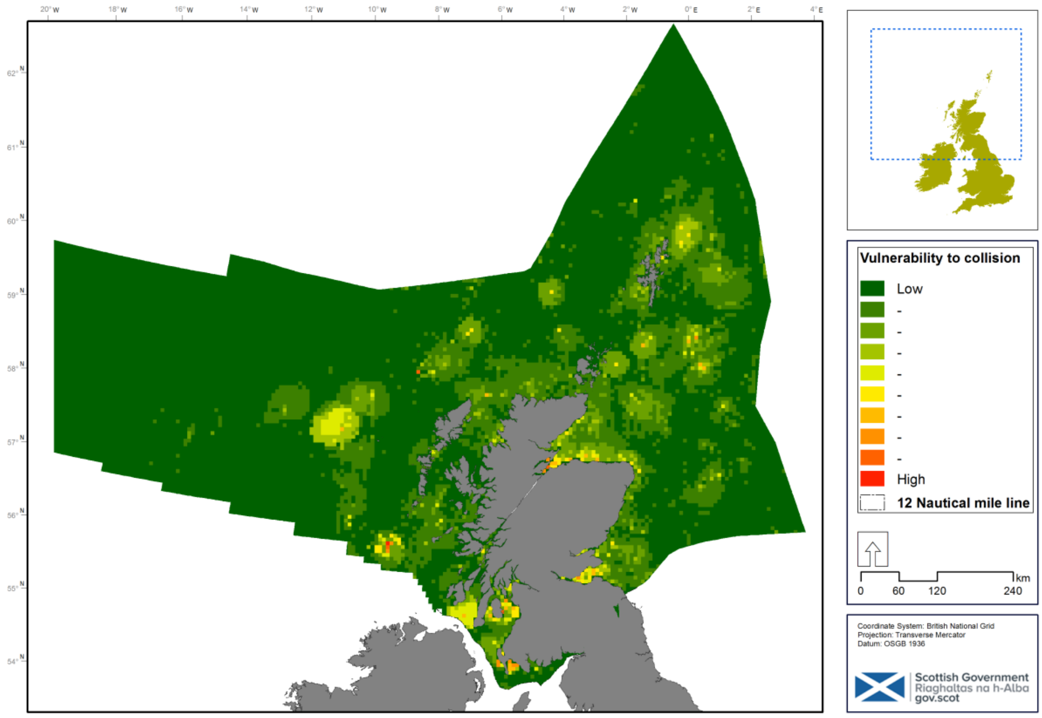

Figure 17: Vulnerability to collision of seabirds during the winter season. © Crown copyright and database rights (2018) OS (100024655).

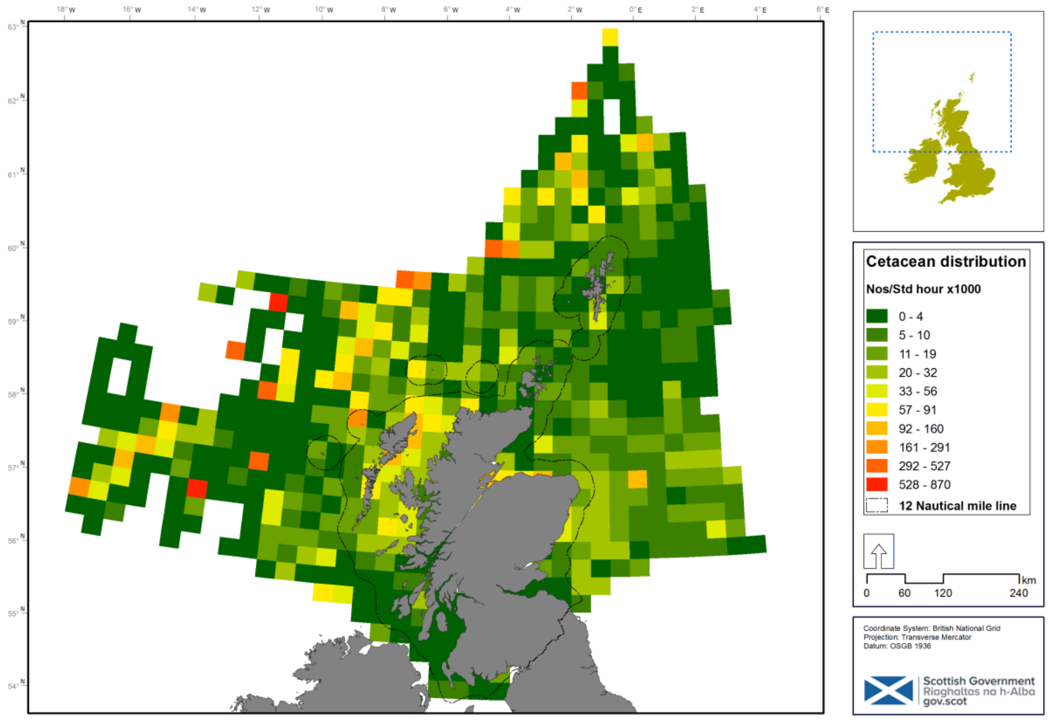

Figure 18: Overall cetacean density distribution created from individual cetacean distribution maps. © Crown copyright and database rights (2018) OS (100024655).

3.5.12 Fish life history layers

Offshore construction may have an adverse effect on sensitive stages of fish life history such as spawning times and early stages of life. It is important to include these aspects of fish biology into this process as construction on or near these sites may have effects on fish populations.

Spatial layers of information have been created to show the probability of aggregations of 0-group fish (fish in their first year of life). These have been combined to allow inclusion of one layer that accounts for this aspect.

The availability of up to date spawning information and its spatial representation varies between species. Some recent studies have generated probability outputs that show where cod and haddock spawning sites are likely to be found (Gonzalez-Irusta and Wright, 2015), (González-irusta and Wright, 2016). Other species will also have to be represented where no new information was available. Layers of the likely spawning footprint and overlap of 11 commercial species (CEFAS, 1998) have been combined to show a cumulative footprint of known spawning grounds. This footprint and overlap is shown in Figure 19 before it was reclassified to three classes. This layer was classified into three classes by using an equal interval classification. The higher number of spatial overlaps was classified as higher constraint and the lowest in to the lowest constraint class.

The 0-group (first year of life) aggregation encounter probability layer, an update of the CEFAS (1998) nursery layers was a composite of the probability of encountering 0-group aggregations for 13 species (Aires, Gonzalez-Irusta and Watret, 2014). This layer was created by reclassifying each species' layer separately into a standard range of 0-9 then adding together these standardised layers. These layers were then classified into three classes distributed so as not to exaggerate or misrepresent the spatial extent of each class. The haddock spawning layer was classified in the same way.

The cod spawning layer had four categories that were converted into three by merging the two less recurring categories into one.

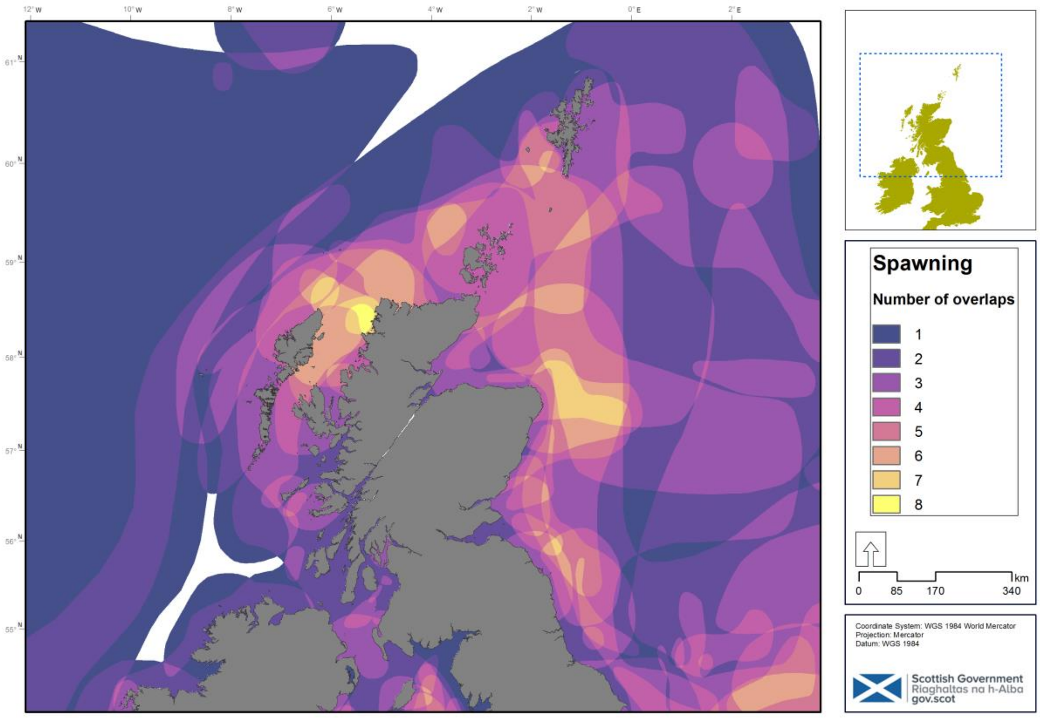

Figure 19: Extent and overlap amount of spawning areas for 11 species listed in (CEFAS, 1998) (cod and haddock excluded as their spawning locations have been updated). © Crown copyright and database rights (2018) OS (100024655).

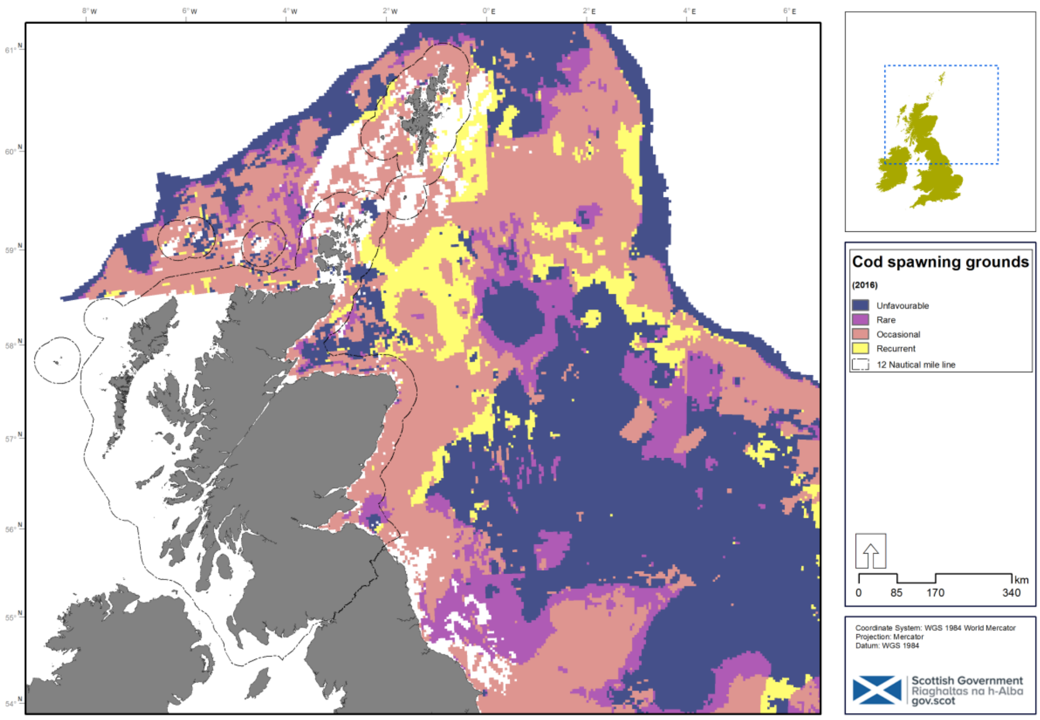

Figure 20: Spawning area preferences of cod from (Gonzalez-Irusta and Wright, 2015). This modelling was restricted to the east and north coasts of Scotland. © Crown copyright and database rights (2018) OS (100024655).

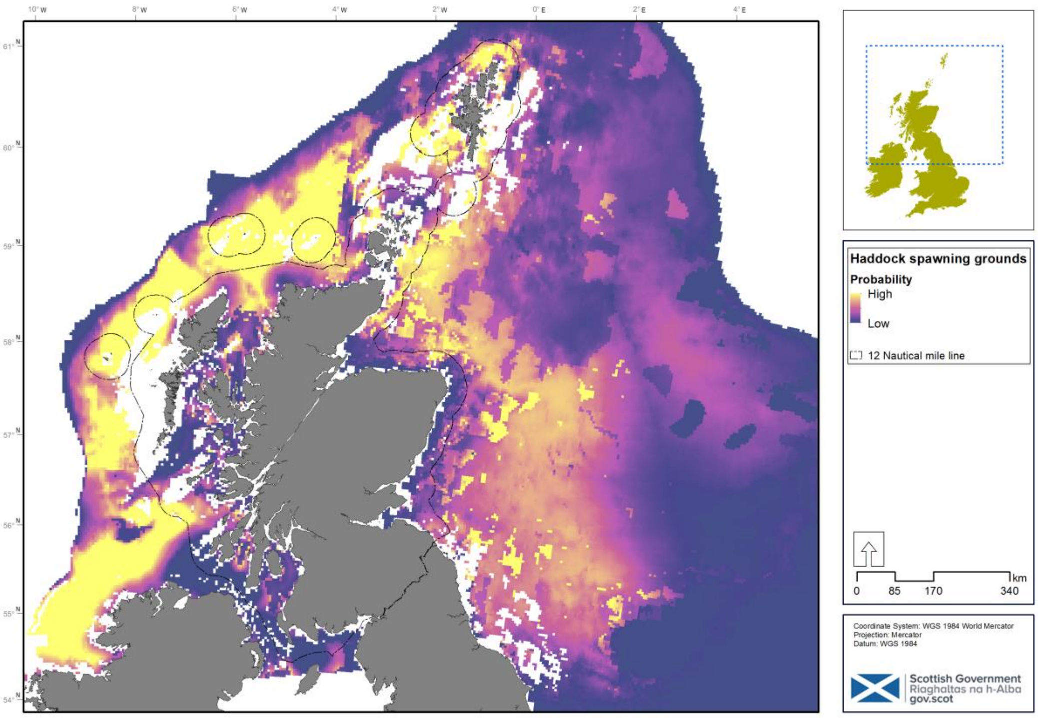

Figure 21: Probability of encountering spawning haddock from (González-irusta and Wright, 2016). © Crown copyright and database rights (2018) OS (100024655).

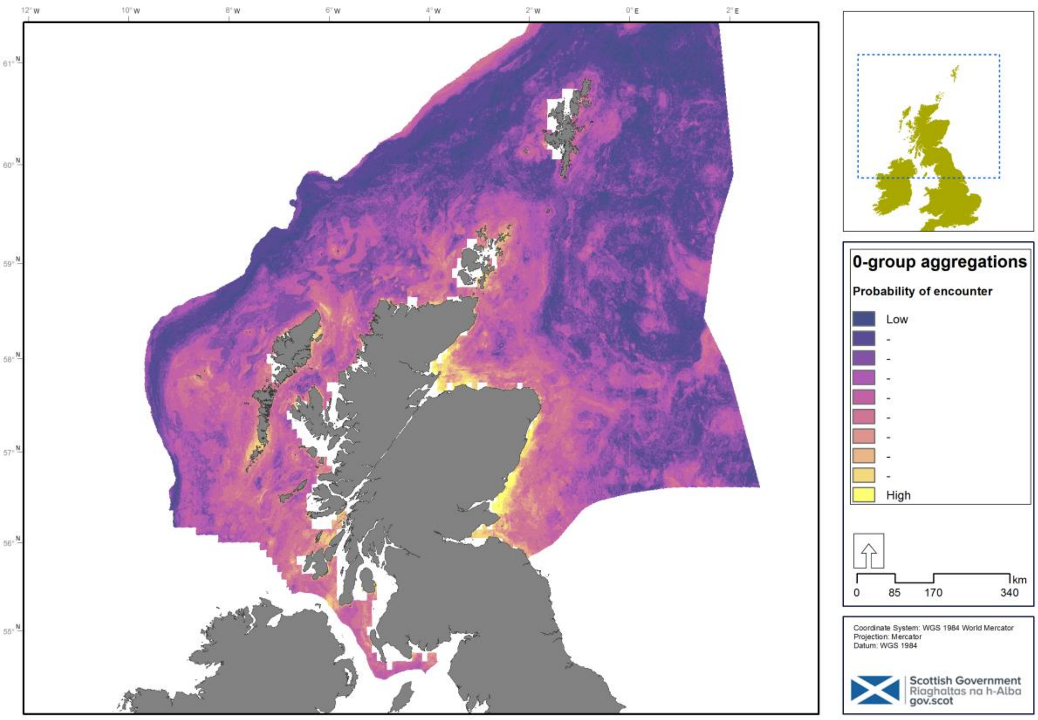

Figure 22: Probability of encountering aggregations of fish in the first year of life from Aires *et al*. (2014). © Crown copyright and database rights (2018) OS (100024655).

4 Opportunities for offshore wind

Once the exclusion and constraint models have been combined, broad areas, that offer the best opportunity and reduced constraint were selected by manually drawing polygons around areas of similar low constraint. These areas are purposefully large to ensure that no potentially suitable sites are excluded at this early stage of the process. Two large areas have been identified in the east coast, one in the south west and one in the north coast. Near Shetland, one area has been identified in the south east and one larger area to the north. All these areas contain the previously identified draft plan options from the sectoral plan for offshore wind. Figure 23 shows the resulting output that combines the exclusion model and the contstraint model as well as the broad scale AoS. At this stage, the selection of broad areas need not account for smaller exclusion areas as these will be further analysed to avoid overlaps.

This process established a multi-criteria baseline which identifies potential opportunity and constraint at a national scale. Obvious areas of high constraint or exclusion areas are easily identifiable and this information is used to define the broad areas. Similarly, areas of opportunity can be presumed to contain less constraint and would encounter less issues in terms of any future development. As this process has considered many different aspects, a further refinement process, applied to the selected areas, can focus on specific issues in more detail. The next stage involved an examination of a selection of relevant spatial layers that were overlaid with the broad areas of search to assess, in detail, the spatail overlap with these activities and to refine the broad areas accordingly. This included layers that depict the activities and users most likely to generate interactions that may conflict with any future development. Section 6 describes this process.

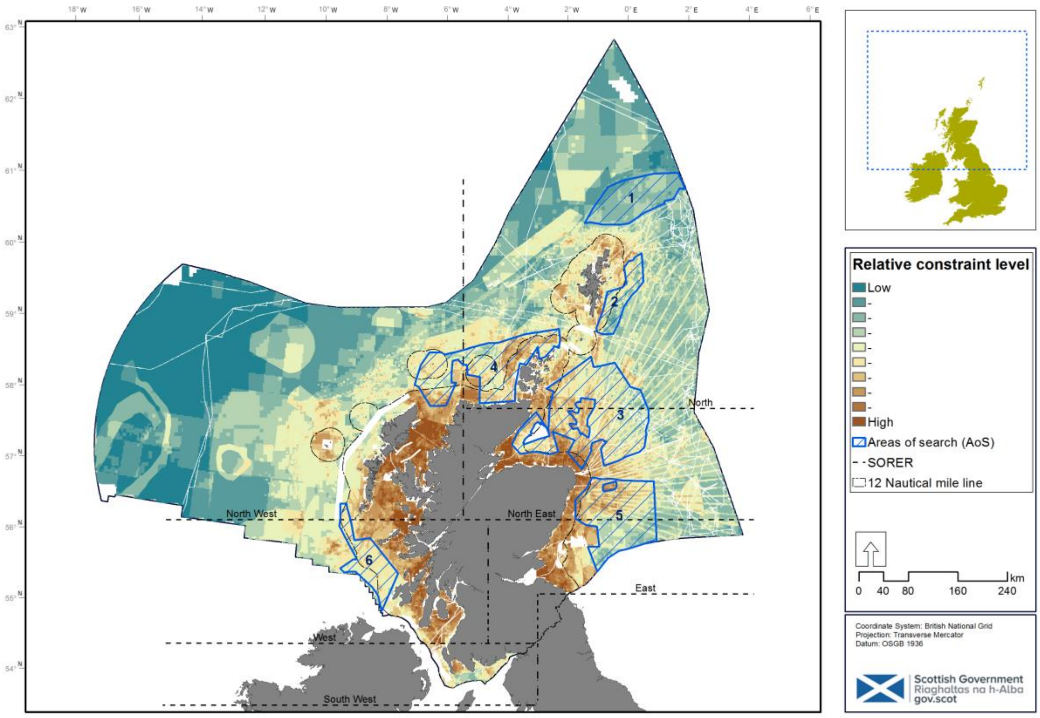

Figure 23: Overall constraint, all themes equally weighted, and exclusion areas with the broad AoS. © Crown copyright and database rights (2018) OS (100024655).Table 3: AoS numbered, area in km2 and SORER area occupied.

Table 3: AoS numbered, area in km2 and SORER area occupied.

Name	Area km^2	SORER
1	7953	North
2	3884	North
3	20590	North East and North
4	13992	North West and North
5	12862	East and North east
6	5655	West and North West

4.1 East Coast. Including SORER Areas North, North East and East

The east coast of Scotland is host to a number of operational and consented offshore wind farms. The first test site to be installed in 2007 was the Beatrice demonstrator project which allowed evaluation of the feasibility of building wind generating structures in depths of 45 m at more than 20 km from the shore (Repsol Sinopec, 2017).

The east coast offers plentiful wind resource as well as conditions of relatively low wave regime, suitable substrate, and depths where current seabed installed technologies can be developed. This is reflected in the large amount of area that this study has identified as potentially suitable for development which will be narrowed down to focussed options that minimise interaction with other users. Currently installed developments occupy the areas closer to land in depths of up to 45 m.

There is generally a marked decrease in constraint as the distance from the coast increases. Two large AoS have been identified that show broad suitability. The highest constraint level is within 30 km from the shore and is mostly composed of Industrial activities like fishing and shipping. Nature protected areas and sea leisure activities contribute also to the cumulative constraint in the Firth of Forth. East of the Firth of Forth developments, at approximately 120 km from the shore there is a notable decrease in relative constraint south of the areas covered by the helicopter transit lines. The inner Moray Firth and the Moray Coast show a high level of constraint relative to areas nearby. The fishing activity and Special Area of Conservation (SAC) designated for the protection of bottlenose dolphin combine to make these two areas unattractive from a consenting point of view. Areas north and south of the existing Moray Firth offshore wind developments show some opportunity although those closer to shore may be hampered by visual impact issues. Further offshore the constraint level shows a gradual decrease with distance but helicopter transit lines, areas of fish sensitivity and offshore fishing activity contribute to some patches of higher constraint.

Different fisheries overlap at different distances from the shore. The scallop fishery shows activity up till 150 km, the nephrops and whitefish fisheries extent further offshore and present areas of interaction with the AoS at some distance offshore. The refined AoS will take into account the fishing activity that occurs further offshore.

The oil and gas industry infrastructure is an important aspect of the North Sea. AoS 3 overlaps with a cluster of infrastructure at its eastern limits. These overlaps will be addressed when the AoS are further refined. The helicopter transit lines to and from the North Sea oil and gas locations are an essential inclusion into the suite of likely constraints. Their effect on the overall constraint can be seen emanating from the east coast of the mainland and Shetland and extending towards the oil and gas fields located further offshore.

Existing wind leases and areas of search in the Moray Firth and the Forth and Tay area have been included into the exclusion layer.

4.2 North Coast. Including SORER Areas North and North West

The north coast of Scotland presents some good areas of opportunity. The combination of grid connection, good wind resource and appropriate depths in an area with a low population makes this an attractive choice for development. A busy shipping lane crosses the north coast through this general area. This shipping lane traffic is composed predominantly of hydrocarbon transporting tankers, fishing vessels and cargo vessels. Sailing vessel traffic is also conspicuous around this location but in lower densities and generally closer to the coast. The AoS selected stretches eastward towards Orkney and straddles its west coast. A relative increase in constraint can be seen directly west of Orkney due to an accumulation of activities.

The AoS extends also towards the North of the Minch. This is a challenging environment for any offshore energy project, however the resource and depth as well as the areas relatively free from shipping and fishing make this a possibility for developments.

4.3 West coast. Including SORER Areas North West and West

The west coast is relatively constrained particularly in the Minches. The cumulative overlay of the fishing and shipping activity together with protected nature conservation areas, including a large SAC for harbour porpoise, account for this. This analysis suggests that consenting a farm in much of this part of Scotland could encounter a significant amount of obstacles.

The southern AoS that has been identified as containing a large area of relatively low constraint spans from west of Islay northwards to the southern tip of the Hebrides at the height of Barra. This AoS extends outwards from the 12 NM limit and contains a moderate amount of constraint throughout. Sites within this AoS would also present challenging conditions to developers; as well as high potential generation if those challenges were met. The north section of this AoS lies mostly over hard substrate, the cost of seabed attachment would have to be balanced against the benefits from the exploitable resource.

4.4 Orkney and Shetland. Including SORER Area North

Around Shetland the accumulation of fishing and shipping activity overlaid by the oil and gas activity and the helicopter transit lines make for some constrained areas. In addition to this specific sites that see annual fish life history evens such as herring spawning add to the activity around Shetland. The south east of Shetland shows a relatively decreased area of constraint, and the resource and closeness of infrastructure could potentially be an advantage. Approximately 80 km north of Shetland a large AoS has been identified that, although relatively far away from land, presents a good level of opportunity with minimised constraint.

The AoS that includes the western part of the Orkney isles presents some constraint due to the overlapping of fishing activities and nature designated areas but there are patches of decreased constraint that could be exploited.

5 Sensitivity analysis

The constraint maps are composed of a number of layers, it is helpful to know how stable and predictable the output is at the chosen set of weightings and how changes in these can affect the output.

The sensitivity of the output to variations in the weightings of each data theme ie: environmental, industrial, technical or socio-cultural was investigated by weighting an overlay output of all the layers in each theme as per the final output except for one theme which was weighted twice as highly as the other three data themes.

Using this approach a matrix of combinations was created to show the combination of overall relative weightings used in the sensitivity test. Table 4 shows the overall relative weightings matrix resultant from the sensitivity test. The results (Figures 24-27) show that although there are regional scale differences in the outputs the overall constraint level remains higher inshore and the relative areas of minimised constraint appear in the same locations. These figures show that with a doubling of weighting on each of the themes in turn the relative output remains within similar relative ranges of constraint. Hence it is acceptable to consider that the original weighted map is an apt representation of the constraints generated by the layers and relative weightings included in the constraint model.

Table 4: Matrix showing combinations of weightings per theme. In turn each theme has been weighted twice as high as the three others to assess the effect this has on the overall output.

	Relative weight			
Theme	Environmental weighted	Industrial weighted	Sociocultural weighted	Technical weighted
Environmental	2	1	1	1
Industrial	1	2	1	1
Sociocultural	1	1	2	1
Technical	1	1	1	2

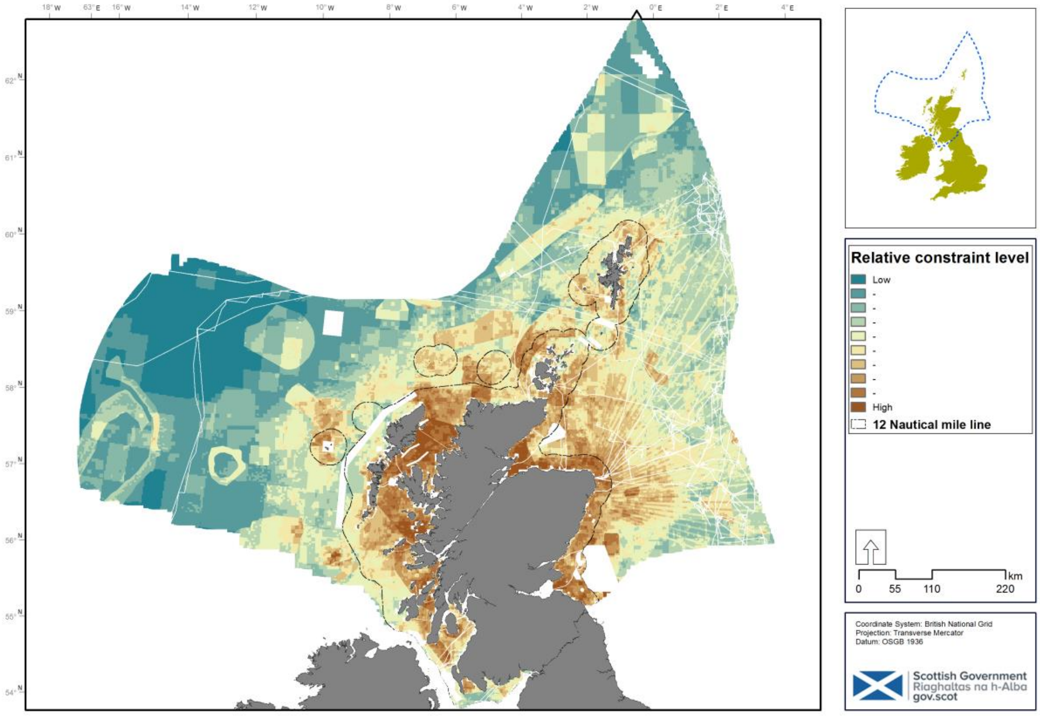

Figure 24: Constraint output with the environmental layer set weighted at twice as much as the rest of the layers. © Crown copyright and database rights (2018) OS (100024655).

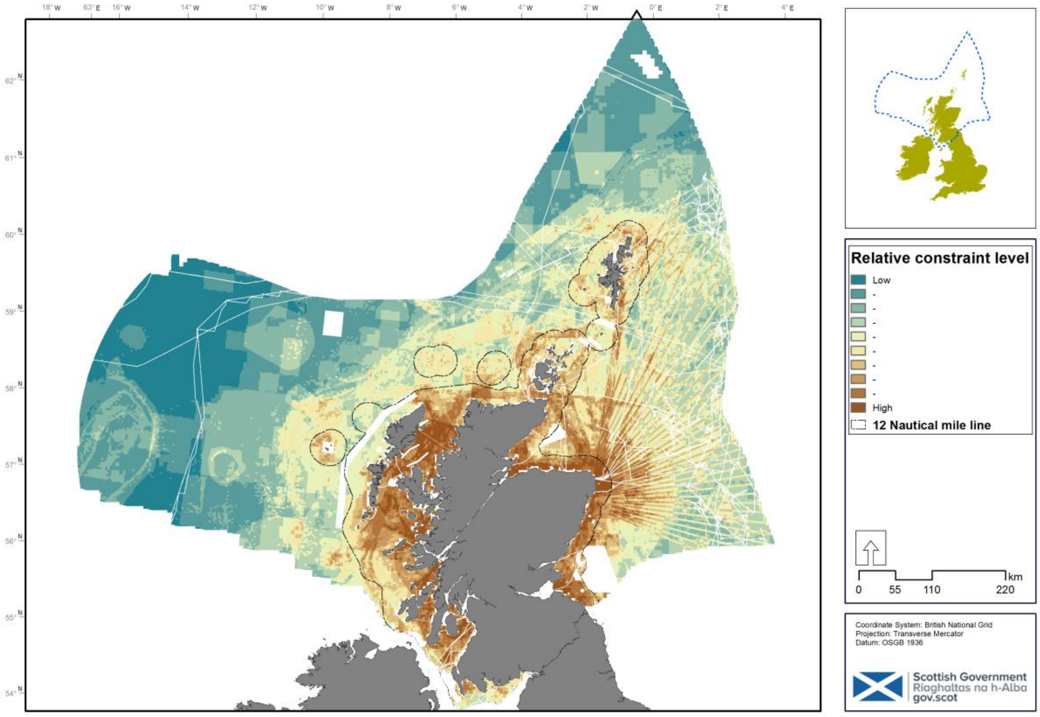

Figure 25: Constraint output with the industrial layer set weighted at twice as much as the rest of the layers. © Crown copyright and database rights (2018) OS (100024655).

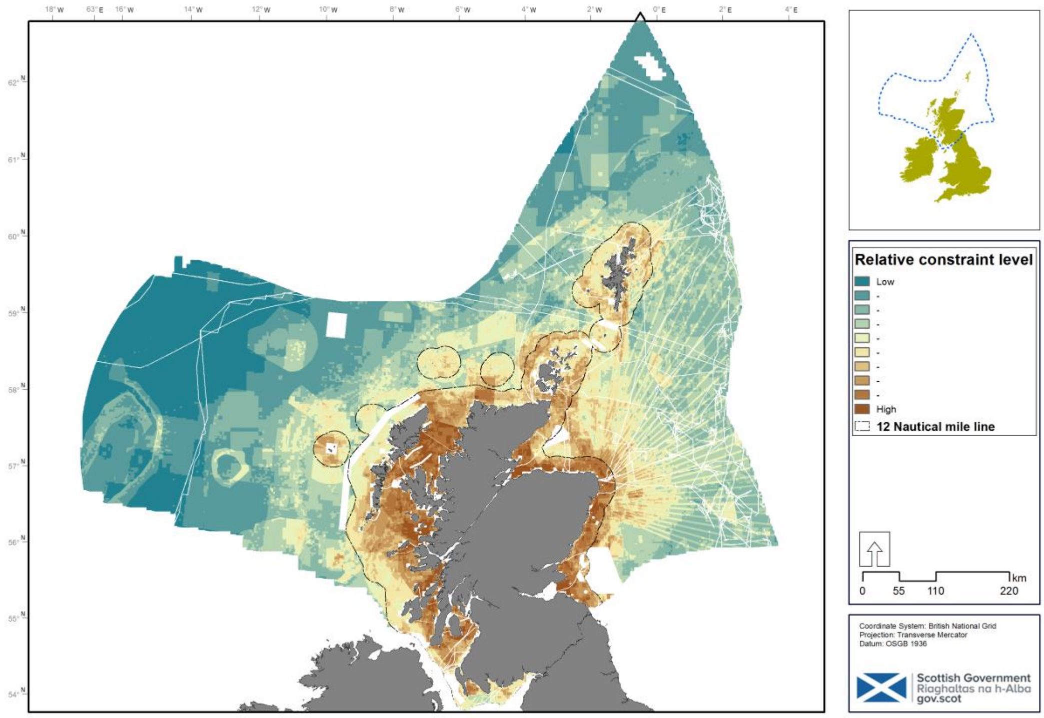

Figure 26: Constraint output with the socio-cultural layer set weighted at twice as much as the rest of the layers. © Crown copyright and database rights (2018) OS (100024655).

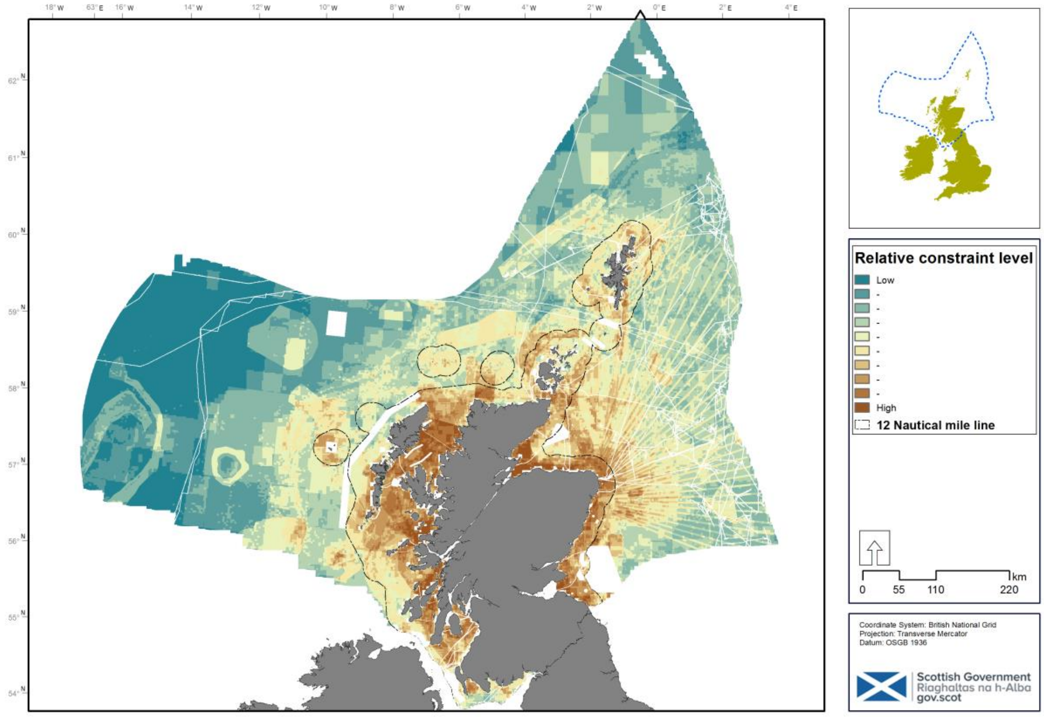

Figure 27: Constraint output with the technical layer set weighted at twice as much as the rest of the layers. © Crown copyright and database rights (2018) OS (100024655).

The changes in each of the outputs where one data theme eg: environmental, were double weighted did not differ significantly from the output that did not alter the relative weighting of the themes. The output composed of layers weighted as per Table 1 was used for assessing the best opportunities and drawing the initial AoS.

6 Further processing of the AoS

The initial constraint output provides a guide as to the relative suitability of the study area for offshore wind energy projects. By avoiding areas with the highest levels of constraint, the resulting AoS are the first step towards identifying the locations potentially suitable for development. As such, the multi-criteria analysis serves as a useful and versatile tool to visualise many spatial layers of information simultaneously. However, the multi-criteria analysis could potentially lead to some individual issues being obscured where a greater density of constraint layers create a cumulative effect elsewhere

A selected set of interactions have been overlaid individually on the AoS to visualise where some of the single issues that are more likely to create barriers to development exist. These single issues can act to significantly limit or delay development opportunity, but may not have registered in the constraint output as high. This exercise was undertaken to alter or remove parts of AoS that had high probability of conflict with the principal single issue users of the sea.

The single issue interaction layers used to revise the AoS were:

- Fishing- offshore fishing intensity data (VMS information on vessels larger than 15 m in length) were used to further identify likely interactions fishing types included:
    - Scallop dredging
    - Nephrops trawling and creeling
    - Demersal trawling
    - Pelagic trawling
    - Crab and lobster creeling
- Shipping traffic- processed AIS data for all vessels for the year 2015 were used to discern the most heavily used routes and to draw the revised AoS around them.
- Nature protected sites- overlap with all MPAs, SACs, SPAs, Offshore SACs, RAMSAR sites, draft offshore SPAs and SSSIs was considered and changes made to avoid likely constraints.
- Oil and gas installation locations in the eastern North Sea overlapped with some of the AoS. The AoS were revised to decrease the overlap with oil and gas clusters.

Given that this process splits the AoS using these layers as a guide the resulting revisions are more numerous but individually cover a smaller area. The resulting revised AoS are shown in Figure 28 together with the originally identified AoS. Table 4 lists the names given to these revised AoS as well as the area they cover and what SORER area they are predominantly within.

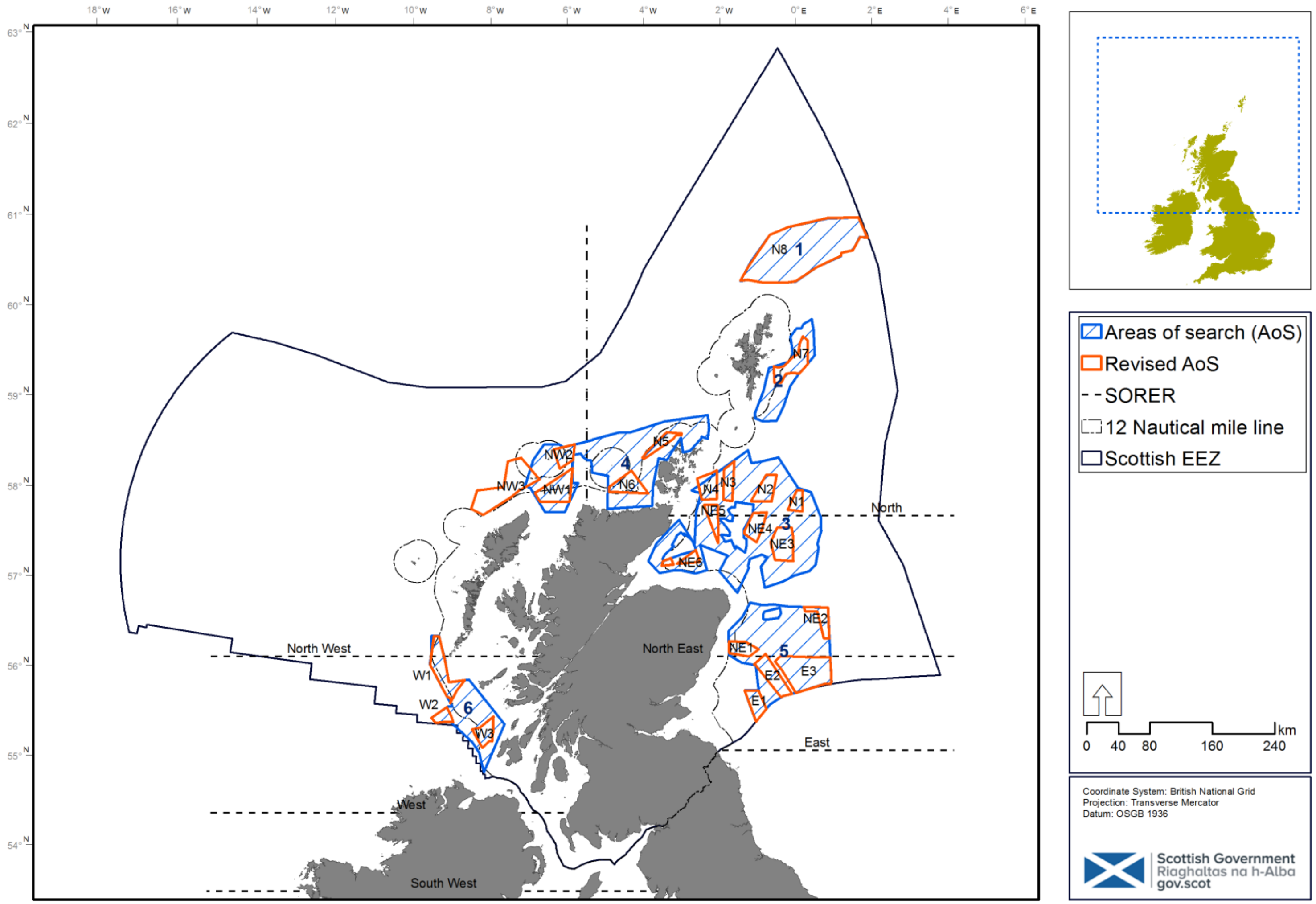

Figure 28: Revised AoS to account for the foreseeable impacts of single issue activities. This includes fishing, shipping traffic, oil and gas infrastructure and overlap with designated nature protected areas. © Crown copyright and database rights (2018) OS (100024655).

Once the process of consultation on these AoS begins, the stakeholders may alert MS to interactions that could further alter their spatial extent.

Table 5: Names and area in km^2 of the revised AoS, the SORER area in which most of their area falls into is indicated also.

Area km2	AoS name	SORER occupied
588	E1	East
937	E2	East
2397	E3	East
354	N1	North
687	N2	North
547	N3	North
724	N4	North
435	N5	North
804	N6	North
1016	N7	North
7937	N8	North
534	NE1	North East
525	NE2	North East
1059	NE3	North East
650	NE4	North East
440	NE5	North East
222	NE6	North East
86	NE7	North East
1193	NW1	North West
513	NW2	North West
2406	NW3	North West
1258	W1	West
320	W2	West
554	W3	West

6.1 Detailed description of the modifications applied to the initial AoS

The opportunity and constraint mapping process described above provided an initial set of AoS. These areas were presented at various workshops held early in the initial scoping stage to relevant stakeholders such as representatives of the OW industry, Scottish nature conservancy organisations, Royal Yachting Association and fishing industry representatives among others. As a result of feedback from these events and a more detailed single issue analysis the AoS have been further refined. The changes made to each of the areas are described below. The process of AoS revision follows the SORER regions.

6.1.1 South West

The Areas of Search Study has not identified any options in the South West Region, as Scottish Ministers' have previously ruled this region unsuitable for development in both 2011 and 2013, with the consideration to the potential adverse, economic environmental and visual impacts, and the related community concerns raised in the assessment and consultation processes at the time. Scottish Ministers' intend to maintain this position for the development of the new Sectoral Marine Pan for Offshore Wind Energy, unless sufficient evidence to the contrary is presented during the initial scoping stage consultation.

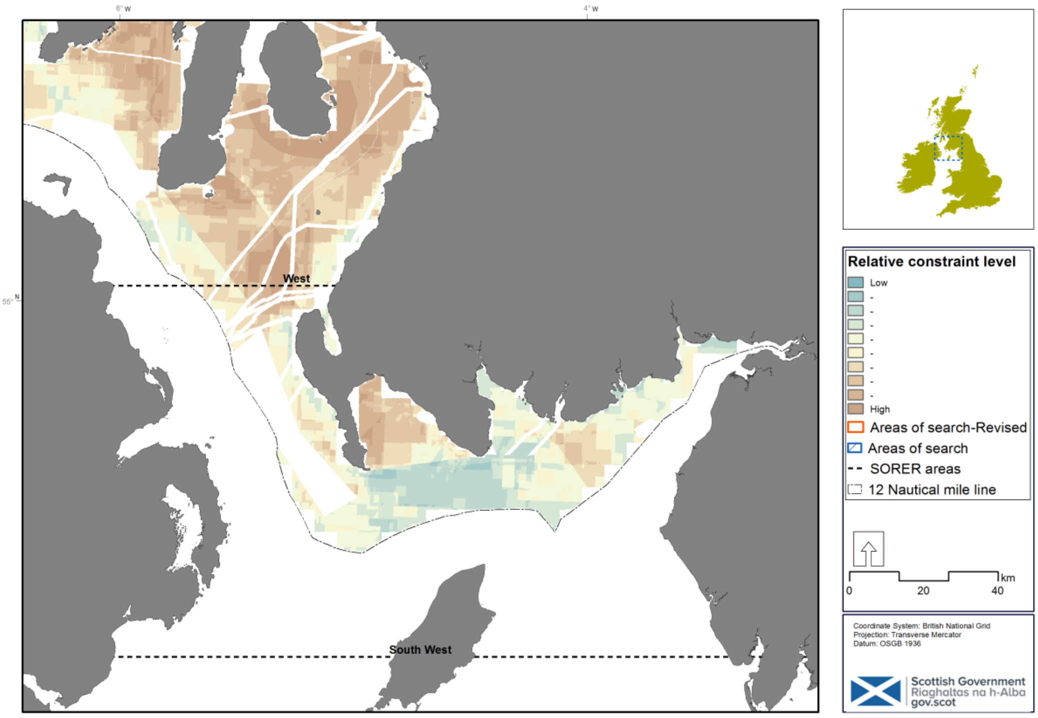

Figure 29: Detail of the south west SORER area. No AoS have been identified at this location. © Crown copyright and database rights (2018) OS (100024655).

6.1.2 West

The opportunity and constraint mapping exercise identified a large potential AoS (AoS 6) that extended from the west coast of Islay, north west to the west coast of Barra.

Further analysis of the individual constraints that may affect this location suggested that the AoS should be divided into three distinct areas. High levels of shipping traffic are found in this area leading to the route between Scotland and Northern Ireland. Accordingly, a large section of AoS 6 (west and south west of Tiree) has been removed to allow suitable space for the shipping traffic. The remaining northern section (W1) has been slightly modified to account for the deep water channel, whilst the west section (W2) was also reduced in size to account for the shipping traffic. W3, the remaining section north west of Islay, has also been reduced in size to account for the shipping traffic to the west and for potential visual impacts at the east coast of Islay.

Both W1 and W3 include large sections of the existing Draft Plan Options (Marine Scotland, 2013a), adjusted for updated opportunity and constraint mapping.

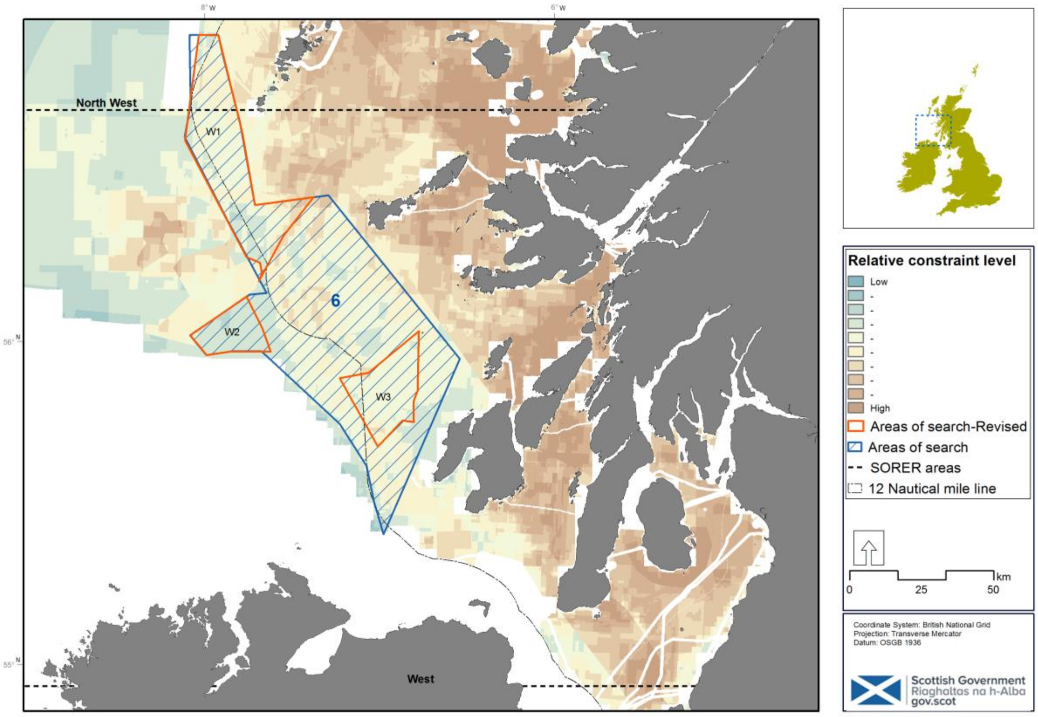

Figure 30: Detail of the west SORER area showing how AoS 6 has been modified. © Crown copyright and database rights (2018) OS (100024655).

6.1.3 North West

A large AoS (AoS 4) bridged the North West and North regions. In the North West region, this AoS occupied the area between Lewis and mainland Scotland and extended north past North Rona. The AoS has been split in two (NW1 and NW2), accounting for shipping traffic as described by the AIS data above. This partition will allow for shipping traffic navigating around Scotland, specifically those vessels which will make use of the deep water channel to the west of Lewis.

Additionally, the opportunity and constraint mapping process highlighted a potential area of opportunity further west of Lewis which was not originally considered in the initial AoS exercise. This new AoS (NW2) has now been included. NW2 includes the area north west of the deep water channel north of Lewis. The area selected excludes a location identified as containing a high level of fishing activity and remains distant from North Rona and Sula Sgeir, avoiding the SPAs in the same location. The opportunity and constraint exercise also suggested that the area between Lewis and the deep water channel could offer a potential area for offshore wind development. However, the potential visual impact at this location would suggest that the more distant AoS (NW2) is more appropriate.

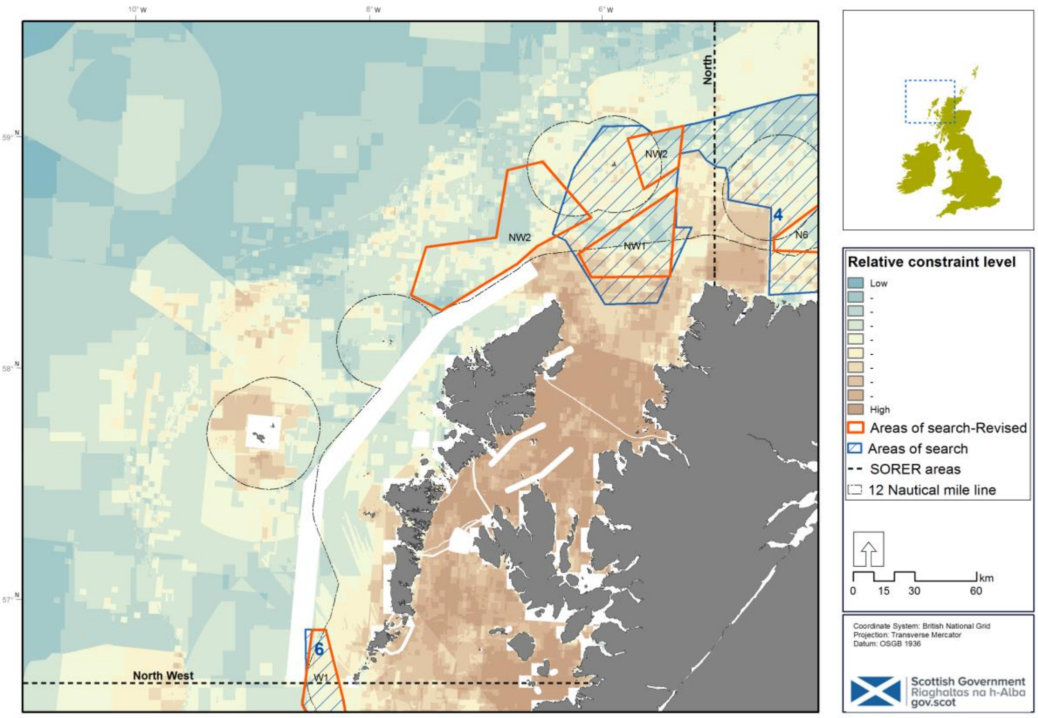

Figure 31: Detail of the north east SORER area showing how area 4 has been modified. © Crown copyright and database rights (2018) OS (100024655).

6.1.4 North

In the North region, AoS 4 extended from the east of North Rona, down to the north coast of mainland Scotland, avoiding the Solan Bank Reef SAC. It extended east encompassing much of the west coast of Orkney and also the existing wind Draft Plan Option.

As a result of further analysis of single issue constraints, this AoS has been reduced to two smaller areas. N6 is now located off the north coast of mainland Scotland encompassing an area between higher levels of shipping traffic. Similarly, N5 off the east coast of Orkney is situated within the previous Draft Plan Option but now encompasses a much reduced area due to shipping traffic and higher levels of fishing activity in the area.

North of Shetland, the opportunity and constraint exercise identified a large potential area of search. This AoS (AoS 1) remains unchanged following examination of specific single issues.

AoS 2 east of Shetland covered a large area along the east coast of Shetland. Whilst the opportunity and constraint exercise highlights this a potential area of opportunity, including the previous Draft Plan option, looking specifically at the demersal fishing activity in the area suggests that the southern section of this AoS could be reduced. N7 now includes only the northern most section of the previous Draft Plan Option.

AoS 3 extends from the east coast of Orkney south into the Moray Firth and further east. Specific analysis of individual issues, including shipping traffic, fishing activity, oil and gas infrastructure and suggested helicopter routes to oil and gas locations suggested that this large AoS should be split into several distinct AoS. Four of these distinct areas are now located in the North region. N1, N2, N3 and N4 occupy areas of low shipping traffic whilst also allowing for helicopter routes through to the oil and gas infrastructure to the east.

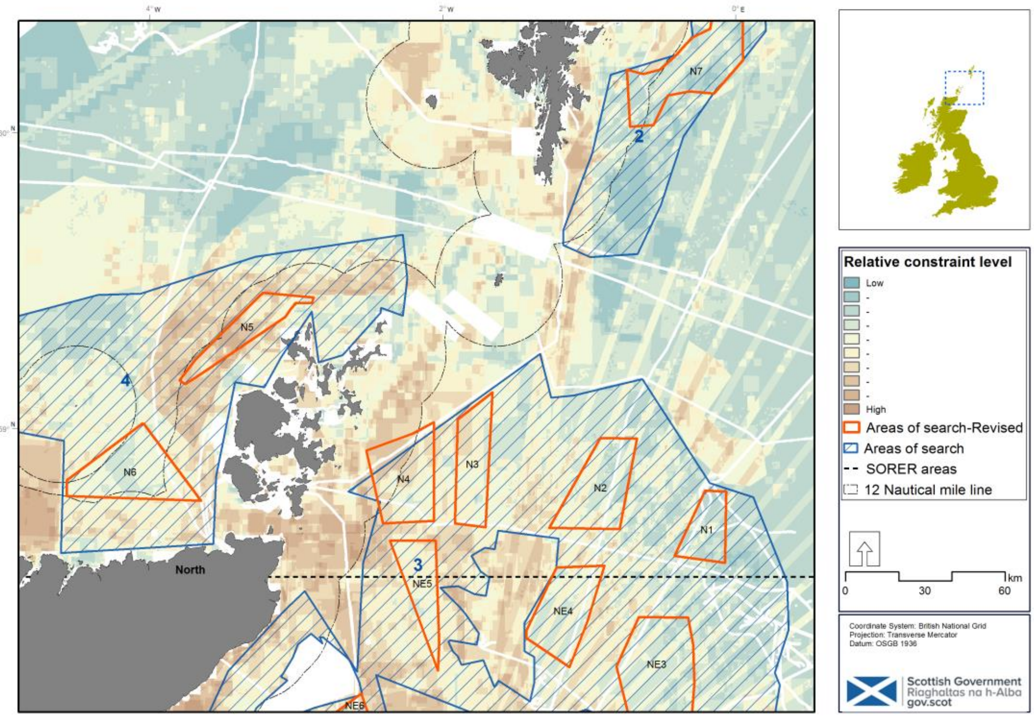

Figure 32: Detail of the north SORER area showing the modifications to AoS 3, AoS 4 and part of AoS 2. © Crown copyright and database rights (2018) OS (100024655).

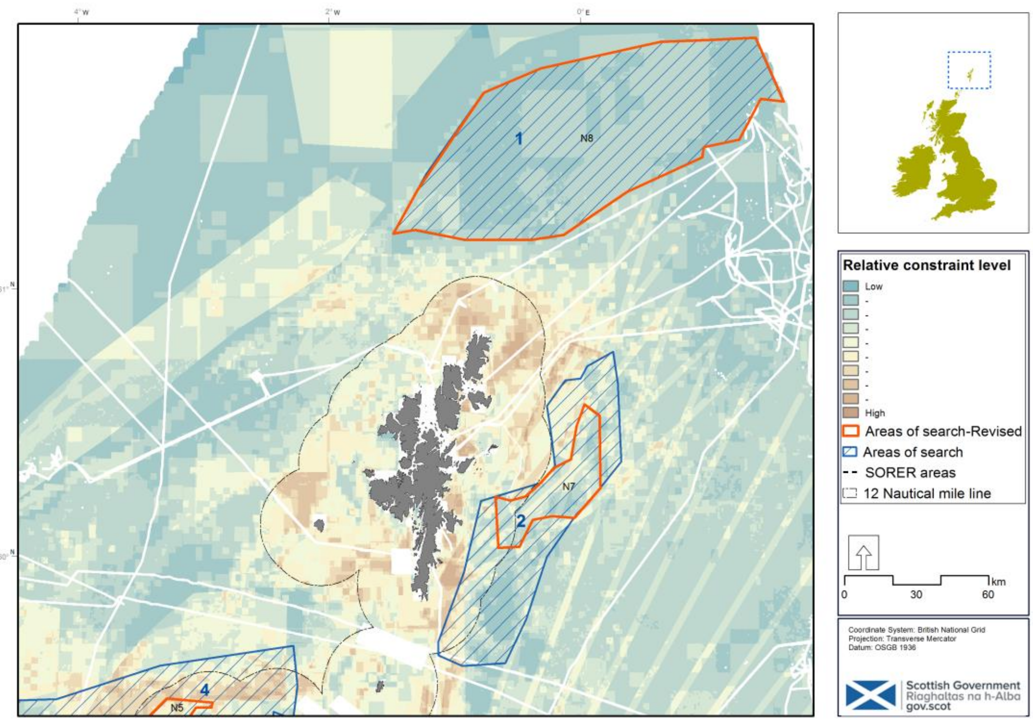

Figure 33: Detail of the north SORER area showing the modifications to AoS 1 and 2. © Crown copyright and database rights (2018) OS (100024655).

6.1.5 North East

As in the North region, AoS 3 has been divided into distinct smaller areas in the North East region. In addition to accounting for shipping traffic, a high level of fishing activity was already identified during the initial opportunity and constraint mapping process and this area was removed from the initial AoS. This area remains excluded in the new AoS and that location, between NE4 and NE5, has now been expanded.

Much of AoS 3 in the Moray firth has been reduced, due to anticipated visual impact issues and shipping traffic. NE6 and NE7 remain as AoS within the Moray Firth occupying areas with lower constraint.

These refinements have removed the previous Draft Plan Option, north east of Fraserburgh, from the AoS.

Further south, AoS 5 extended across the North East and East regions. Whilst the opportunity and constraint exercise identified a large initial area of search, a single issue analysis recommended reducing the AoS inside the North East region. Shipping traffic closer to shore was taken into account and an area of focused pelagic and demersal fishing indicates potential conflict that is not clear in the opportunity and constraint mapping exercise. Accordingly, the north section of AoS 5 has been reduced to two smaller AoS (NE1 and NE2) which account for these additional constraints.

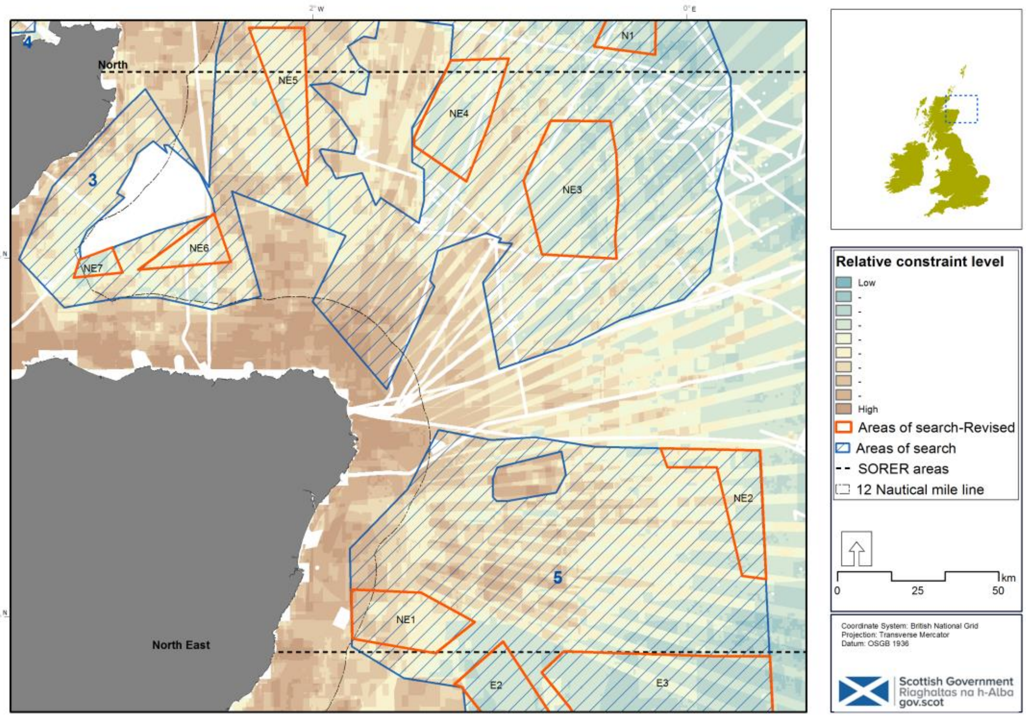

Figure 34: Detail of the north east SORER area showing the modifications to AoS 3 and 5. © Crown copyright and database rights (2018) OS (100024655).

6.1.6 East

As above, AoS 5 has been modified after further analysis of single issues. E2 and E3 both represent areas of greater opportunity but are reduced from the original AoS 5 so as to account for higher levels of shipping traffic and common shipping lanes. The same fishing activity as described above resulted in E2 and E3 not extending any further to the north. The new AoS were modified to account for the Marine Protected Areas (MPA) in this region.

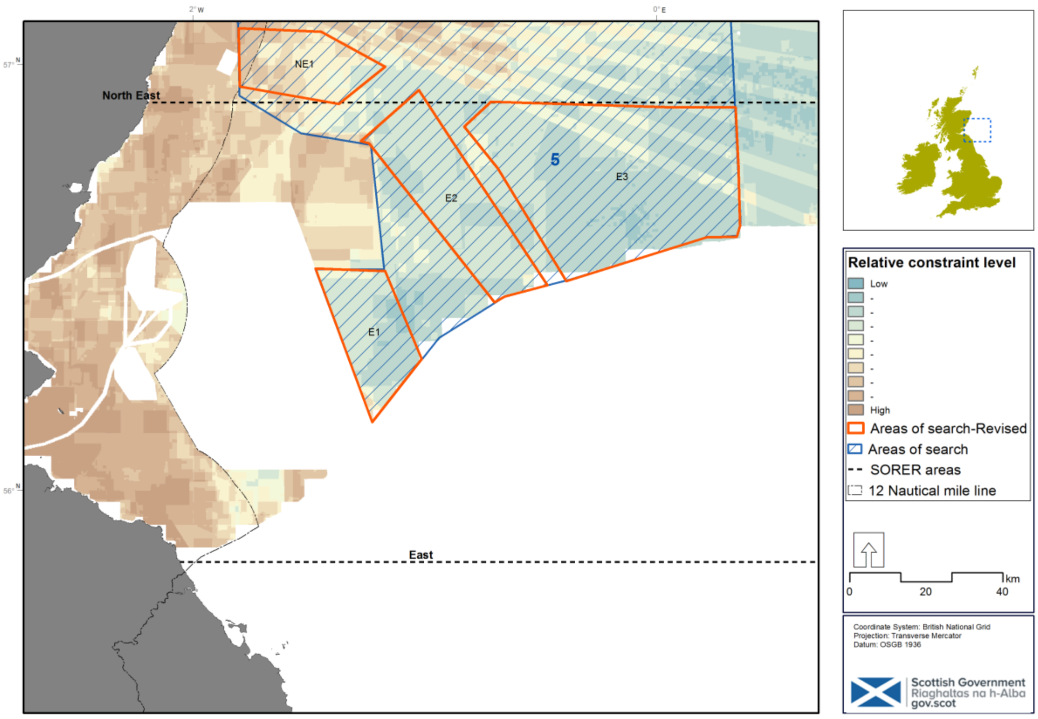

Figure 35: Detail of the east SORER region showing the modifications to the southern part of AoS 5. © Crown copyright and database rights (2018) OS (100024655).

7 Conclusion

Scotland's seas contain resources and technical aspects that can potentially serve the offshore wind industry. Analyses such as this can be used to visualise where these aspects accumulate. This preliminary study uses the best available data to discern broad locations that may be further investigated to eventually become draft sectoral Plan Options and finally Plan Options. Firstly, it is useful to visualise together all the aspects that are likely to have an impact on the location of a wind farm. This helps to eliminate those locations that are less likely to be able to proceed as development options. Once the potential broad scale locations that offer opportunity are identified, the next process is to apply single issue analysis using key data layers that are expected to generate interactions, for example fishing or shipping. This analysis is used to identify suitable areas within the AoS that avoid constraint. This process underlines the quality control of the process as it helps to ensure that constrained areas that may not have registered in the constraint output are included in the final AoS selection.

One benefit this study enjoyed was that of experience gained from previous consultations on scoping studies for AoS. The initial approach of this study is conditioned by lessons learnt from previous consultations. Aspects that can be considered to be hard barriers to the consenting process have been identified at this stage and not left to be identified at the stakeholder consultation stage. The individual issues that experience tells us are more likely to constitute definite constraints to offshore wind development are: visual impact, shipping, fishing, oil and gas and nature conservation areas.

This study has used the most up to date and detailed data when available. Some issues emerged during this scoping study and these may require further consideration as the sectoral marine plan progresses:

- There may be a relative overweighting of fish life history layers due to these being supplied in four different layers, each with the same weighting (3). Updates of the spawning data were available for cod and haddock but not for all species. Older spawning layers had to be used to represent other species (CEFAS, 1998).
- The leisure use of Scottish waters has been taken from the Scottish Marine Recreation and Tourism Survey (LUC, 2016). The derived heat map of overall activity provides new geographical data that describes where human leisure activity happens around the Scottish coasts. Since the leisure activity map is based on voluntarily provided data some bias due to larger responses at locations of larger populations can be expected. As such, interactions with AoS closer to the shore may be higher than the opportunity and constraint process describes the sectoral process will address these issues and specific regional activities will be considered.
- Seascape was not included as a data layer in this analysis. Visual impact has proven to be an important part of the constraints that can affect the consenting of offshore developments. Suitable layers to express the relative importance of the view at a national level were not available at the time of this study. The revised AoS are generally further offshore and as such, are less likely to generate visual impact from the coastline. Should visual impact issues be identified as being potentially generated by the suggested AoS these will be addressed through the sectoral plan process.
- Different considerations of interaction with different types of fishing activity was assumed. Demersal, scallop and nephrops trawling activities were deemed wholly incompatible with any development. Creeling was deemed potentially more able to co-locate with offshore wind developments. Seasonally changing shorter term fisheries like pelagic and squid fishing were considered more capable of absorbing the effect of offshore developments than demersal, scallop and nephrops trawling activities.
- Information on seals and basking sharks was not included in the analysis. These issues will be considered as the plan progresses should they need to be addressed
- Seabird population interactions were considered to be reduced in overall amount given the increased distance from shore of the revised AoS.
- The cetacean distribution layer would benefit from an update. This would improve the consideration of these important species in a conservation context
- The offshore wind layer used was generalised and presented little in spatial variation, especially when re-classified to three classes. This is sufficient for this stage of the study as it will be expected that particular developments will investigate the regional resource variations if consented.

8 Technical Annex

8.1 GIS Processing

The ESRI ArcGIS suite of products was the sole mapping software used for this analysis. ESRI's ArcMap version 10.4.1 and ArcGIS Pro 2.1.1 were the two GIS platforms where the analysis and data processing were completed.

All layers were converted to rasters if not already in that format. A raster is a geo-referenced grid of values. Once all the rasters are standardised they can be added together to generate a cumulative output. Furthermore, each layer's relative level of influence, or weighting, can be chosen within each run of the overlaying tool. The GIS tool used to overlay and weight the layers is the *Weighted Sum* tool from the *Spatial Analyst* extension toolbox.

The *Spatial Analyst* extension was essential for all of the raster based processing tasks. This extension enhances the functionality of the basic ArcGIS platform to allow additional raster processing tools to be included in the analysis. These additional tools allow extraction of specific shapes, raster projection, conversion of vector data to raster format and raster overlay. The overlaying tools only accept raster format so this added functionality is essential.

All the layers can be processed in a standard manner by setting the ArcGIS geo-processing environment at the top hierarchy level to deal with all the layers using the same cell size, extent, coordinate reference system and location. It is important to apply the *snap raster* function to a known layer, in this case the Scottish EEZ, to ensure that all the layers used occupy exactly the same processing space.

The layer grid size to which all layers were standardised was 180 m^2. The bathymetry layer as provided by Ocean Wise which has a resolution of 0.0016680567 of 1 degree was the layer that was used as a grid size template and carried over to all of the layers used in this study.

All layers were projected to the WGS84 coordinate reference system and masked to the Scottish renewables EEZ during processing.

8.2 Data classification approach

Each data layer had to be considered individually as the values and value distributions were not consistent for all layers. In most cases the statistical capabilities of ArcGIS were used to identify the most appropriate points to use as a cut-off for the reclassification. Some data are categorical like the sediment classification layer or the cod spawning layer.

As an example of the classification into three classes the fishing layer composed of the VMS and ScotMap fishery values is described. First, the 'Quantile' classification system was applied to the data. The zero values were then excluded and the number of classes put to 3. This automatically calculated subdivision was considered an appropriate representation of the range of values in this layer. The values themselves have a skewed distribution towards the lower values. Figure 36 shows the classification process as applied using the ArcGIS layer classification interface.

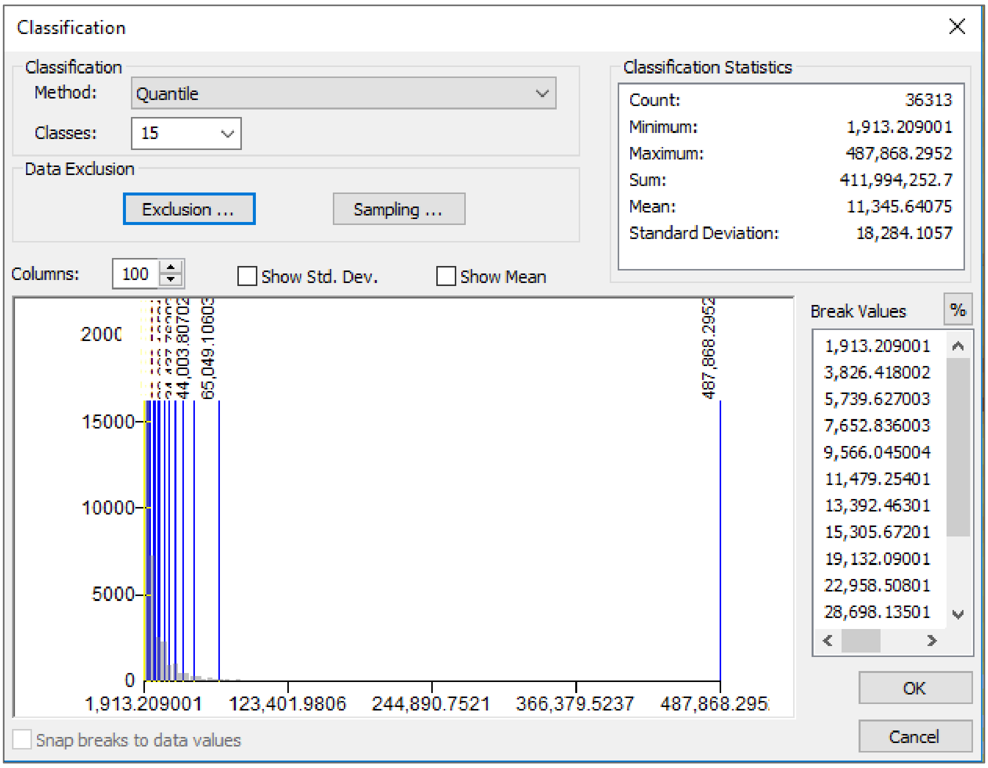

Figure 36: Reclassification of the fishing layer by using the 'Quantile' classification method.

This selection process converts a layer with a large range of data values into one with 3 groups. Figures 37 and 38 show the original layer and the reclassified version.

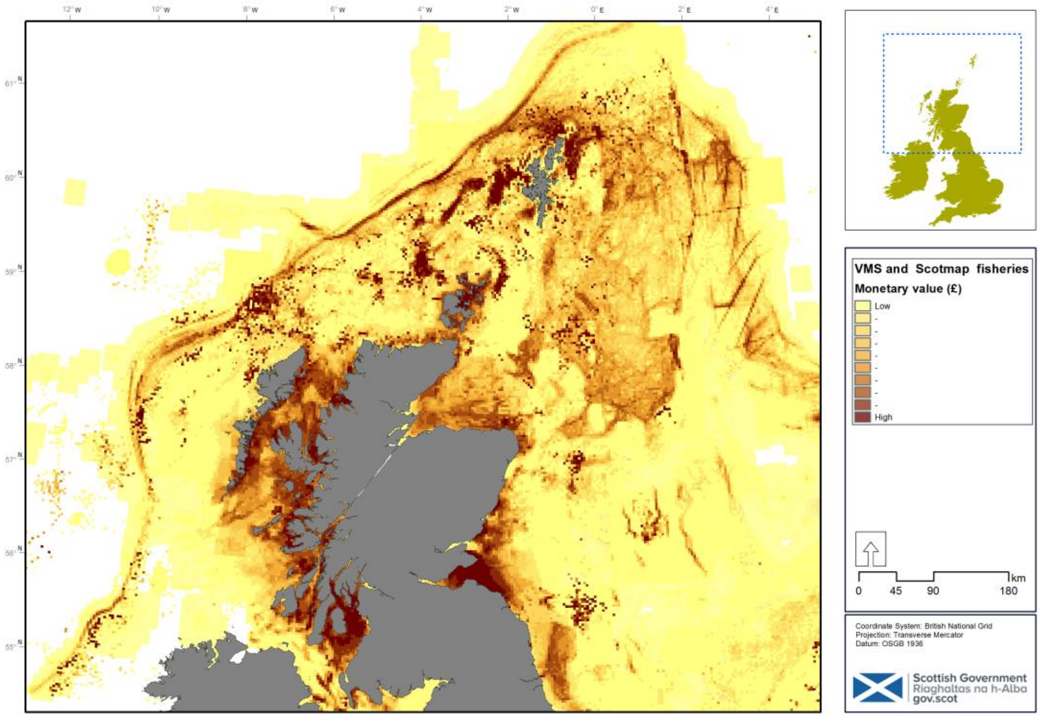

Figure 37: Fishing value layer pre-reclassification showing the range of values described by a range of colour hues. © Crown copyright and database rights (2018) OS (100024655).

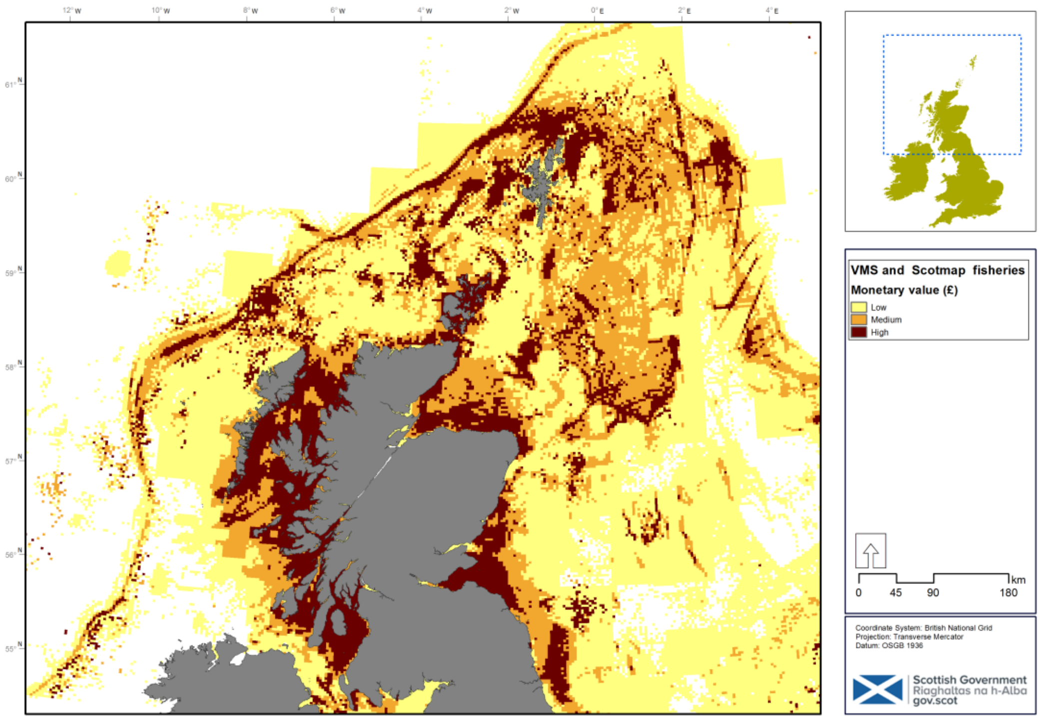

Figure 38: Fishing layer after reclassification into three classes. © Crown copyright and database rights (2018) OS (100024655).

9 Responding to this Consultation

We are inviting responses to this consultation by **18 July 2018**

Please respond to this consultation using the Scottish Government's consultation platform, Citizen Space. You view and respond to this consultation online at https://consult.gov.scot/marine-scotland/offshore-wind-scoping. You can save and return to your responses while the consultation is still open. Please ensure that consultation responses are submitted before the closing date of **18 July 2018**

If you are unable to respond online, please complete the Respondent Information Form (see "Handling your Response" below) to: SectoralMarinePlanning@gov.scot

Or by post to:

Offshore Wind Sectoral Marine Plan Scoping Consultation
Marine Scotland Planning and Policy (1A South)
Scottish Government, Victoria Quay
Edinburgh
EH6 6QQ

Handling your response

If you respond using Citizen Space (http://consult.scotland.gov.uk/), you will be directed to the Respondent Information Form. Please indicate how you wish your response to be handled and, in particular, whether you are happy for your response to published.

If you are unable to respond via Citizen Space, please complete and return the Respondent Information Form attached included in this document. If you ask for your response not to be published, we will regard it as confidential, and we will treat it accordingly.

All respondents should be aware that the Scottish Government is subject to the provisions of the Freedom of Information (Scotland) Act 2002 and would therefore have to consider any request made to it under the Act for information relating to responses made to this consultation exercise.

Next steps in the process

Where respondents have given permission for their response to be made public, and after we have checked that they contain no potentially defamatory material, responses will be made available to the public at http://consult.scotland.gov.uk. If you use Citizen Space to respond, you will receive a copy of your response via email.

Following the closing date, all responses will be analysed and considered along with any other available evidence to help us. Responses will be published where we have been given permission to do so.

Comments and complaints

If you have any comments about how this consultation exercise has been conducted, please send them SectoralMarinePlanning@gov.scot

Scottish Government consultation process

Consultation is an essential part of the policy-making process. It gives us the opportunity to consider your opinion and expertise on a proposed area of work.

You can find all our consultations online: http://consult.scotland.gov.uk. Each consultation details the issues under consideration, as well as a way for you to give us your views, either online, by email or by post.

Consultations may involve seeking views in a number of different ways, such as public meetings, focus groups, or other online methods such as Dialogue (https://www.ideas.gov.scot)

Responses will be analysed and used as part of the decision making process, along with a range of other available information and evidence. We will publish a report of this analysis for every consultation. Depending on the nature of the consultation exercise the responses received may:

- indicate the need for policy development or review
- inform the development of a particular policy
- help decisions to be made between alternative policy proposals
- be used to finalise legislation before it is implemented

While details of particular circumstances described in a response to a consultation exercise may usefully inform the policy process, consultation exercises cannot address individual concerns and comments, which should be directed to the relevant public body.

Scottish Government
Riaghaltas na h-Alba
gov.scot

10 Respondent Information Form

Scoping 'Areas of Search' Study for offshore wind energy in Scottish Waters, 2018

Please Note this form **must** be completed and returned with your response.
Are you responding as an individual or an organisation?

☐ Individual

☐ Organisation

Full name or organisation's name

Phone number

Address

Postcode

Email

The Scottish Government would like your permission to publish your consultation response. Please indicate your publishing preference:

☐ Publish response with name

☐ Publish response only (without name)

☐ Do not publish response

Information for organisations:

The option 'Publish response only (without name)' is available for individual respondents only. If this option is selected, the organisation name will still be published.

If you choose the option 'Do not publish response', your organisation name may still be listed as having responded to the consultation in, for example, the analysis report.

We will share your response internally with other Scottish Government policy teams who may be addressing the issues you discuss. They may wish to contact you again in the future, but we require your permission to do so. Are you content for Scottish Government to contact you again in relation to this consultation exercise?

☐ Yes

☐ No

Consultation Questions

The Scoping ‘Areas of Search’ Study for offshore wind energy in Scottish Waters report provides a description of the methodology and data used to create the opportunity and constraint mapping model from which the Areas of Search were determined. We would welcome any general comments about the Area of Search study and/or comments relating to specific Areas of Search.

1. Please provide any comments you have in relation to the Scoping ‘Areas of Search’ Study for offshore wind energy in Scottish Waters, 2018

2. Please provide any comments you have in relation to specific Areas of Search. Please indicate which Area of Search your comments relate to using the area names (e.g. NW2).

3. Are there areas within Scottish Waters that you think should be included in the Areas of Search that are not included in this report? Please provide information about the location you think should be considered and any supporting evidence you feel is relevant. Locations can be indicated by coordinates or description. More specific location information can be provided to SectoralMarinePlanning@gov.scot

11 Literature and website resources referenced

11.1 Cited literature

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11.2 Cited websites

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http://www.renewables-atlas.info/

- ABPMer UK 2015 national dataset of marine vessel traffic: processed AIS transit lines for UK waters for 2015. The first week of every month is used to create the shipping density map.

http://www.abpmer.co.uk/buzz/view-the-new-uk-2015-national-dataset-of-marine-vessel-traffic/

- BSH (Federal Maritime and Hydrographic Agency of Germany) Project NorthSEE: information on the NorthSEE project was taken from this site.

http://www.bsh.de/en/Marine_uses/Spatial_Planning_in_the_German_EEZ/Project_NorthSEE.jsp

- Nature conservation designated sites: updated shapefiles for the marine protected sites were downloaded from this site.

http://jncc.defra.gov.uk/page-1461

- Kis-Orca Offshore renewables and cable awareness: spatial data to update the subsea cable information http://www.kis-orca.eu/

- NATS self-assessments maps: information on potential radar interference extent and shapefiles for the interference at 200 m height were sourced from this website.

https://www.nats.aero/services/information/wind-farms/self-assessment-maps/

- Helicopter main routes (NATS, digitised from the ENR 6 - En Route Charts section of the source listed below)

http://www.nats-uk.ead-it.com/public/index.php%3Foption=com_content&task=blogcategory&id=4&Itemid=11.html

- OceanWise: licensed bathymetry data from OceanWise.

https://www.oceanwise.eu/data

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