New Site Suitability Model for Fixed Platform Offshore Wind Turbines in Ireland using MCDA and Stakeholder Engagement

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Abstract

Building sufficient offshore wind infrastructure to reach Ireland's 2030 goal of 5 GW installed capacity mandates a site selection process for offshore wind farm locations. This study proposes a Multi Criteria Decision Analysis (MCDA) approach using Geographic Information System (GIS) tools to optimize the site selection for fixed platform offshore wind turbines in the Irish Exclusive Economic Zone (EEZ). While MCDA/GIS site selection analyses have been done on Irish floating wind, there has yet to be a fixed platform focused study using these tools in the Irish EEZ. This study uses a traditional Analytical Hierarchy Process (AHP) along with a highly efficient Rank Order Centroid (ROC) method to weight 11 suitability factors and create a dynamic site suitability model that can prioritize different stakeholder preferences for factor importance. It calibrates this model using stakeholder interviews and a co-creation method to adapt the parameters of the model. The output is a cohesive site suitability analysis for fixed offshore wind farms in the Irish EEZ.

Introduction and Literature Review

Background

The dangers posed by climate change have the potential to create negative externalities for a variety of natural and anthropogenic systems. Biodiversity, agriculture, economy, and human health are all at high risk of impact from the environmental consequences associated with the effects of burning fossil fuels (Abbass et al. 2022). Reducing these greenhouse gas emissions while maintaining energy consumption will require finding alternatives to burning fossil fuels, and a proven way to achieve this is through the use of renewable energy sources such as wind energy (Reilly 2017). One approach to generating wind energy is offshore wind farming, where turbines are placed in marine environments to reduce their impact on human activities and to benefit from the increased wind speeds present in the ocean. While this technology has been successfully implemented on small to medium scales, there are many challenges that must be overcome to fully realize the potential of offshore wind to a point where a holistic transition away from fossil fuels can be made possible (Huang et al. 2021).

Ireland possesses a high potential for generating electricity through the means of offshore wind energy production (Gaughan & Fitzgerald 2020; Walsh et al. 2024). This is due to a plethora of factors, the most important of which is that wind speeds in the oceans surrounding Ireland are some of the most powerful found in any country's Exclusive Economic Zone (EEZ), with wind power density exceeding 1500

W/m2 in some locations (Gaughan & Fitzgerald 2020; Roux et al. 2022). In addition, the country has a very high ocean to land ratio, with its EEZ encompassing a marine area many times greater than the terrestrial area of the island (Walsh et al. 2024). There is also a generally positive public perception of offshore wind development in Ireland, which can be a vital component in large-scale energy development projects worldwide (Cronin et al. 2021). Due to these favorable factors, the Irish government has established a goal of 5 GW of offshore wind power to be installed by 2030 (Roux et al. 2022). This is essential in order to facilitate the country's larger target of generating 80% of their energy budget with renewables by 2030 (Esmaeli et al. 2024).

However, there are many challenges associated with the development of offshore wind in Ireland. For one, while the Irish EEZ is comparatively large, much of the ocean encompassed in it is very deep (>100m), limiting potential exploitation in the majority of the area to floating wind platforms (Martinez et al. 2022). This is problematic because floating offshore wind farms are still an experimental technology, and currently fixed platform turbines are the only method approved for development by the Irish government (Martinez et al. 2022). This limits current developers to waters shallow enough for fixed platform projects, which currently are optimized at 30-40m depth and are not viable deeper than 60m (Higgins et al. 2014; Walsh et al. 2024). Limiting development to these more anthropogenically intermingled depths means that there is competition and conflict between stakeholders with different priorities for the use and preservation of these waters, and for this reason fixed platform projects face pressure from a variety of different groups (Huang et al. 2022).

For example, there is great concern among shoreline residents and users about the visual impact of offshore wind farms, and occasionally this has negatively impacted public opinion of the industry (Hall 2024; Cronin et al. 2021). Additionally, there is the possibility that wind farms can overlap with Irish Marine Protected Areas such as Special Areas of Conservation (SACs) or Special Protection Areas (SPAs), warranting collaboration between environmental protection advocates and offshore wind developers (Johnston et al. 2025). Perhaps the greatest anthropogenic challenge faced by developers in Ireland is that of fisheries, with fishermen raising multiple concerns about the impact of offshore wind development on their longstanding industry (Reilly 2017). The loss of fishing space, as well as the potential for wind farm sites to be built on spawning grounds of high demand fish, has created conflict with both recreational and commercial fisherman who have strong economic and cultural ties to the fishing lifestyle (Reilly 2017).

Almost all of these problems have a spatial element. It may be possible to mitigate many of the challenges faced by offshore wind developers by using a comprehensive spatial analytics approach to offshore wind site selection in order to minimize difficulties (Caceoglu et al. 2022). The primary objective of this analysis is to determine the most optimal locations for fixed platform offshore wind farms in Ireland by using a cohesive multi criteria decision analysis (MCDA) influenced by stakeholder preferences in conjunction with an assessment of physical and environmental factors. This type of analysis is typically conducted using a Geographical Information Systems (GIS) approach (Johnston et al. 2025; Diaz et al. 2022).

GIS is one of the primary methods used to analyze offshore wind site suitability. GIS can integrate data from multiple sources and categories onto a spatial representation of the study area (Watt & Wilby 2025). This can be used to compare and contrast the relationship between different variables in a multitude of ways. For example, an inclusion exclusion analysis can be used to combine the locations of favorable factors with the locations of unfavorable factors even if they come from different datasets (Johnston et al. 2025). Additionally, there is a high quantity of pre-existing data on offshore wind related factors that is publicly available for download, meaning that no additional data collection is required for further analysis (Walsh et al. 2024).

As only fixed foundation turbines are currently being considered for development in Ireland, these will be the primary focus of this analysis. This decision to only develop fixed wind turbines is mostly due to the much higher Levelized Cost of Energy (LCOE) currently associated with floating offshore wind platforms, which are still a developing technology (Martinez et al. 2019).

Factors Contributing to Offshore Wind Site Selection

There are a multitude of physical factors that determine where it is best to construct an offshore wind farm (Caceoglu et al. 2022). Perhaps the most important of these factors is wind speed, which is the variable that ultimately determines the total power output of the finished facility (Mytilinou et al. 2018). The exact speed that is optimal for a wind farm is highly dependent on the specifics of each individual facility, but typically the average wind speed must be greater than 8-10m/s (Martinez et al. 2018; Pham et al. 2021). Lack of variation in wind speed is also an important factor, as wind speeds that are very high (~25 m/s) or very low (~4 m/s) will cause the turbine to stop generating electricity (Johnston et al. 2025; Martinez et al. 2018). Similarly, reliability in terms of direction is also very important as this allows for maximum time with the wind flowing over the turbines in the optimal direction (Mytilinou et al. 2018).

Another physical factor that plays a critical role in offshore wind site suitability is that of the seafloor depth (bathymetry). The bathymetry of a site influences the feasibility of construction as well as the type of foundation that can be deployed (Johnston et al. 2025). This constraint also influences the construction cost, with deeper site locations tending to be more expensive (Higgins 2014).

Table 1. *Table showing the different depths currently deemed economical for each foundation type.(Johnston et al. 2025; Pham et al. 2021)*

Foundation Type	**Water Depth**
Fixed, Gravity Base	0m-40m
Fixed, Monopile	10m-50m
Fixed, Jacket	40m-60m
Floating, Semi-Submersible	>50m
Floating, Spar	>100m

The other seabed factor that affects offshore wind foundations is substrate type. Along with the bathymetry, substrate makes up the primary physical constraints on what type of foundation is to be used at a given site (Johnston et al. 2025; Sanchez et al. 2019). The vast majority (60.1%) of existing fixed monopile foundations have been constructed on seafloors with a sandy bottom. Additionally, some monopiles (14.3%) have been constructed atop a clay substrate, and 10.3% in a combination of clay and sand (Sanchez et al. 2019). One of the most challenging substrates to work with is that of rock and other hard bottoms, and these are usually avoided if possible (Sanchez et al. 2019).

The primary geographical factor that must be considered is the development's proximity to an electrical grid connection (Diaz & Soares, 2021). Efficient connection of an offshore wind farm to the national grid determines a large portion of the cost of installation and maintenance of the facility (Hall 2024). In general, offshore wind platforms that are further from shore are much more expensive and challenging to integrate into the grid than near shore installations (Martinez et al. 2019). Similarly, a site's distance from the port used for construction and maintenance matters significantly, as a longer travel time means that the project will be more expensive (Huang et al. 2022).

In addition to physical and geographical factors that control where it is possible to construct offshore wind farms, there is also a plethora of social and anthropogenic elements that have major influence on the site selection process. One of the most problematic concerns is the impact that offshore wind farms will have on the view from shore (Cronin et al. 2021). Viewing the turbines from shore is generally considered a negative externality of offshore wind by the public (Cronin et al. 2021; Watt &

Wilby 2025). The magnitude of this effect is primarily influenced by the turbine's distance from shore as well as the size of the turbine (Diaz et al. 2022; Cronin et al. 2021). For this reason, distance from shore is generally included as a criteria in GIS offshore wind site suitability analysis (Diaz et al. 2022).

Another major anthropogenic conflict that arises is the competing interests between fisheries and offshore wind developers. It has been postulated in a multitude of studies that commercial fishing will be more heavily affected by offshore wind energy than any other industry (Reilly 2017). The primary impact of offshore wind on fisheries generally manifests in the loss of access to fishing areas that are converted to wind farms, however there are also concerns with factors such as fish disturbance during construction, loss of harbour space, and difficulties navigating around offshore wind developments (Reilly 2017). This problem is especially prevalent in Ireland due to its combination of a large fishing industry, a lack of solid spatial data on fishing practices (especially in inshore areas), and the chaotic bureaucratic nature of marine renewable energy in the nation (Reilly 2017; Cronin and Cummings, 2020). One aspect of this problem that is particularly troublesome is the apparent lack of understanding the public has about the possibility for the two industries to thrive simultaneously. One study surveying fishermen and the general public in Ireland found that while 70% of surveyed fishermen believed that fisheries could coexist with MRE, just 57% of the public believed that these two industries could coexist (Cronin et al. 2021). It has been suggested that site suitability analysis could be a way to mitigate this conflict by carefully selecting sites away from fishing areas (Reilly 2017).

Analysis Methods for Offshore Wind Site Selection

Along with GIS, another method often employed in the site selection process is Multi-Criteria Decision-Analysis (MCDA). MCDA is essentially a framework of ideas for making complex decisions where many conflicting variables are present. It is often used in conjunction with GIS to analyze site suitability for renewable energy (Hall 2024). One example of this is a 2024 study of onshore and offshore renewable energy sources on the Isle of Man using a GIS-MCDA approach (Watt & Wiliby 2025). This study emphasized traditional GIS techniques such as taking the slope from Digital Terrain Models (DTMs), and creating buffers around exclusion areas unsuitable for development. It also used an MCDA approach to integrate the various complex factors such as the wind energy potential, electricity grid integration, and the slope (Watt & Wiliby 2025). The specific weighting method of MCDA that is used in this and many other similar studies is the Analytical Hierarchy Process (Watt & Wiliby 2025; Caceoğlu et al. 2022).

Analytical Hierarchy Process (AHP) is one of the most reliable and commonly used approaches in MCDA in offshore wind. Essentially, it is a method for weighing different criteria in a decision making process (Diaz et al. 2022). AHP is often used to process results from stakeholder engagement with the spatial analysis of GIS tools, because it is well suited to combining subjective results with the quantitative methods used by GIS (Diaz et al. 2022). It works by performing a pairwise comparison between each variable and using the results to output a weight for each factor (Caceoğlu et al. 2022). AHP is excellent for offshore wind site selection due to the high multitude of differently prioritized qualitative and quantitative elements that must be considered (Diaz et al. 2022). However, one drawback of the AHP method is that detailed input data on how each factor compares to every other factor is an input requirement for the model (Barron & Barrett 1996; Danielson & Ekenberg 2017).

Another approach to MCDA weight assignment is the Rank Order Centroid (ROC) method. The ROC method is similar to the AHP except that instead of imputing pairwise comparisons of suitability factors, it inputs a ranking comparison of these factors (Barron & Barrett 1996; Danielson & Ekenberg 2017). This means that less detailed inputs are needed, which in turn allows for MCDA weights to be generated with a lower level of factor interaction understanding (Barron & Barrett 1996; Danielson & Ekenberg 2017). In contrast to the oft-utilized AHP, ROC is not generally used in MCDA offshore wind site selection studies (Caceoğlu et al. 2022; Diaz & Soares 2021, Vagiona & Kamilakis 2018). However, it facilitates faster and simpler stakeholder engagement due to a single ranking query taking less time than a full pairwise comparison of every considered factor (Dolan et al. 2015).

Given the multitude of physical and human factors involved in offshore wind site selection, stakeholder engagement is an essential part of the decision making process. Stakeholder engagement has been a weak point in some Irish marine energy projects in the past, which is speculated to lead to an increased need for its competent execution in future processes (Cronin and Cummings 2020). While its primary function is understanding the economic and environmental considerations of a development project, the communication and transparency of the engagement process itself can also provide "intangible" stakeholder engagement benefits if it is done effectively (Cronin et al. 2021; Cronin and Cummings 2020). Most research currently indicates that the best stakeholder engagement strategies combine multiple assessment methods in order to most accurately understand stakeholder positions (Cronin and Cummings 2020). These methods can consist of semi-structured interviews, questionnaires, participatory mapping exercises, focus groups, stakeholder workshops, and further engagement activities (Cronin and Cummings 2020). Additionally, many research studies on offshore wind site suitability use expert opinion and stakeholder engagement to generate inputs for their MCDA weighting schemes, however few use the expert opinion to modify the factors included/excluded in the model itself

(Caceoğlu et al. 2022; Diaz & Soares 2021, Vagiona & Kamilakis 2018). This method, sometimes referred to as co-creation, can provide more effective results (Galvagno & Dalli 2014).

Knowledge Gap Addressed

While many studies have used GIS, MCDA, and stakeholder analysis to look at site suitability for offshore wind, there has not yet been a study of fixed offshore wind sites in the Irish EEZ combining these methods. The research question of this analysis is to determine the areas in the Irish EEZ that are most suitable for the implementation of fixed platform offshore wind farms. This study addresses this knowledge gap by using stakeholder engagement techniques such as interviews and questionnaires to assess stakeholder preference. It processes these results by weighing them with AHP and ROC, and compares them to physical variables using GIS. It also employs co-creation to leverage expert input to shape the GIS and MCDA models, further enhancing their practicality. Using these results, the mode can create both stakeholder-specific and broadly applicable site suitability maps to provide decision makers with spatially explicit site analyses.

Methodology

The primary focus of the methods employed in this project was to identify the fixed wind turbine site suitability for the ocean surrounding Ireland. This is done by using stakeholder engagement, GIS, and MCDA. The stakeholder engagement portion of this project consisted of expert interviews and questionnaires soliciting the opinions of developers and other stakeholders in the offshore wind field. Seeing as this analysis was spatial, the strongest option for implementing the results of the stakeholder engagements and the existing data was GIS, the primary method for spatial analysis (Watt & Wilby 2025). The core GIS steps in this analysis were the collection of data from various open-source geoportals and existing studies, preprocessing this data in QGIS, normalizing the datasets, and finally combining them with the results of the MCDA rankings. Given the dynamic and complex nature of offshore wind site suitability, MCDA is the best choice for incorporating the numerous factors at play into a cohesive output of site quality (Diaz & Soares 2021). The MCDA for this project consisted of building an Analytical Hierarchy Process (AHP) model and a Rank Order Centroid (ROC). The interviews and surveys of stakeholders were analyzed, and their results were used to determine the inputs of the AHP model. The factor weights could then be exported to QGIS where they were applied to create the final product of site suitability models (Fig 4; Appendix A1-2).

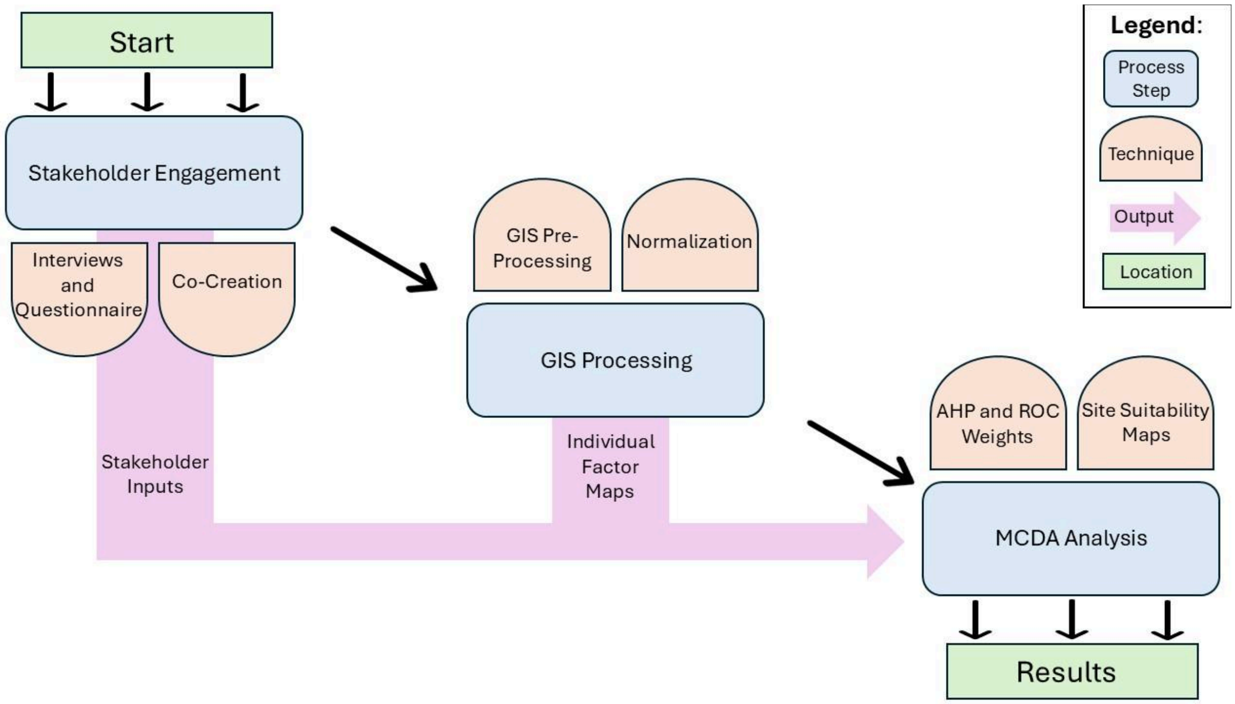


Fig 1. *Workflow Diagram*

Stakeholder Engagement

The stakeholder engagement portion of this study consisted of two primary components: a questionnaire and a collection of interviews. The questionnaire was targeted towards stakeholders in offshore wind development. Ethics approval for these interviews was obtained from University College Cork CACSSS Ethics Committee. These could consist of developers, legislators, and liaisons with other industries or interests. The interviews were targeted towards industry experts. The primary objectives of both engagement methods were to determine the importance level of the various site suitability factors and to garner context for the ranking system. The responses from the stakeholder engagement efforts of the study were used to inform the Analytical Hierarchy Process (AHP) and Rank Order Centroid (ROC) MCDA methods for weighting the suitability factors in the study.

The stakeholder engagement outcomes were also used in a co-creation application to inform the parameters of the final site suitability models beyond their inclusion in the AHP system. For example, given that developer opinion considered the possibility of fixed foundation technology achieving deeper maximum deployment depths in the near future very likely, the depth-dependent study area was increased from the current maximum depth of 60m to a future probable maximum of 90m (Appendix A3.2).

GIS Preprocessing

The potential study area for this project consisted of the entirety of the Irish Exclusive Economic Zone (EEZ). Given that the study is on fixed wind turbines, the study area can more accurately be defined as the ocean surrounding Ireland at a depth shallower than 90m. This value is chosen to encompass the extent of the seafloor currently deemed economically for fixed platform turbines(<60m) (Johnston et al, 2025) as well as the areas projected by stakeholders interviewed to be economically in the near future (<90m) (Appendix 3.1). This yielded one study area for each scenario(current and future) which covered an area of 15,348 km^2 for the 60m zone and 38,707 km^2 for the 90m zone (Fig 4).

Several factors were considered as exclusion criteria, however ultimately no hard exclusions were made due to a lack of consensus in the stakeholder interviews (Appendix 3.1). Seeing as there was not a ubiquitous opinion on whether or not to exclude these areas, they were included in the model to ensure that suitable areas were not prematurely rejected. Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) were not used in the AHP or ROC ranking systems as these are not optimized to evaluate Boolean criteria, however they were considered as potential exclusion criteria in the primary models (Diaz & Soares 2021). The other considered exclusion criteria was commercially integral fish spawning grounds (Table 2), which in expert interviews were indicated to occasionally have higher importance to fisheries personnel than actual fishing intensive areas. Spawning grounds were also ultimately not used as a hard exclusion criteria due to their vastness (Fig 7). For these reasons, ultimately no hard exclusion areas were applied to the model, but the spawning grounds and SPA/SACs are displayed for consideration in Fig 7 of the results.

Table 2. *Soft exclusion criteria*

Considered Exclusion Variable	Reason For Considered Exclusion	Source
Horse Mackerel Spawning Ground	#1 in landed weight and #2 in landed value of fish in Irish EEZ	Gerritsen, H.D. and Lordan, C. 2014. Atlas of Commercial Fisheries Around Ireland, Marine Institute, Ireland. ISBN 978-1-902895-56-7. 59 pp.
Mackerel Spawning Ground	#2 in landed weight and #1 in landed value of fish in Irish EEZ	Gerritsen, H.D. and Lordan, C. 2014. Atlas of Commercial Fisheries Around Ireland, Marine Institute, Ireland. ISBN 978-1-902895-56-7. 59 pp.
Blue Whiting Spawning Ground	3rd in landed weight of fish in Irish EEZ	Gerritsen, H.D. and Lordan, C. 2014. Atlas of Commercial Fisheries Around Ireland, Marine Institute, Ireland. ISBN 978-1-902895-56-7. 59 pp.
Nephrops Spawning Ground	3rd in landed value, as well as highest share caught by Irish vessels (77%) of top 5 value-landed fish	Gerritsen, H.D. and Lordan, C. 2014. Atlas of Commercial Fisheries Around Ireland, Marine Institute, Ireland. ISBN 978-1-902895-56-7. 59 pp.
Herring Spawning Ground	4th in landed weight, as well as highest share caught by Irish vessels (87%) among top 5 weight-landed fish	Gerritsen, H.D. and Lordan, C. 2014. Atlas of Commercial Fisheries Around Ireland, Marine Institute, Ireland. ISBN 978-1-902895-56-7. 59 pp.
Special Protection Areas (SPAs)	Avoid potentially negative environmental interactions	National Parks and Wildlife Service, 2025
Special Areas of Conservation (SACs)	Avoid potentially negative environmental interactions	National Parks and Wildlife Service, 2025

This project used 11 geospatial datasets for MCDA analysis, which are displayed in Table 3. Vector datasets were rasterized, and all datasets were projected into Irish Transverse Mercator (ITM) (Appendix A1-2). Additionally these 11 datasets were clipped to the two study areas and then normalized on a scale of 1 to 100 (Equation 1), with high values indicating the most suitable conditions on the basis of each variable.

Equation 1. Calculation for normalizing the various site suitability layers

$$F_{normalized} = \left(\frac{F - F_{\min}}{F_{\max} - F_{\min}} \right) \times 99 + 1$$

Table 3. *The primary datasets used in the MCDA model*

Criteria	**Source**	**Description**	**Reason for Inclusion**
Bathymetry	INFOMAR 2025	Rasterized depth dataset of all surveyed ocean	Method for determining the extent of the study area, as well evaluating site quality within study area based on depth
Seafloor Substrate	INFOMAR 2025	Vector dataset of the believed seabed substrate characteristics, derived from bathymetry surveys	Determining which areas have seafloor suitable for fixed turbine construction
Wind Speed	SEAI 2013	Vector dataset of the average wind speeds at a hub height of 100m	Used for deriving Wind Power Density (WPD) at 100m hub height, which determines power generation capacity
Visual Impact	SEAI 2010	Vector dataset identifying areas susceptible to visual impact by turbines.	Controlling for areas where visual impact has been identified as a concern
Vessel Traffic	EMODnet 2025	Raster dataset of the average vessel traffic density	Controlling for areas likely to face interference from high volume of vessel traffic
Bathymetry Slope	Derived from INFORMAR bathymetry	Raster dataset of the bathymetric slope in the study area	Controlling for steep areas less suitable for turbine construction
Distance to Substation	All-Island Ten Year Transmission Statement 2022	Raster dataset of the Euclidean distance from each cell to an electrical substation, generated from locations of substations given in source	Used as a proxy for grid connection convenience
Distance to Suitable Port	Martinez et al. 2021	Rasterized dataset of the relative distance over ocean from each cell to a port suitable for offshore construction	Represents ease of transport for construction and servicing of turbines
Wave Height	Irish Spatial Data Exchange	Vector dataset showing the maximum and minimum wave heights in Irish waters	Reference for conditional allowance for maintenance/construction

365-day wind forecast	O’Brian et al. 2025	NetCDF dataset of forecasted wind speeds over a 365 day period in Irish waters	Reference for conditional allowance for maintenance/construction
Fishing Vessel Activity	EMODnet 2025	2023 dataset of fishing hours logged in the study area with top 1% clipped out	Accounts for areas with high amounts of fishing activity

The bathymetry dataset was used for two purposes: To define the study areas by depth and to be used in the site quality analysis as a MCDA parameter. Two depth values were used to define dual study areas, one with a maximum depth of 60m and one with a maximum depth of 90m. The 60m model uses the current parameter for the deepest economical depth for fixed turbines (Johnston et al, 2025), and the 90m model indicates area available with technology that is likely accessible in the near future (Appendix 3.1). The bathymetry was also cleaned for erroneous values indicating greater than 0 values, as these would indicate land.

The Seafloor Substrate dataset was assigned values based on seabed construction viability, with areas left as unclassified seabed or mixed sediments assigned a neutral value.

Table 4. *Substrate suitability rankings*

Substrate Type	**Suitability Score**
Rock or other hard substrate	1
Fine mud	2
Mud	3
Mixed sediment or unclassified seabed	4
Muddy Sand/Sandy Mud	5
Coarse Substrate	6
Sand	7

The wind speed dataset was cleaned for erroneous outliers by clipping the top 1% of wind speed values. The wind speeds were then converted into wind power density using Equation 2, as this metric is more useful for projecting power output than raw wind speeds (Craden et al. 2016).

Equation 2. Wind power density (WPD) formula used to convert mean wind speed (WS) to mean wind power density using the density of air (ρ).

$$WPD = \frac{1}{2}\rho \cdot (WS^3)$$

Additionally, the visual impact dataset was assigned suitability values corresponding to Table 5.

Table 5. *Suitability Score for Visual Impact dataset.*

Category	**Suitability Score**
Substantial	1
Moderate	33
Slight-Moderate	66
No Impact	100

The substation proximity dataset was created using the substations identified for potential to accommodate generation from offshore renewable sources. Their coordinates were located using Google Earth and used to create a shapefile on QGIS. These consisted of 220, 275, and 400 kV stations, which will be the primary nodes for renewable connection (All Island Ten Year Transmission Statement, 2022). A 500m buffer was created around each substation and it was then rasterized. The buffer was used in order to ensure that the substations would be large enough to take up at least one raster cell. The substation raster was then used to create a Eucleadean proximity map to the substation points (Eucleadean chosen as cables can travel over both land and ocean), and clipped to the 60m and 90m models.

To determine the port distances, suitable ports were first determined using those outlined in Martinez et al. (2021), with the exception of the Port of Dublin which was deemed too busy to support offshore wind construction in stakeholder interviews (Appendix A3.1). While these ports are identified as suitable for floating wind development, the requirements for fixed are very similar in terms of requiring deep water access, sufficient port infrastructure, and storage capacity (Craden et al. 2016). Coordinates for these ports were taken from Martinez et al. (2021) and used to create a shapefile in QGIS. The port points were then buffered to 500m and rasterized. Then, using these rasterized port points, a cost-distance analysis was performed to determine the relative travel distance through the ocean to any point in the study area. This method is used as it measures the distance that a ship would have to travel (taking into account that it can only travel through water) in order to maintain or construct offshore wind infrastructure, whereas an Euclidean distance would cut over land. To accomplish this, a raster was generated from a shapefile of Ireland where ocean cells were assigned a cost factor of 1 and land cells were assigned a value approaching infinity. Using the land/ocean mask as the unit cost layer and the suitable ports raster as the starting points layer, a cumulative cost model was generated indicating the relative distance from port (by sea) to each raster cell. This was then clipped to the study area and normalized on a scale of 1 to 100. Low cost values were deemed most suitable and assigned high values.

The TRANSLATE raster dataset (O'Brien et al. 2025) displaying the daily wind speed averaged over 30 years was pre-processed in jupyter notebook (python), and a new raster displaying the number of days/year with a wind speed over 10 m/s was extracted. This is used as an indicator of maintenance accessibility, as 10 m/s is often cited as the wind speed where crew transfer servicing can be performed on offshore wind turbines (Craden et al. 2016).

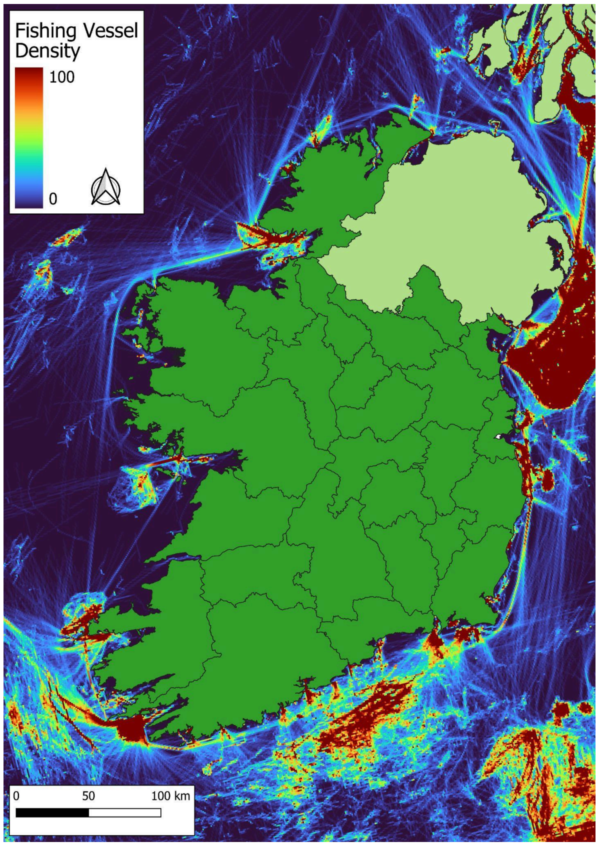


Fig 2. *Fishing vessel density (Table 3) is one of the eleven site suitability criteria used to generate the MCDA model. This example shows a pre-clipped layer of raw data with a pre-clip normalization. After being clipped to the study area, the data is re-normalized.*

MCDA Processing

Two approaches were taken in the process of using MCDA to assign weights to the various factors. These consisted of a Rank Order Centroid (ROC) and an Analytical Hierarchy Process (AHP) approach. These two methods were selected to account for the differing level of stakeholder data that could be imputed into the GIS model, with the ROC approach oriented towards implementing data from a simple ranking survey of stakeholder data (Danielson & Ekenberg 2017), and the AHP approach capable of implementing comparatively complex full pairwise comparisons of all possible variables (Walsh et al. 2024).

The ROC weighting approach consisted of arranging the suitability factors in a table with their corresponding ranks. The weights of each factor can then be computed with Equation 3 where n is equal to the number of ranked suitability factors and *i* is the ranking number for the given suitability factor. The output is the weight value that is assigned to each normalized factor layer in the MCDA map computation (Danielson & Ekenberg 2017).

Equation 3. *ROC ranking formula (Danielson & Ekenberg 2017)*

$$(\text{ROC}) = \frac{1}{n}\sum_{k=i}^{n}\frac{1}{k}$$

For the AHP approach, the suitability factors were arranged in a table such that each factor had both a row and a column, and for each pairwise interaction of factors, a value from 1/9 to 9 was assigned (Caceoglu et al. 2022). A high (>1) value indicated that the row variable was more important and a low (<1) value indicated the column variable to be more important, with a stronger difference manifesting as a larger difference from 1 (Caceoglu et al. 2022). For each factor, interactions were then converted to a percentage of the total sum of pairwise interactions for that factor. This percentage was averaged across each pairwise interaction to calculate the final output weight for a given factor. Using this method, it is possible to account for the relationship between each variable and each other variable, allowing for greater accuracy so long as input data for each pairwise interaction is available (Caceoglu et al. 2022).

The input rankings for both the AHP and the ROC were decided through a combination of the expert interview responses (Appendix A3.1) and the existing literature (Table 6.), and the final input values were consolidated by the researcher. These inputs can be found in the supplementary material. Below is the table of reviewed papers that helped to inform the input AHP rankings.

Table 6. *Table showing the MCDA weightings used by offshore wind analysis in other countries. These are all analyses of fixed foundation wind turbines. All of these studies employ the AHP method to assign weights to their variables.*

Study	Order	Criterion	Weight
Gavériaux et al. (2019)	1	Depth (Water Depth)	0.33
	2	Distance from ports	0.24
	3	Wind	0.14
	4	Distance from electrical grid in land	0.10
	5	Distance from the shore	0.06
	6	Distance from fishing areas (Fishing vessel density)	0.05
	7	Distance from the flora and the fauna	0.035
	8	Distance from recreation zones	0.035
Huang et al. (2022)	1	Wind speed	0.1805
	2	Distance from coastlines	0.1805
	3	Distance from shipping lanes	0.1805
	4	Distance from protected areas and ecological redlines	0.1805
	5	Water depth	0.1169
	6	Distance from ports	0.1169
	7	Distance from sea use activities	0.0442
Vagiona & Kamilakis (2018)	1	Wind velocity	0.52
	2	Population served	0.20
	3	Distance from environmentally protected areas	0.20
	4	Shipping density	0.08

Using the weights derived from the ROC and AHP processes, the normalized layers could be integrated using QGIS. This was done by multiplying each factor layer by its MCDA-given weight and summing the results (Huang et al. 2022).

Equation 4. *The final calculation for generating MCDA maps. W is the AHP weight, L is the normalized layer, and S is the output site suitability (Huang et al. 2022).*

$$S = \sum_{i=1}^{n} W_i \cdot L_i$$

This calculation is performed using the raster calculator function in QGIS. The final maps are then projected using RGB color values in the ITM format (Fig 4).

Results

The resulting output of this study primarily consists of the MCDA maps of offshore wind site suitability (Fig 4), with the secondary outputs being the stakeholder interview outcomes (Appendix 3) and the framework of the MCDA model itself. This section details the results of the stakeholder interviews, the AHP and ROC weighting systems, the MCDA map results, and the individual suitability results of each of the eleven factors analyzed. The MCDA outputs consist of four primary maps: 60m maps for both AHP weighting and ROC weighting (shown in fig 4-a and fig 4-b.), as well as 90m maps using the same parameters (shown in fig 4-c and fig 4-d.). The normalized layers for each of the 11 variables analyzed are also displayed in the supplementary material in both the 60m and 90m models. The values of the maps are normalized on a scale of 1 to 100, with 100 (shown in red) indicating the areas deemed most suitable by the model (Appendix A1-2).

The stakeholder interviews indicated strong consensus on which of the suitability factors were most important. All interviewed stakeholders indicated that wind power density (WPD) is the most crucial as it directly determines the power output of the wind farm (Appendix A3). They also indicated that grid connection convenience was the second most important suitability factor (Appendix A3). Additionally, there was consensus that visual impact was the least important factor of those presented in the interviews (Appendix A3). All interviewees noted that a stakeholder engagement survey seeking to discern the exact importance hierarchy of offshore wind site suitability factors would be subject to uncertainty due to differences of opinion within the field and the complexities of each specific wind farm site (Appendix A3).

There were also several co-creation elements that were drawn from the interviews. In particular, the decision to generate a 90m depth model in addition to the 60m depth model arose from expert recommendations that the technical capabilities of fixed platform turbines were likely to increase enough to practicalize plans for such depths (Appendix A3). Additionally, interviews indicated that the Port of Dublin should be removed as a possible construction/maintenance port due to its current overcrowding (Appendix A3). The decision not to use SACs and SPAs as hard exclusion criteria also originated from the interviews, as a stakeholder expert indicated that they were not necessarily avoided in all circumstances (Appendix A3.2).

Individual Suitability Factor Results

The eleven site suitability factor maps are displayed in the supplementary material. Suitability derived from wind power density showed low values close to shore and gradually increased with distance from the coastline (Appendix A1-2). The highest wind power density was located on the west coast, where both near-shore and far-shore values were higher than corresponding locations on the east coast (Appendix A1-2). The substation proximity suitability map showed a mostly opposite trend with areas close to shore generally receiving higher suitability scores, and the east coast scoring far higher than the west coast. However there were some areas adjacent to the coastline that were very distant from a substation, namely offshore of Co. Mayo and Co. Donegal, and these locations scored significantly lower than comparably well-connected east coast locations >50 km offshore (Fig 3).

Depth suitability scored high in shallow areas close to the shoreline, as well as higher in the comparatively shallow sea off the east coast than the steeper seaboard on the west coast (Appendix A1-2). Substrate suitability varied significantly across the study area, however the southern and parts of the western coast exhibited much lower suitability scores than the east coast (Appendix A1-2). The port travel time suitability map found that even areas at the offshore limit of the 90m and 60m zones scored reasonably high, and the primary determining factor was lateral distance along the coastline (Appendix A1-2). The lowest scoring areas in terms of the port travel time were located offshore of Co. Donegal, Co. Mayo, and Co. Louth. Slope suitability was highly varied, and low and high suitability areas were distributed around all coasts, near and far from shore (Appendix A1-2).

The suitability maps generated from wave height and the “days under 10 m/s wind” dataset followed almost identical trends, with high suitability areas located close to shore and on the eastern coast, and low suitability on the west coast and further offshore. There were some exceptions on the west coast where land shelter provided reasonably high suitability for these two factors, namely offshore of Co. Kerry and Co. Sligo. In terms of fishing intensity, the most suitable areas were located on the west coast (Appendix A1-2). The south coast showed large areas with medium suitability scores, and the east coast had the largest amount of low suitability areas. The pockets with the most intensive fishing in the 90m study area (which includes the 60m study area) were located offshore of Co. Louth, Co. Dublin, Co. Wicklow, and Castletownbere. Traffic suitability was very high almost everywhere in the study area, with a few low suitability areas around major ports such as Dublin, Ringaskiddy, Rosslare, and Rossavel. The visual impact suitability showed the highest values farther offshore, and the east coast was comparatively much more suitable than the west coast both close to and far from the shoreline (Appendix A1-2).

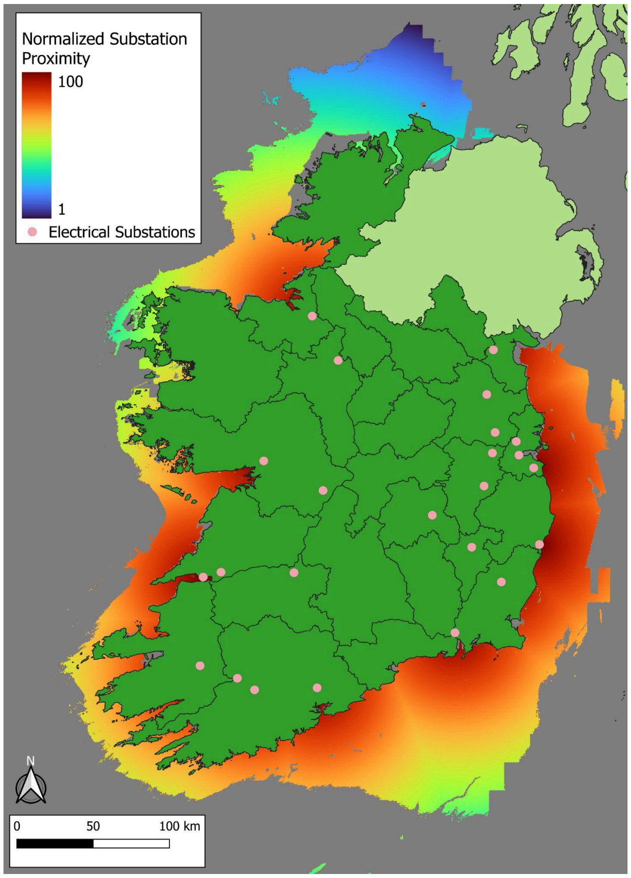


Fig 3. *Example of one of the clipped and normalized suitability factors. This shows the Euclidean distance to substations in the 90m study area.*

AHP and ROC results

The differences between the outputs of the ROC and AHP weighting methods was quite low (Table 7), with a maximum difference of 2.24% (water distance to port). The outcomes of the two methods are displayed in table 7. However, this is expected as both were determined by the researcher using identical literature analysis and the same expert interviews as the basis for the input data. The primary difference between the two methods is that theoretically the AHP allows for much more detailed input weights, whereas the ROC allows for more easier-obtained results derived from a single ranking question (Dolan et al. 2015).

Table 7. *AHP and ROC factor weight results*

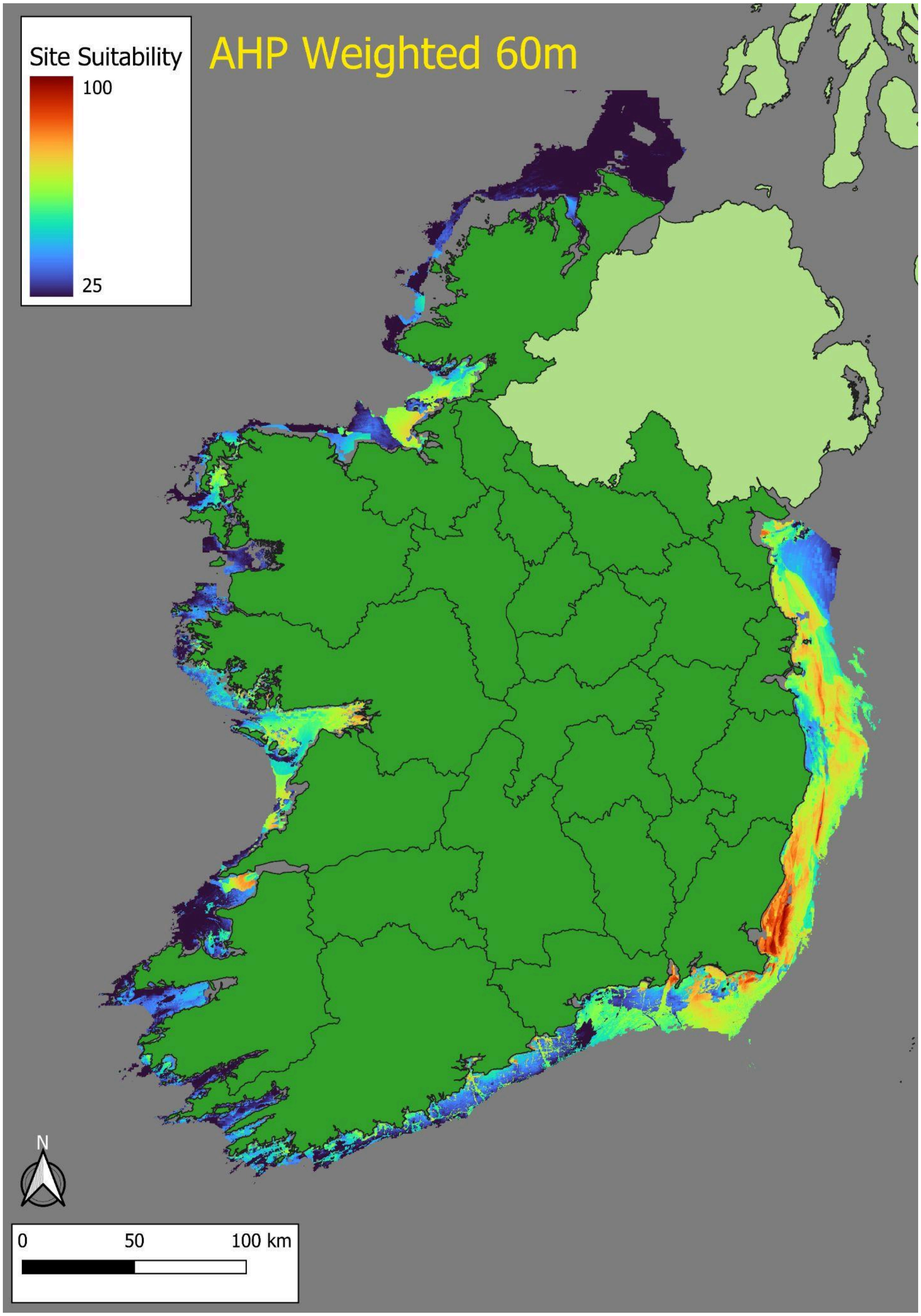
Suitability Factor	Analytical Hierarchy Process (AHP)	Rank Order Centroid (ROC)
Wind Power Density	28.56%	27.45%
Electrical Substation Proximity	19.73%	18.36%
Depth	12.02%	13.82%
Substrate	10.98%	10.79%
Water Distance to Port	6.27%	8.51%
Bathymetric Slope	5.49%	6.70%
Wave Height	4.91%	5.18%
Days with a wind speed under 10m/s	4.89%	3.88%
Fishing Hours	4.19%	2.75%
Vessel Traffic	1.70%	1.74%
Visual Impact	1.21%	0.83%

MCDA Map Outputs

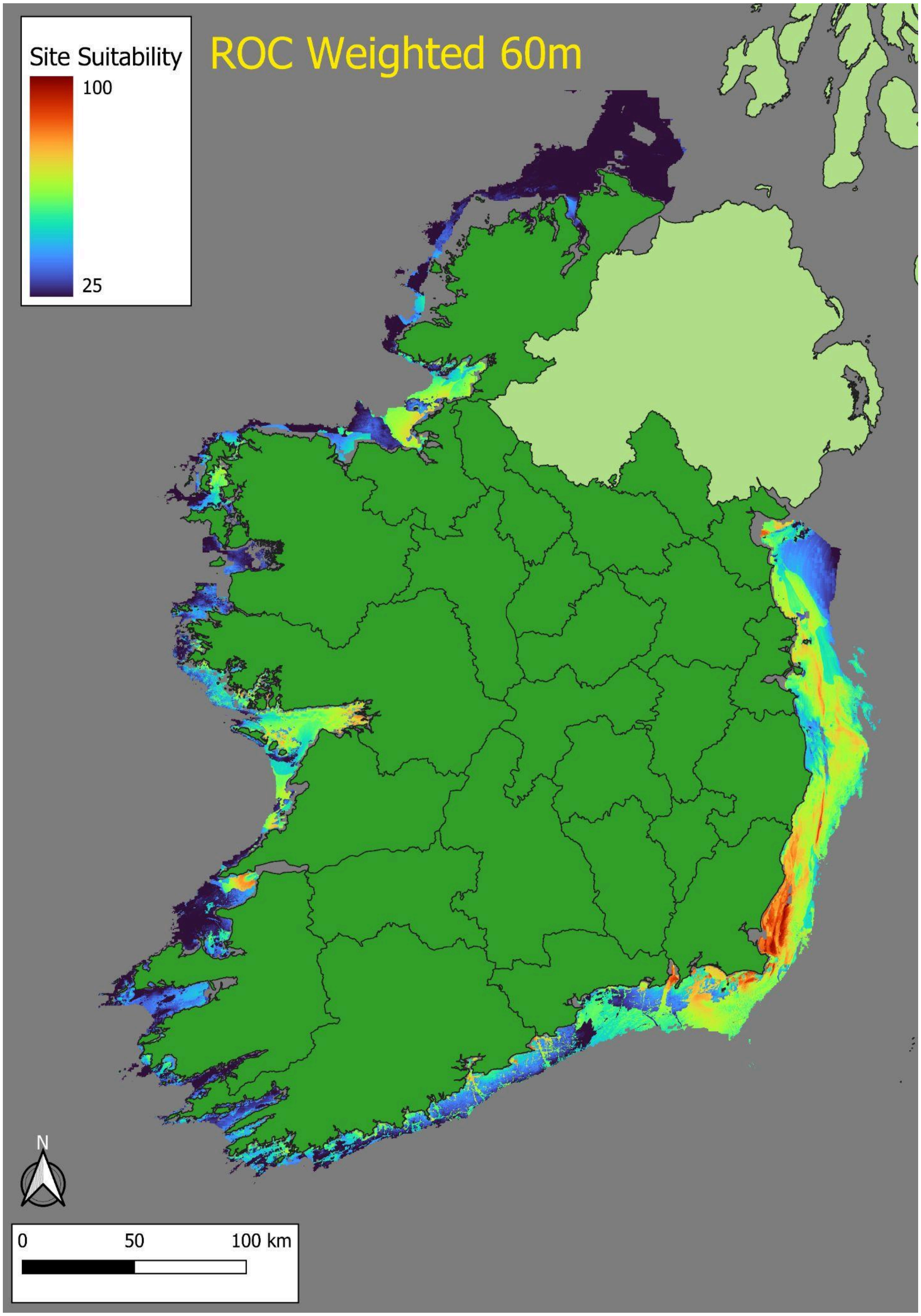
The 60m model encompassed an area of 15,348 km² (Fig 4), and indicated that the east coast was the most suitable for fixed platform turbines. However, there were outliers on the west coast with medium to high suitability levels, namely offshore of Ballybunion, Doonbeg, Galway, and Sligo. The locations, however, were significantly smaller in area when compared to the large swaths of suitable areas on the east coast. On the east coast, the most suitable areas were located in the southeastern portion of the coastline offshore of Wexford and Waterford. There are also a series of banks farther north offshore of Dublin and Arklow which the model deemed highly suitable (Fig 6). Arklow Bank Wind Farm, the only existing active offshore wind farm, was located on the highest scoring of these banks. The southwest portion of the coastline contained effectively no reasonably sized areas of high suitability. Additionally, essentially all areas north of Donegal are deemed unsuitable due to a plethora of factors, primarily the inability to integrate easily into the electrical grid (Fig 4).

The 90m model extended to cover an area of 38,707 km^2, approximately three and a half times greater than the 60m model (Fig 4). The suitability is identical to the 60m model at depths below 60m, but with the 90m models it is shown that some suitable areas are even larger if they are exploited with more depth-capable equipment. The high suitability area in water deeper than 60m is located offshore of Doonbeg, albeit with decreasing favorability as it gets further offshore. Additionally, there is an area >90m offshore of Waterford with mid-high suitability scores. For the most part, the deeper seabed analyzed by the 90m model is much less suitable than the study area encompassed by the 60m model (Fig 4).

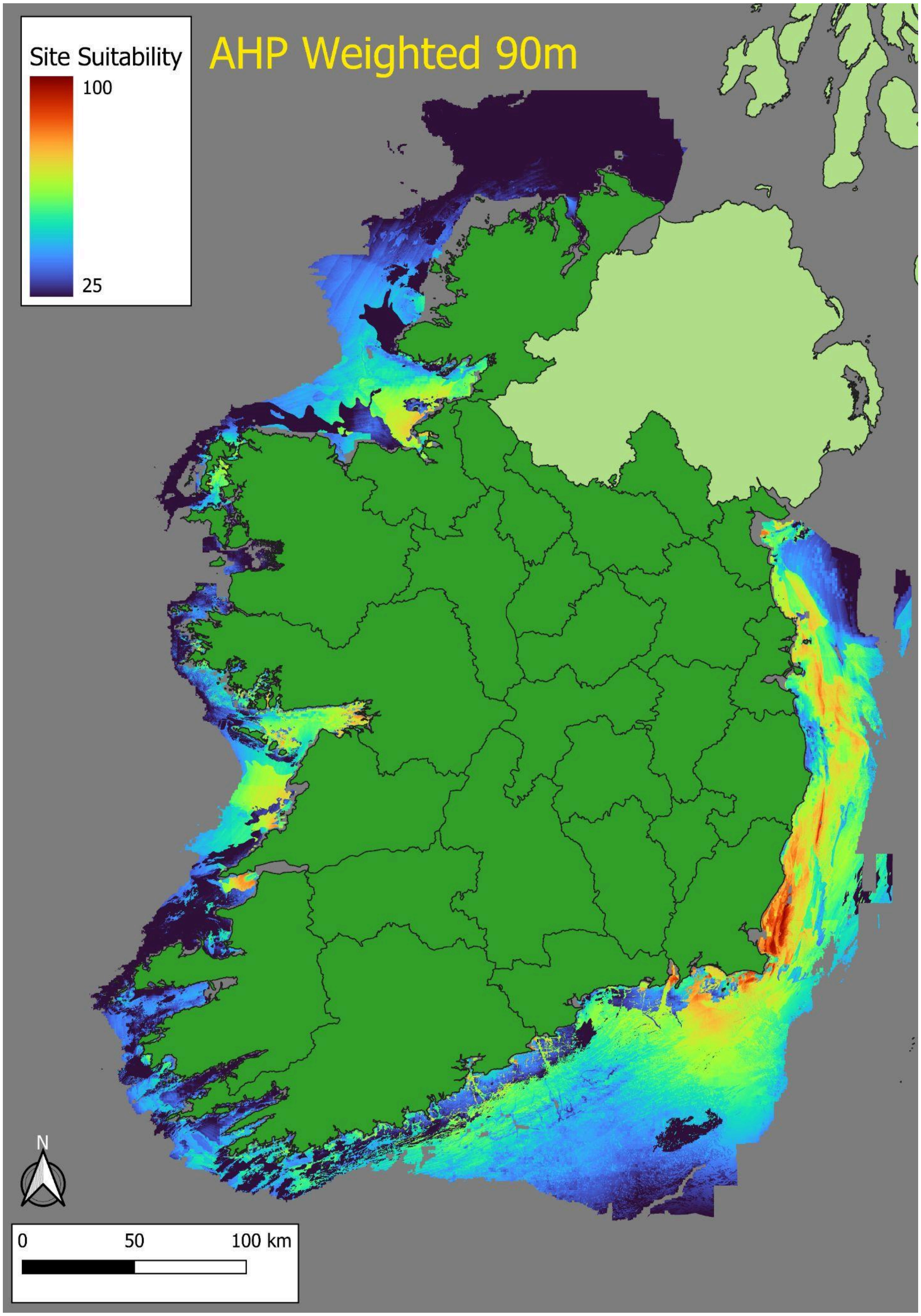
a)



b)



c)



d)

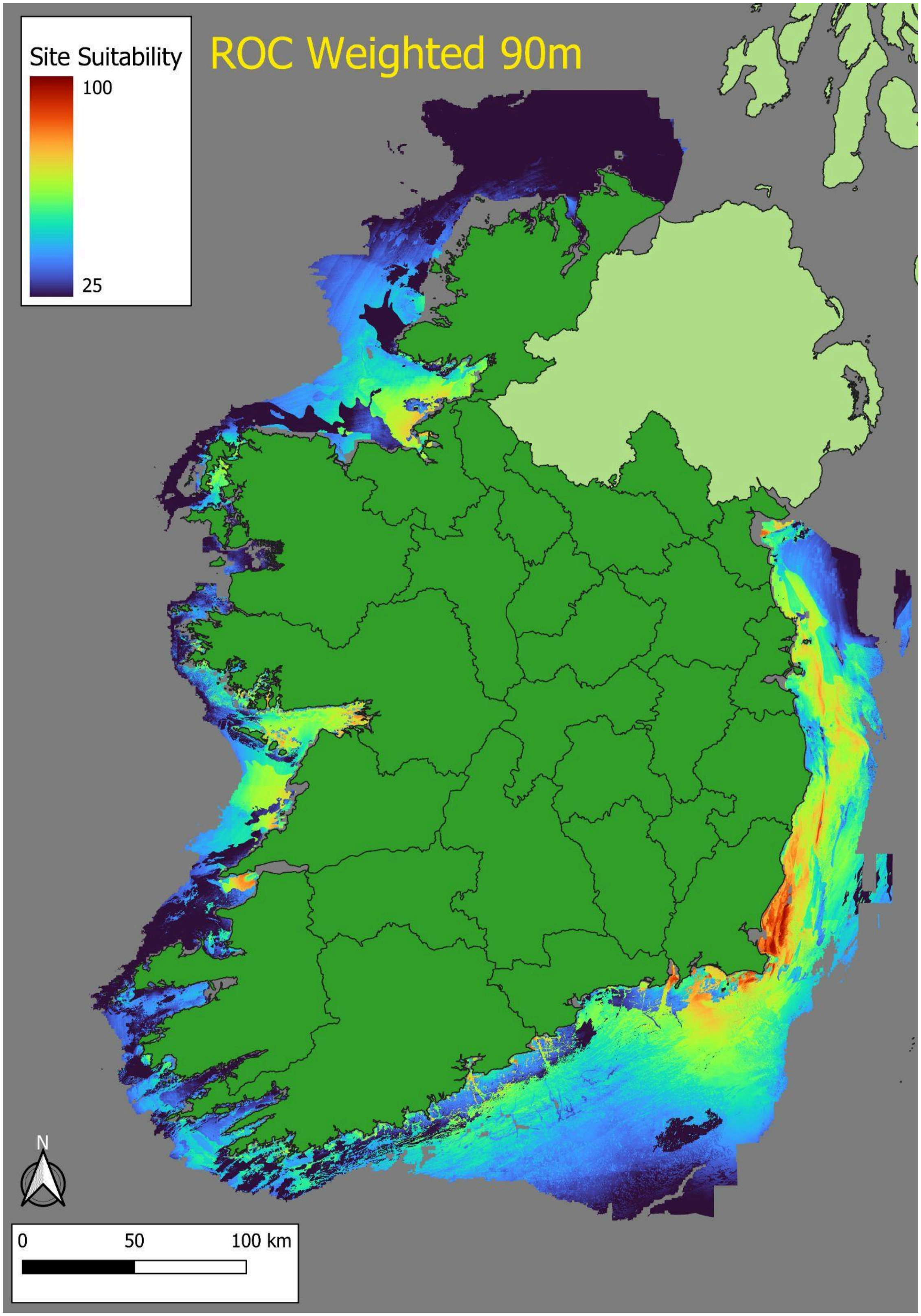


Fig 4. *MCDA output maps of 60m AHP (A), 60m ROC (B), 90m AHP(C), 90m ROC (D)*

Similarly to the weights, the difference between the AHP and the ROC in the final model is very small (>5%) (Table 7). The AHP model predicts slightly higher values along the east coast, while the ROC predicts slightly higher values on the west coast (Fig 5.). An ensemble model is also created in C and D that shows the averages between the two MCDA weighting models (Fig 5). In addition, a difference model shows variation between the two methods at both scenario models (Fig 5).

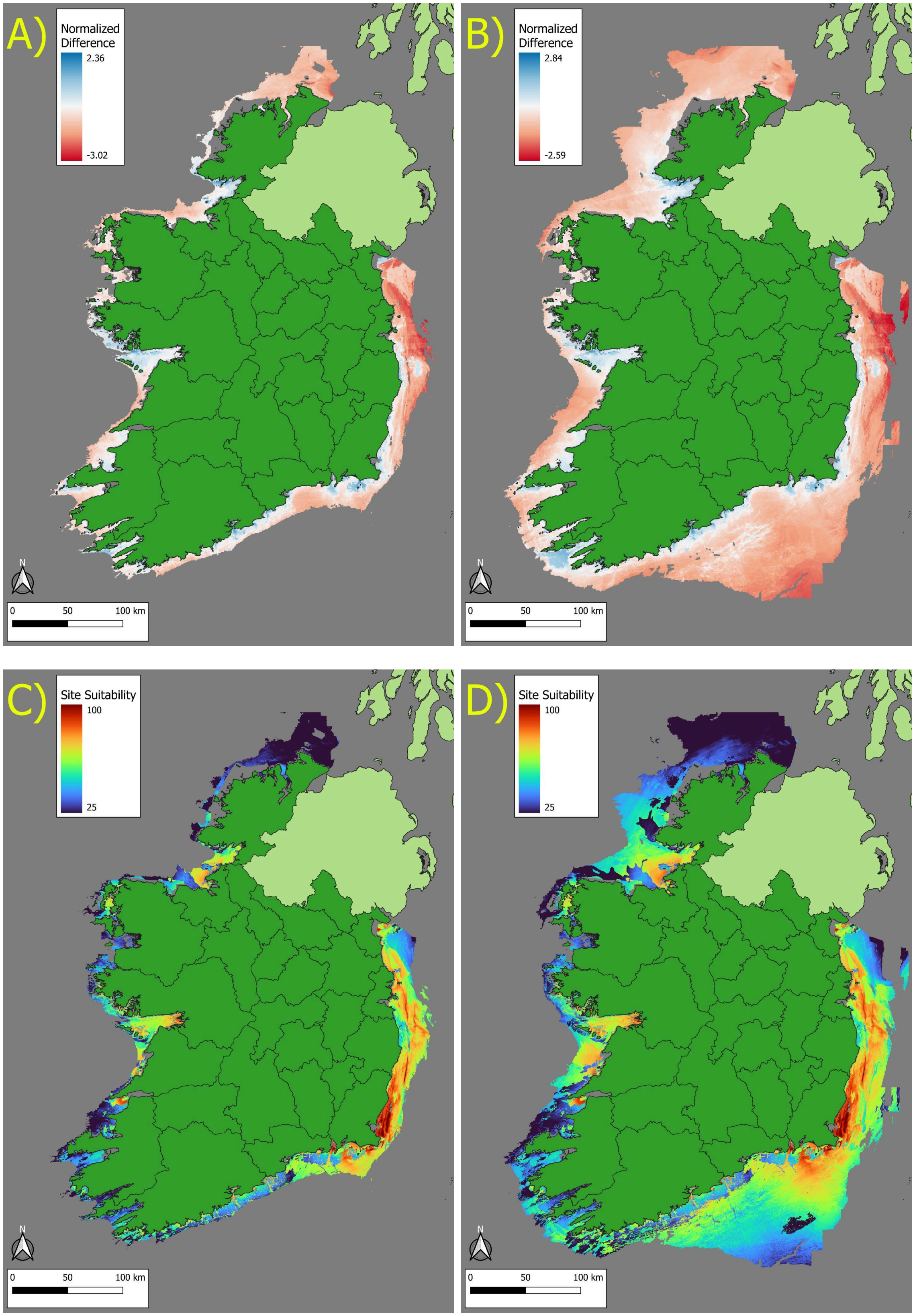


Fig 5. *Differences of the AHP and ROC at 60m (A) and 90m (B), as well as the ensemble averages at 60m (C) and 90m (D)*

While the eastern coastline showed the highest suitability scores, there was significant variation over the extent of the area with some portions of the coastline in the bottom quartile of suitability (Fig 6). In this area, both of the highest weighted variables, the grid connection and the wind speed, remain relatively constant (Appendix A1-2). This meant that the lower weighted variables played a much higher role in determining the suitability score. Of these, depth and substrate have a large degree of influence (weighted 3rd and 4th respectively) in determining the suitability scores within the area (Appendix A1-2). The distance to port plays a significant role as the only viable port on the east coast is located far south at Wexford, reducing the viability of the coastline's northern extent (Appendix A1-2). Fishing intensity is especially significant on this coastline as well, as despite its relatively low ranking the majority of the highest intensity fishing within the study area occurs along the eastern coastline (Appendix A1-2). The ocean offshore of Co. Louth and Co. Wicklow exhibits lower suitability in fishing-intense zones (Appendix A1-2).

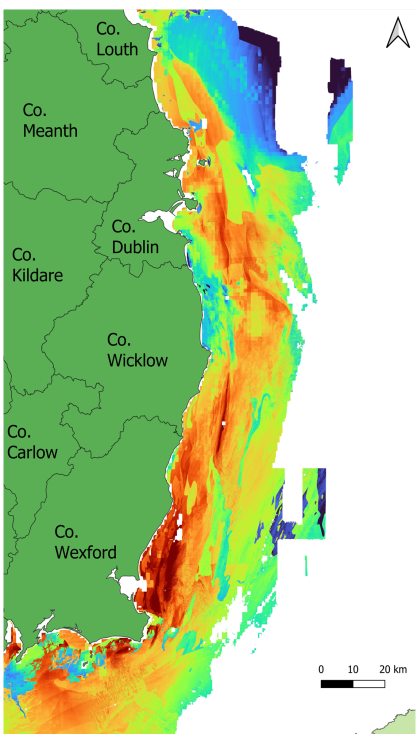


Fig 6. *The east coast MCDA site suitability map*

The exclusion areas were mapped onto the existing MCDA models, with Fig 7 showing the 90m model with the potential exclusion layers overlaid. The majority of exclusion layers fall on low suitability zones, with the only major overlaps located offshore of Co. Wexford and Co. Waterford. Additionally, there is an overlap offshore of Co. Dublin as well (Fig 7).

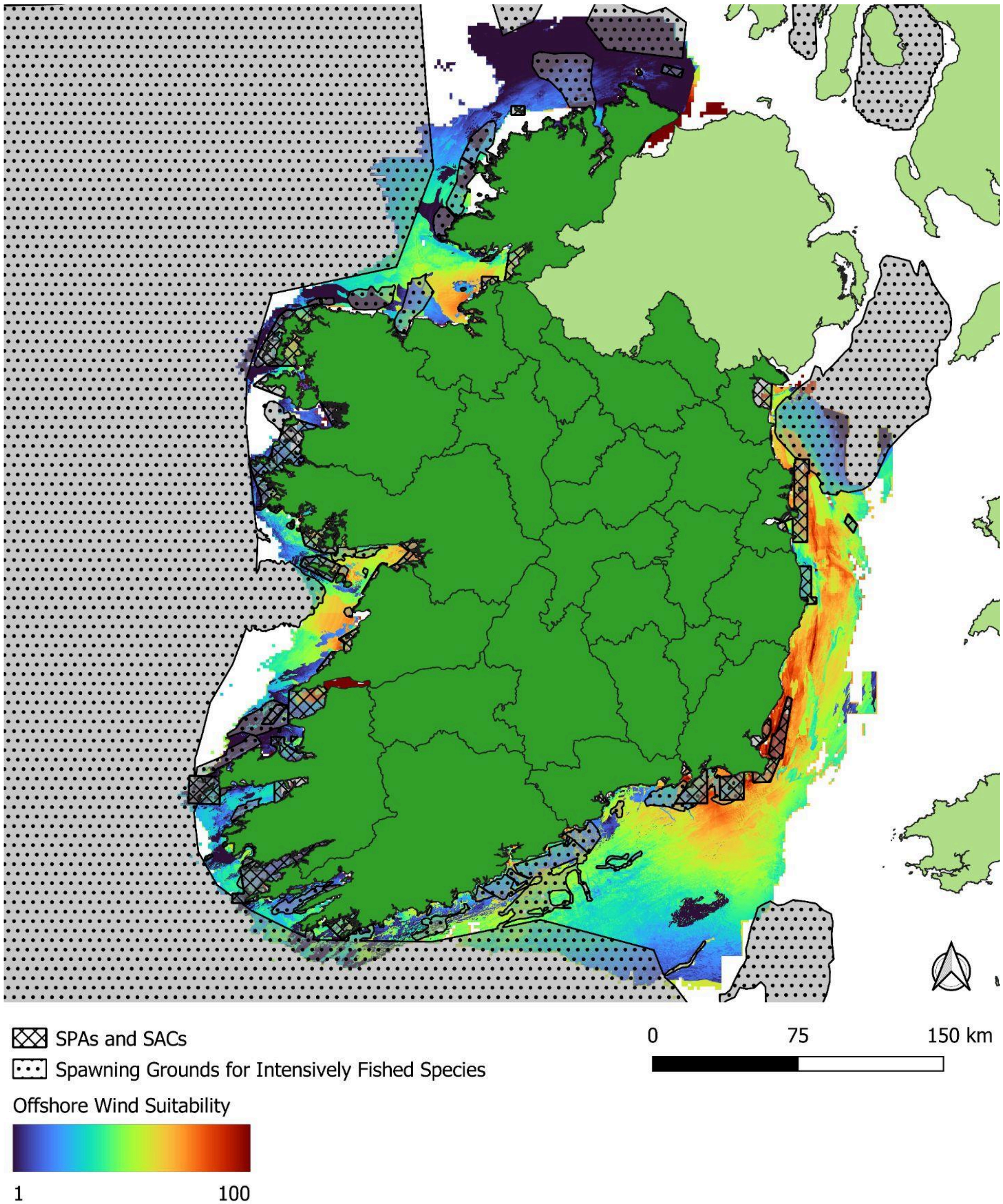


Fig 7. *"Soft" exclusion areas*

In addition to the output MCDA maps, the model itself has intrinsic value as a result due to dynamic capability to input multiple different types of stakeholder data and develop a site suitability map. It can be customized with detailed inputs via AHP or robust inputs via ROC to reflect a given factor priority hierarchy that suits a specific stakeholder or set of stakeholders. This is shown in Fig 8 where the model is run twice, once to prioritize avoidance of fishing areas (A) and again to prioritize proximity to port.

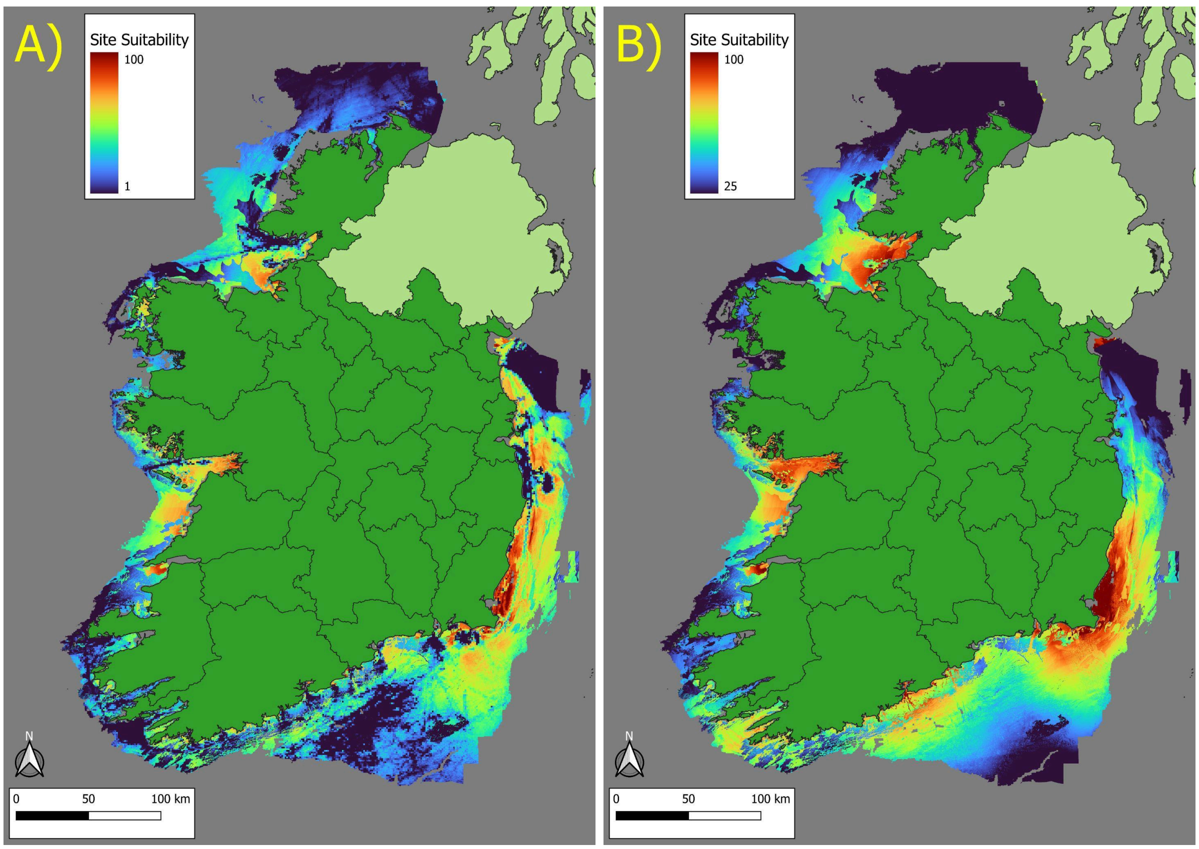


Fig 8. *Two different iterations of the 90m ROC model. (A) uses a ranking with the avoidance of fishing vessel dense areas as the heaviest weighted variable, while (B) ranks travel distance to port as the heaviest weighted variable. The rest of the 11 variables are ranked identically to the primary model (see Table 7). NOTE this is to show the customizability of the model, not necessarily the most suitable areas for offshore wind turbines.*

Discussion

The research goal for this project was to use MCDA and GIS to create a model that shows the site suitability for fixed offshore wind turbines in the Irish EEZ. The MCDA maps generated in this study closely align with the planned and active wind farm sites in the Irish EEZ, with all but one of the planned fixed offshore wind projects in the EEZ are located on the eastern or southern seabed (Fig 9). As mentioned in the results section Arklow Bank, the only active offshore wind farm in Ireland, is situated on some of the model's highest scoring seabed in the entire 60m and 90m study areas (Fig 9; Fig 4). The singular planned offshore wind farm that was located on the west coast invoked confusion from all interviewed stakeholders, with one interviewee saying "if there was one place on the entire Irish coastline where you would not try and do heavy offshore engineering, it's right there" (Appendix A3). This project, Scerdie Rocks Offshore Wind Farm, was abandoned in April 2025, and it is reported that issues with site selection constituted the primary reason for withdrawal (O'Sullivan 2025). This implies that diligent site selection is of extreme importance to maximizing the chance of success for offshore wind projects, and that more research is needed to minimize the occurrences of project failures such as Scerdie Rocks.

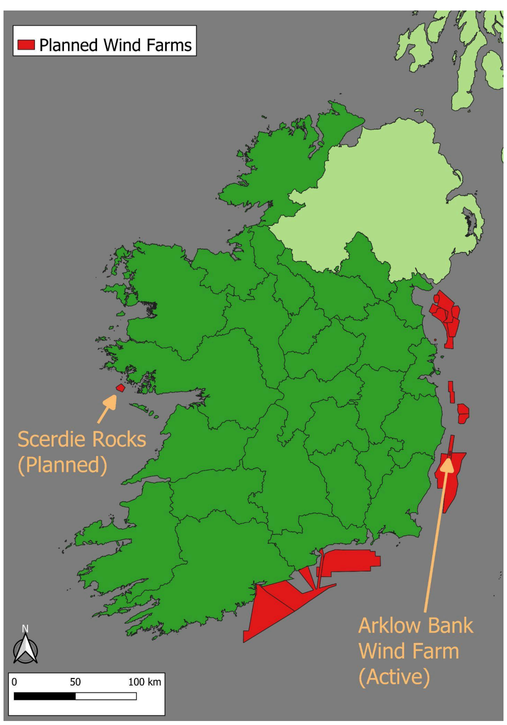


Fig 9. *Location of planned wind farms in the Irish EEZ (EMODnet dataset)*

The model's prediction of the east coast (Fig 6) showing higher suitability for fixed foundation development is counterintuitive compared to the fact that the east coast displays the lowest values of the heaviest weighted variable in the MCDA: wind power density (WPD). This is primarily because less heavily weighted variables, in particular substation proximity and depth (weighted 2 and 3 respectively), as well as wave height and days under 10 m/s wind speed (which essentially were inversely proportional to WPD) combined to outweigh WPD in the model (Appendix A1-2). This implies that even though WPD is the most important resource for an offshore wind farm, its exceeding high opportunity cost in the context of fixed platform wind farms in the Irish EEZ may warrant confining such wind farms to comparatively low WPD areas like the eastern seaboard. This is generally supported in the literature, however it is noted that the Levilized Cost of Energy (LCOE) may be higher in these sites due to the lower WPD (Martinez et al. 2022).

One noteworthy takeaway from this study is that despite encompassing more than three times as much seabed, the 90m depth study model still showed the majority of high suitability areas to be located in ocean shallower than 60m (Fig 4).

As noted in numerous other offshore wind MCDA site selection studies, the complexities of offshore wind site selection means that large scale MCDA maps are not guaranteed to be practical in every instance, and are best used as an overview for where the best sites to investigate further are located (Gavériaux et al. 2019; Martinez et al. 2022). In particular, there are some criteria that overall have a relatively low importance in an MCDA study, yet have the potential to completely terminate a project. One example of this is the visual impact suitability factor, which is the lowest weighted in this analysis. While both literature and expert interviews supported this low weighting, projects with strong financial backing have occasionally been forced to stop development due to strong public backlash on visual impact, with one example being the Cape Wind project in Massachusetts, USA (Cronin et al. 2021). This project was very well funded but public backlash, primarily due to the site's impact on the view from shore, led to its eventual termination (Cronin et al. 2021). This would suggest that even if a selected site has a high overall suitability score it is still important to consider individual factors with low scores during the course of a project’s development and lifespan. Developers and stakeholders should give any factors with poor suitability scores on their site the highest possible degree of consideration, even if the factor has a very low weighting in the MCDA model.

Model Applications

While the MCDA output maps generated in this research are a valuable result on its own, the actual MCDA model with its customizable weighting through the AHP/ROC system has the potential to be of additional use for offshore wind developers, stakeholder NGOs, and regulating bodies. With the ability to generate bespoke offshore wind site suitability maps that reflect a specific stakeholder's priorities, this MCDA model could be used in multiple applications. For example, an offshore wind developer that has excellent relationships with Irish fisheries yet struggles to interact with local communities could use the model to generate a suitability map that weights visual impact as a heavy parameter, and fishing intensity as a much lighter parameter. Likewise, a community NGO could use the model to generate a map of offshore wind sites that prioritize minimizing impact on an issue of their choosing (such as vessel traffic, fishing intensity, visual impact, etc.), and use this map to better negotiate with developers and governing bodies. This can be accomplished simply by changing the ranking input of the user-friendly ROC to reflect the stakeholder's desired rankings. Additionally, the soft exclusion criteria can be switched to hard exclusion at the behest of the model user, which further adds customizability. While many GIS-MCDA offshore wind site suitability studies present their final map outputs as static results, it is possible that additional value lies in the potential to customize the model in a variety of ways (Diaz & Soares 2021; Diaz et al. 2022; Vagiona et al. 2018). This concept is supported by the stakeholder interviews where all interviewees acknowledged the tendency for bias in the ranking system, and that stakeholder opinions on some factors were likely to vary depending on who was interviewed.

One way to decrease bias in a study that requires stakeholder or expert input is to increase the sample size of experts interviewed (Butler et al. 2015). One benefit of using the ROC ranking in addition to the classical AHP ranking in this model is that there is potential for much quicker and more streamlined stakeholder analysis (Dolan et al. 2015) in future research that employs this model (or a similar one). This is because interviewing an expert or stakeholder to determine their factor weighting via an AHP approach requires soliciting their pairwise comparison of each variable to each other variable, meaning that it is necessary to ask N(N-1)/2 questions where n is the number of variables considered (Triantaphyllou et al. 1994). To determine the stakeholder opinions with an ROC approach, only one ranking of all the variables is needed. Given that all interviewed stakeholders acknowledged the tendency for stakeholder bias to influence GIS-MCDA offshore wind models, the ROC presents a potential solution to this problem as it opens up the possibility of much larger-scale expert/stakeholder opinion surveys for use in site suitability models. These methods have been shown to yield analogous results, with Dolan et al. (2015) finding that rank order and AHP MCDA methods produced very similar output weights, and the same final factor rankings >90% of the time (Dolan et al. 2015). The impracticalities of acquiring large scale pairwise comparisons for an MCDA offshore wind site suitability analysis is evident in that most of these studies interview a relatively small amount of experts or stakeholders, some examples being (Diaz & Soares et al. 2021) which interviewed 5 experts, (Diaz et al. 2022) which interviewed 9 experts, and (Caceoglu et al. 2022) which interviewed 11 experts. With the ROC ranking system it is conceivable that a MCDA study could include input from hundreds of stakeholders or experts.

Limitations

There were a few limitations of this study, namely the small sample size of stakeholder interviews and the lack of data on inshore fisheries (Appendix A3). Given the relatively short timeframe for the study, only two stakeholders were interviewed for this study. This limits the accuracy of the stakeholder engagement portion of the study, where it is recommended to have more than seven experts/stakeholders interviewed for a bias-minimized sample (Butler et al. 2015). However, both interviewees were leaders in their fields/operational oversight, meaning their responses would most likely be in line with others in the industry working under them. This limitation could be overcome in future research by conducting a high number of interviews/questionnaires optimized with the efficient one-question ROC method to survey a large sample size. These responses could be plugged into the model for a MCDA output using their answers.

Additionally, it is challenging to accurately quantify the fisheries of the Irish EEZ, especially inshore fisheries (Appendix A3; Reilly 2017). The fishing vessel density dataset is a proxy for fishing intensity, and is not necessarily an accurate representation of which areas are most important to fisheries. This means that areas that are shown by the model to be highly suitable in terms of fishing vessel density still have the potential to cause conflicts with fisheries. More research is needed to ascertain a more detailed understanding of the offshore wind site suitability in terms of the impact it might have on fishing in the Irish EEZ (Reilly 2017).

Conclusion

This study aims to create a detailed fixed platform offshore wind site suitability map and model using MCDA and GIS methods paired with stakeholder engagement. The analysis creates a high resolution map of the best areas for fixed offshore wind development (Fig 4), as well as a model that can be customized to the user's bespoke criteria priority rankings. The AHP/ROC weighting systems provide both a detailed and efficient weighting system to account for a variety of stakeholder engagement input levels. To the best of the researcher's knowledge, this analysis is the first MCDA/GIS approach focusing solely on fixed foundation turbines in the Irish EEZ. The results of this study can be used to assist site selection decision making, and the dynamic tool can be used by stakeholders to present the best sites based on their interests.

Ethics Statement

This work was approved by the CACSSS Ethics Committee of UCC, with reference number CEA-2025-6-18-53420.

Appendix

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Plagiarism Statement

All work presented in this document is my own work. AI was used for the purposes of code editing, research supplementation, citation management, and grammatical writing checks in parts of this project.

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