The siting of renewable energy developments in a crowded marine space

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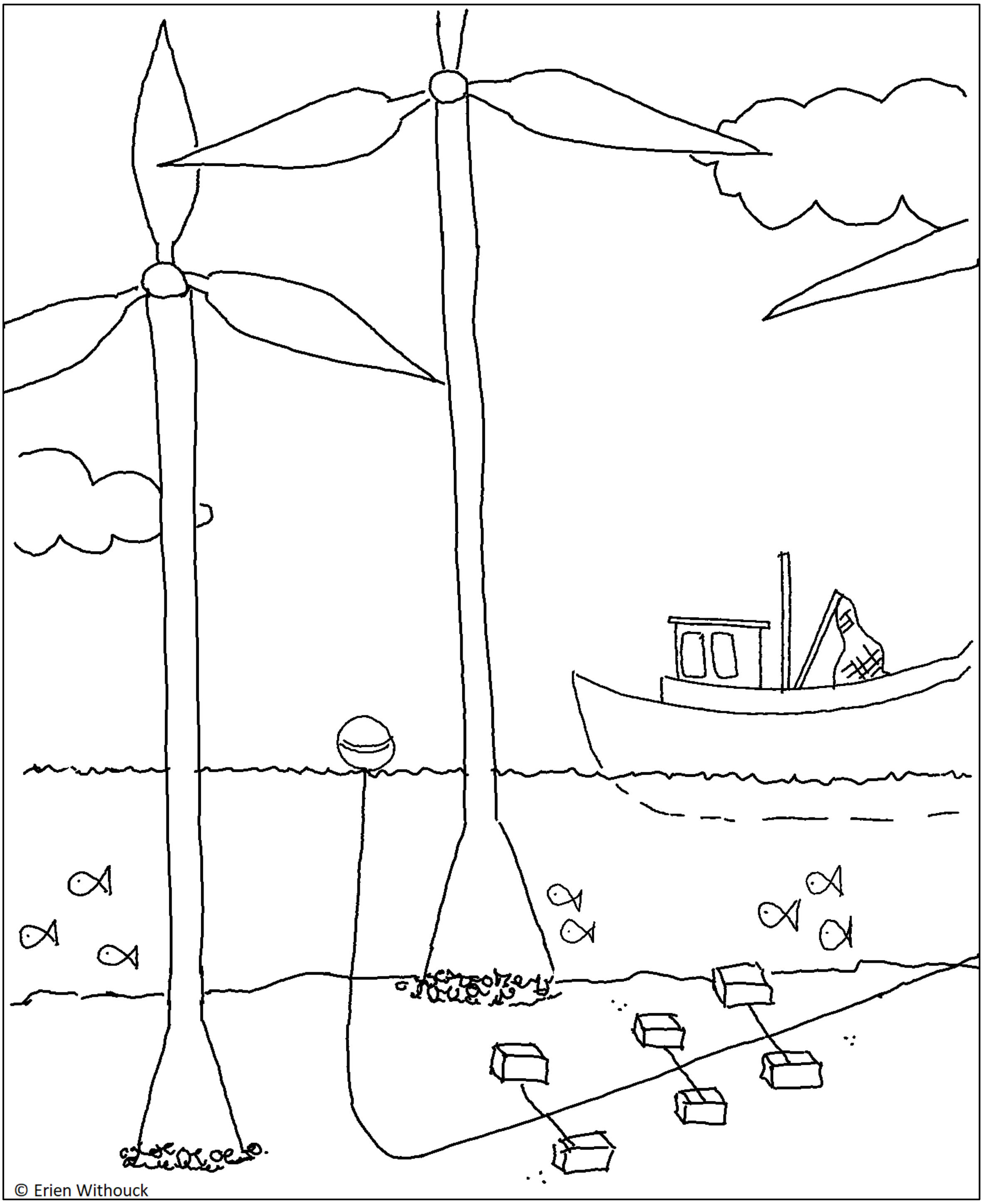

Abstract

As Scotland transitions to net zero, justice for existing marine users who may be impacted by offshore renewable energy developments can be considered across three tenets, procedural, recognitional and distributional justice, and they will all influence whether a just transition is achieved. This thesis explores these dimensions of energy justice across a range of marine planning scales - from the national allocation of renewable energy sites through to site adjustments made at the project level. A better understanding of how justice can be integrated into marine spatial planning can enable inclusive decision-making.

Procedural justice is affected by the way in which socio-economic values are considered in spatial decision support tools that inform siting, such as multi-criteria suitability mapping. To ensure consideration of procedural justice, marine planning policies are in place to ensure that existing users are taken into consideration during the siting of novel developments, but these policies are not commonly integrated into spatial decision support tools. This thesis developed a procedural framework for integrating marine planning policies into mapping tools to ensure their inclusion in the siting process. The procedural framework was developed using a value-focused thinking approach. The framework improves transparency in the siting process by unfolding how the adopted tool method, affects how planning policies are interpreted and implemented in the siting process at both a strategic level and project level. The framework can also be used to test how implementable a policy is for spatial decision-making.

As well as procedural justice, recognitional justice is also a concern for strategic-level multi-criteria mapping. Socio-economic values of remote and island communities may be overshadowed by higher intensities of socio-economic activity in densely populated areas. In response, this thesis developed novel fuzzy standardisation techniques for marine suitability mapping, to improve local representation in national-level mapping efforts. The techniques can improve recognitional justice considerations in the mapping process, by representing both local and national areas of importance in suitability layers.

The fishing industry is the sector most likely to experience changes due to the emergence of more energy projects at sea, which can have repercussions for distributional justice. Through a case study analysis of offshore energy planning in Scotland using a combination of document analysis and interviews, this thesis found that engagement with the fishing industry during initial spatial decision-making at a strategic level has improved over time, with increased representation of fisheries voices. At both a project level and strategic level, constructive communication between the energy and fisheries sectors was found to be as important for fostering procedural justice as sufficient fisheries data. However, compared to larger-scale fisheries, resource constraints prevented small-scale fisheries from being as involved in spatial decisions, indicating recognitional justice concerns.

Accounting explicitly for justice during the siting of novel energy developments, using the methods presented in this thesis, can foster a better mutual understanding between emerging and existing sectors of the blue economy. This has the potential to prevent conflicts in the future and facilitate a just energy transition towards renewable sources.

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Acknowledgements

This PhD has been such a memorable journey that brought me across the North Sea from Oostende to the Shetland Isles. Shetland has been given the nickname of 'schatteneilanden' or treasure islands by the Ostend sailors that passed by on the way to Iceland in the 1800s. It's been so great to be based at the Shetland UHI campus in Scalloway, where my daily walk to work always had something in store, whether it was interesting beach comb finds or a curious otter. Living in Shetland brought a perspective into my research which I could not have achieved otherwise.

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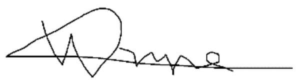
Author’s declaration

I declare that all the material contained in this thesis is my own work.

Inne Withouck



List of Abbreviations

AHP	Analytical Hierarchy Process
AIS	Automatic Identification System
CBA	Cost-benefit Analysis
CFMS	Commercial Fisheries Mitigation Strategy
CFWG	Commercial Fisheries Working Group
EA	Environmental Appraisal
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
ES	Environmental Statement
ESI	Environmental Supporting Information
FIR	Fisheries Industry Representative
FLMAP	Fishing Liaison Mitigation Action Plan
FLO	Fisheries Liaison Officer
FLOWW	Fishing Liaison with Offshore Wind and Wet Renewables Group
FMMS	Fisheries Management and Mitigation Strategy
GBP	Great British Pounds
GIS	Geographic Information System
GW	Giga Watt
HDD	Horizontal Directional Drilling
HVDC	High Voltage Direct Current
MCDA	Multi-Criteria Decision Analysis
MMO	Marine Management Organisation
MPA	Marine Protected Area
MRE	Marine Renewable Energy
MS-LOT	Marine Scotland Licensing Operations Team
MSP	Marine Spatial Plan
MW	Mega Watt
NFFO	National Federation of Fisherman's Organisations
NMP	National Marine Plan
nm	nautical miles (1.852 km)
PAC	Pre-Application Consultation
RIFG	Regional Inshore Fisheries Group
SHEPD	Scottish Hydro Electric Power Distribution PLC
SSE	Scottish and Southern Electricity
SSEN	Scottish and Southern Electricity Networks
SSMO	Shetland Shellfish Management Organisation
UHI	University of the Highlands and Islands
UK	United Kingdom
VMS	Vessel Monitoring System
WLC	Weighted Linear Combination

1 Introduction

1.1 Rationale and motivation for research

Since the 1850s, the combustion of fossil fuels has led to a rise in carbon dioxide levels in the atmosphere (Corfee-Morlot et al., 2007; Friedrich and Damassa, 2014; Plass, 1959). This is already leading to more frequent weather extremes and impacts on global food security, and is threatening international peace and security due to increased competition for resources (United Nations, 2019). To reduce carbon dioxide emissions, countries are decarbonising their energy systems by generating electricity using renewable sources instead of fossil fuels, but more than 13 times the capacity present today will be needed to achieve Net Zero emissions by 2050 (IEA, 2021; Potts, 2021). Offshore wind is expected to play a significant role in this rise of renewable capacity, and has been demonstrated to have the potential to use up less space than solar panels or onshore wind (IEA, 2019). An increase in generating capacity will need to be paired with infrastructure to transport this generated electricity, for example via subsea cables (Adeuyi, 2019)

These new developments require space in the marine environment, which may already be in use by marine species and other users. Marine spatial planning (MSP) is the process that aims to balance the space needs of different interests (Ehler and Douvere, 2009). When planning a site for an offshore renewable energy or cable development, marine planning policies are in place to ensure other users and marine species are considered in the decision-making. The marine spatial planning processes that have kickstarted across the world have frequently led to data collection efforts that allow more informed decisions on the allocation of different uses of the marine space (Shucksmith et al., 2020). As well as additional data, sophisticated modelling techniques have allowed this data to be used for spatial models designed to identify optimal locations for proposed developments (Göke et al., 2018; White et al., 2012; Yates et al., 2015).

However, the allocation of space for upcoming developments can be seen as a ‘wicked problem’, defined as having no optimal solution but multiple possible solutions, as the decision context is perceived differently by different involved parties (Ostrom, 2007; Parrott, 2017; Rittel and Webber, 1973). Therefore, data and models need to be combined with inputs from all parties involved, such as participation in the decision-making as well as local knowledge (Feick and Hall, 2004).

1.2 Thesis aim, objective and research questions

This thesis aims to support sustainable use of the marine environment, considering both spatially managed and wider sea usage, in the context of increasing marine use to facilitate a transition towards renewable energy systems. The objectives are to establish a series of principles, methods and tools to assist the development of evidence based marine plans. To address the aim and objectives, these three overarching questions are addressed within five chapters:

A. **What is optimal siting?**
    - How do existing decision support tools interpret optimal siting? (Chapter 1)
    - How can technical, economic, environmental and socio-cultural objectives for a spatial decision problem be defined? (Chapter 2)
    - Is optimal siting 'just' siting? (Chapter 4)

B. **What data and information can be used to inform optimal siting?**
    - What criteria can be used to evaluate whether objectives are met? (Chapter 2)
    - How are fisheries represented with data and information for site selection and impact assessment of developments? (Chapter 3)

C. **How can this data and information be translated into spatial decision support?**
    - How can data and information be transformed into common levels of suitability? (Chapter 2)
    - How can this transformation consider decision rule uncertainty and regional differences in values? (Chapter 5)

The first question explores what can be meant by "optimal siting", and how this has been translated into spatial decision support tools to aid decision makers in achieving optimal siting (Chapters 1 and 2). Since the focus of this PhD thesis is the siting of renewable energy generating and transporting infrastructure to decarbonise the energy system, links with a just energy transition are also investigated (Chapter 4). Chapter 1 presents a literature review of existing applications of multi-criteria decision analysis for marine spatial decision support to inform the siting of novel developments. In Chapter 2, a framework is developed to make the siting process more transparent. Chapter 4 evaluates how siting decisions can facilitate a just transition, with a focus on engagement with fisheries. Two of the chapters that address this optimal siting question consider multi-objective spatial decision support (Chapters 1 and 2), while Chapter 4 focuses specifically on how the fishing industry is included in the siting process for novel developments.

The definition of optimal siting links to the next question on how this siting process is informed by data and information. Chapter 2 adopts approaches from the operational research literature to explore links between spatial decision objectives and underpinning data, and Chapter 3 evaluates what types of fisheries data are used in project level decision-making. For multi-objective spatial decision support, layers representing different interests may be combined into one overall suitability map in different ways. The final overarching question, addressed by Chapters 2 and 5, is addressed through testing novel and existing techniques of standardising input units into suitability values, and evaluates how these techniques can be used to account for uncertainty as well as differences in values across spatial scales. Figure 1-1 illustrates the links between the overarching questions and the thesis chapters. Throughout this thesis results are considered in the context of three dimensions of justice: distributional, procedural and recognitional. Social justice theory is expanded on in the literature review in Section 1.3.

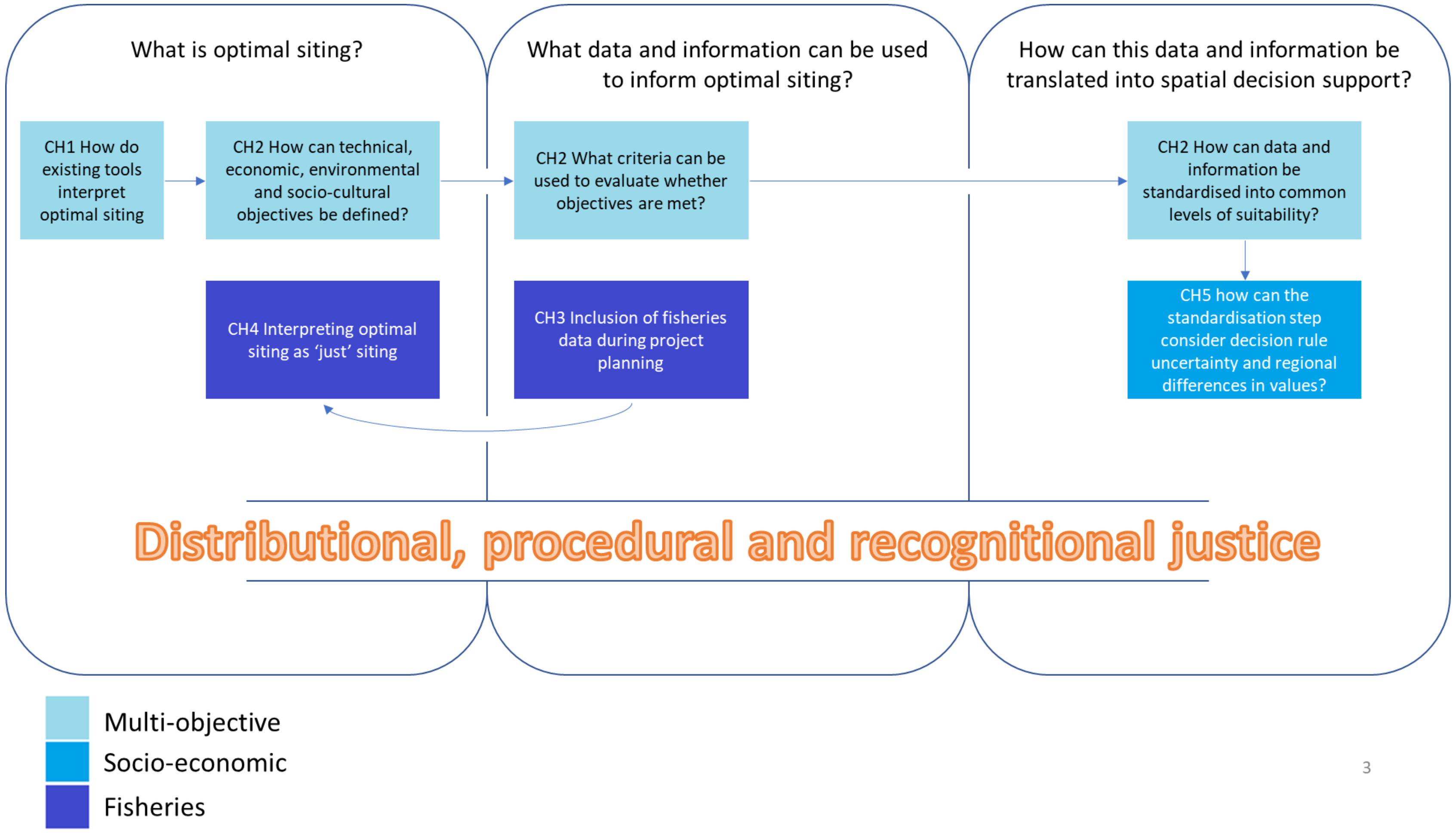


Figure 1-1 Illustration of the overarching questions of this PhD thesis, and how they are addressed with the individual chapters

Throughout this thesis, the siting process of energy infrastructure at sea is approached in a nested way: firstly from a multi-objective perspective (CH1 and CH2), a socio-economic perspective (CH5) and fisheries perspective (CH3 and CH4). In Figure 1-2, the circles represent the three pillars of sustainability, which can be defined as distinct but interacting systems that together lead to sustainable outcomes (Purvis et al., 2019). The siting of a novel development at sea can be perceived as needing three conceptual licences to operate: social, ecological and economic (Tett, 2018). Interactions with existing sectors such as the fishing industry can influence the social licence to operate. However, fisheries or recreational activities also have an economic value, which is why they are mapped as socio-economic interests rather than solely in the social domain (Figure 1-2).

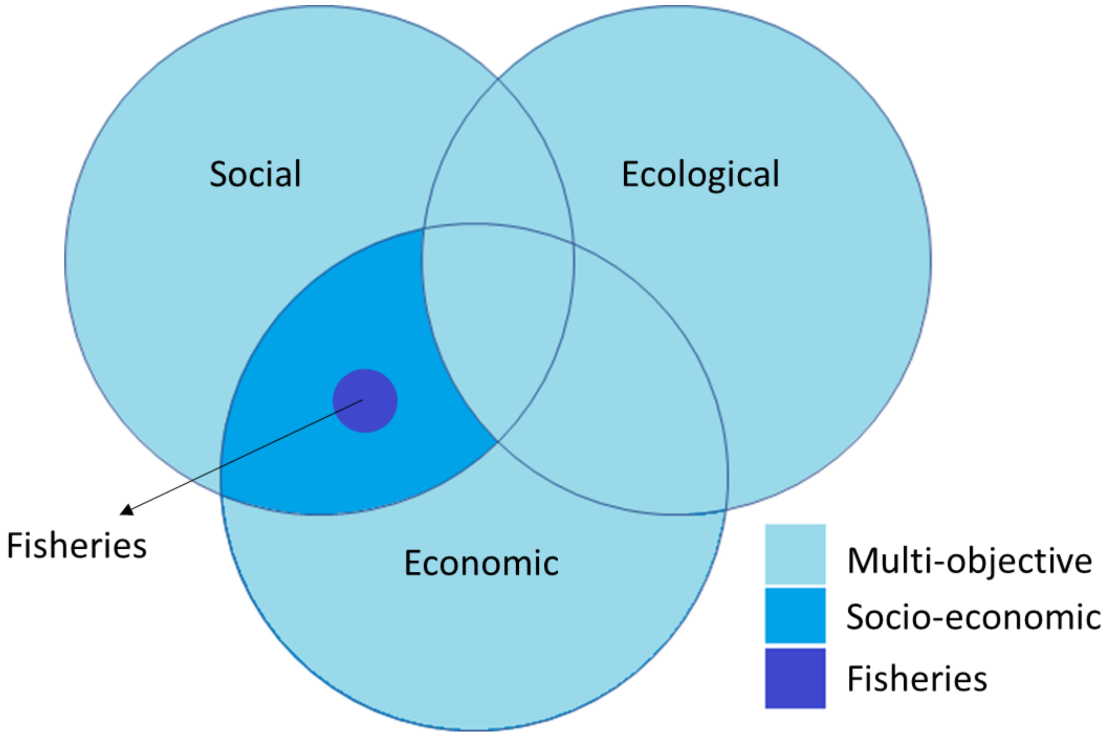


Figure 1-2 Nested perspectives on the siting process

Failure to fully integrate the human dimension in marine spatial decision support, sometimes termed the ‘missing layer’, has been highlighted in recent literature (Pennino et al., 2021; St. Martin and Hall-Arber, 2008; Tolvanen et al., 2019). In response, this PhD thesis focuses on socio-economic aspects of the siting process. Along with providing socio-economic opportunities, proposed energy developments may pose a risk to existing socio-economic activities and values. Socio-economic benefits include energy security, job opportunities and infrastructure improvements (Copping, 2019). Potential negative impacts include loss of access to marine space and resources, anticipated effects on recreational activities and visual changes in the seascape (Firestone and Kempton, 2007; Haggett et al., 2020; Ladenburg, 2009). In addition, upcoming opportunities related to novel development may not be accessible to all (Carley and Konisky, 2020).

Chapters 3 and 4 focus specifically on the fishing industry as this sector is reported to be most at risk from upcoming developments at sea (Kafas, 2018a). The commercial fishing industry is one of the most ubiquitous users of the marine space. Fishers are generally found further offshore than other user groups such as recreational users, therefore they are more likely to overlap with upcoming renewable energy developments. As they are frequently the most well-established sector, they are at risk of being the most affected, such as by displacement due to offshore energy developments (Kafas et al., 2018).

The central field of inquiry of this thesis is energy geographies, which has emerged from the core tenets of geography (physical geography, human geography, nature-society geography, geographic information science, and cartography, Figure 1-3) and focuses on past, current and future patterns of how energy is produced, distributed and consumed at a variety of spatial scales (Calvert, 2016). This field is referred to as pluralistic as it acknowledges that it incorporates philosophical positions from a range of disciplines, as illustrated in Figure 1-3 (Calvert, 2016; Zimmerer, 2011). Relevant existing research in this field includes the study of how energy infrastructure affects livelihoods and environmental justice, and how environmental and economic risks are taken into account during the siting of facilities for energy generation (Calvert, 2016).

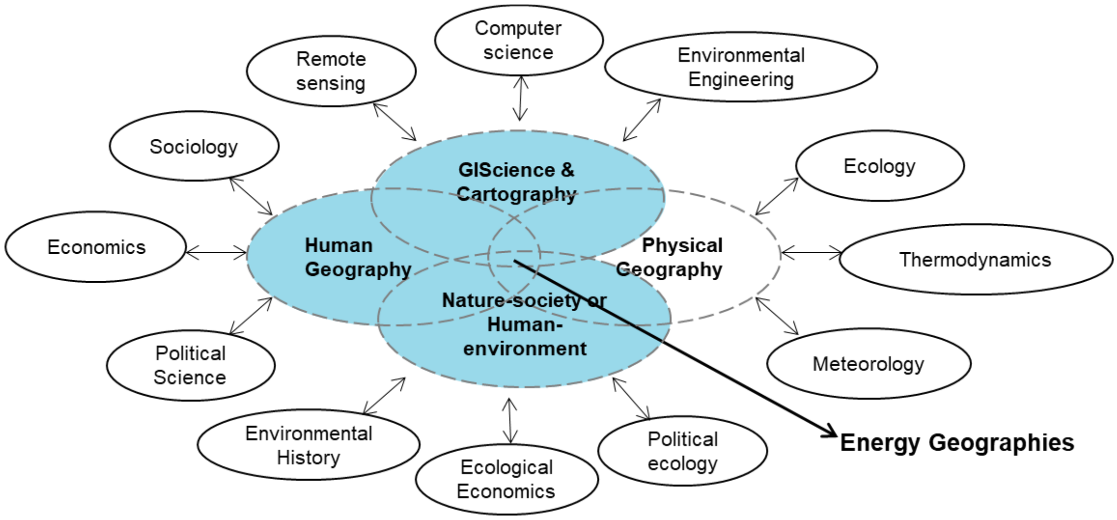


Figure 1-3 The field of energy geographies is an overlap of the central domains of geography, and it integrates theories, concepts and techniques from a range of other disciplines (as denoted with the double arrows). Shaded in blue is where this PhD thesis sits (Figure adapted from Calvert, 2016; Zimmerer, 2010)

Calvert highlights that the ongoing energy transition presents questions that the field of energy geographies can address: 1) how the development of energy generation infrastructure can occur in a way that minimises impacts on social as well as ecological systems, 2) who should be involved in the decisions and how, and 3) what place-based solutions to the challenges of the energy transition may look like (Calvert, 2016). These research gaps also apply in a marine context, which will be addressed through this PhD thesis. Within the field of energy geographies, studies adopt a range of paradigms from naïve realism to relativism, and this PhD thesis situates itself in the ontology of critical realism, which accepts that there are different interpretations of what knowledge is, but that all these types of knowledge relate to an independently existing reality (Bhaskar, 2008; Greenhill, 2020; Mingers, 2006).

Table 1-1 gives a brief overview of each chapter, and how they are linked to each other. As well as an introduction to the thesis and a general literature review, Chapter 1 includes a review of existing decision support tools designed to inform siting of renewable developments. Chapter 2 presents a framework that will also be integrated into Chapter 5. Chapters 4 and 5 draw on a selection of case studies in Scottish waters to understand how fisheries are considered in energy projects. Chapter 6 provides a general discussion and discusses findings that transpired from the individual chapters.

Table 1-1 Brief overview of each chapter of the thesis and how they address gaps in the research field

#	Chapter title	Research question	Contribution to research field	Link with other chapters
1	Introduction	Section 1.3: How are energy developments currently sited and consented in the context of a crowded marine space? Section 1.4: How do existing decision support tools interpret optimal siting?	Section 1.3 introduces the field of study of this thesis and Section 1.4 explores the role multi-criteria decision analysis can play in multi-objective siting by analysing existing approaches to siting and how multiple objectives are considered.	Introduces the overarching field of study of this thesis as well as giving an overview of the upcoming chapters.
2	Applying value-focused thinking to decision support tools for siting offshore renewables	How can a framework for spatial decision support facilitate explicit consideration of multiple objectives and how they are represented with underpinning data?	This procedural framework places emphasis on the objective formulation step of multi-criteria decision analysis so that suitability mapping can be explicitly linked with policy and legislation frameworks.	This chapter will be a starting point where subsequent chapters focus on different aspects of the procedural framework, e.g. data used to inform objectives (CH3) and standardisation techniques (CH5).
3	Evaluating the current use of fisheries data during project planning of energy developments	How are fisheries represented with data and information for site selection and impact assessment of developments?	This chapter gives an overview of which fisheries data is used in cable and offshore renewable energy projects, different perspectives on best practices and what data is still missing.	As described in the framework chapter (CH2), the spatiotemporal dynamic nature of activities needs to be considered, and this chapter further elaborates on this in the context of the use of fisheries data during project level siting and impact assessments.

Table 1-1 (continued)

#	Chapter title	Research question	Contribution to research field	Link with other chapters
4	Just energy transition? How current practice is considering fisheries during the emergence of renewable energy production	How are fisheries engaged with throughout the siting process of renewable energy developments and how does this affect siting and design of the project? Does it facilitate a just energy transition for the fishing industry?	This study uses dimensions of energy justice and the mitigation hierarchy to understand the extent to which a just energy transition is being facilitated at the strategic and project level in relation to the fishing industry.	CH3 focuses on how data is used and whether the available data allows for fisheries to be adequately considered in decision-making. But active engagement by interested parties also influences procedural justice. Therefore, this chapter looks at the same case studies as CH3 and considers how fisheries representatives were involved in decision-making during project planning.
5	Exploring fuzzy and spatially explicit standardisation techniques in spatial decision support for marine planning	How can decision rule uncertainty and spatial differences in values be represented in suitability mapping?	This study applies a standardisation technique that considers decision rule uncertainty and regional differences in socio-economic value. The potential use of this technique for national-level spatial decision support was evaluated in terms of how it can make national level siting more considerate of subnational spatial differences and uncertainty.	This chapter builds on the CH2 framework by focussing on the standardisation step of multi-criteria decision analysis.
6	General discussion	Overarching research questions are revisited.	Insights that transpired from individual chapters are discussed here.	Findings from preceding chapters are summarised here.

1.3 Literature review

Finding space for renewable energy in the marine realm alongside existing users is a challenge on multiple scales, and the success of strategic siting will influence the success of consenting an individual energy development. In this literature review, a general introduction will be given of offshore renewable energy and cables, marine spatial planning, the siting process and the licensing process. Section 1.4 presents a pilot study evaluating existing applications of spatial decision support for the siting of novel offshore energy developments, and points towards knowledge gaps that can be addressed in this thesis.

1.3.1 The need for a renewable energy source

Anthropogenic emissions of greenhouse gases are contributing to global warming and changes in all components of the climate system (IPCC, 2013). The energy sector is the source of at least two-thirds of these emissions (International Energy Agency, 2016). In the Paris Agreement, 195 countries committed to limit global surface warming to below 2°C by 2100 (UNFCCC, 2015). Five years later, at the COP26 in Glasgow in 2021, 197 countries signed the Glasgow Climate Pact and agreed to limit the temperature rise to 1.5 °C above pre-industrial levels (COP26, 2021). To achieve this target, the proportion of energy that comes from renewable sources needs to increase from 2018 levels (14%) to 74% by 2050 (IRENA, 2021). Accordingly, governments around the world have set national targets for renewable energy generation. Scotland was close (95.9%) to reaching its target of meeting 100% of Scottish electricity demand with renewables by 2020 (Scottish Government, 2021a). Scottish waters host extensive offshore energy resources (wind, wave and tide), which can help Scotland meet its target to extract at least 50% of its total energy consumption (including for transportation and heat) from renewable sources by 2030, which was 23.9% in 2019 (Scottish Government, 2021a, 2017). Scotland aims to become net zero by 2045 (Scottish Government, 2020a).

Although less mature than onshore renewable energy, energy extraction in the marine environment, to meet carbon reduction targets, is continually expanding (Borthwick, 2016; Willsteed et al., 2018). Together with other emerging activities at sea such as aquaculture and the designation of marine protected areas, the expansion of marine renewables has been termed the ‘blue acceleration’, referring to the increased interest in the ocean for resources (Jouffray et al., 2020).

1.3.2 Offshore renewable energy generation and transport in Scotland

To decarbonise Scotland's energy sector, renewable electricity generation at sea is currently taking place in various forms in Scottish waters, together with cables to transport electricity. Four examples of electricity infrastructure found at sea will be discussed in Sections 1.3.2.1 - 1.3.2.3.

1.3.2.1 Generation of electricity from wave and tidal energy sources

Around Scotland's coasts, there is an abundant wave and tidal resource, which has placed Scotland on the international stage as an important player in the marine renewable industry (ECO-INNOVATION, 2009). In 2011, The Crown Estate delineated 11 sites for potential future wave and tidal developments in the Pentland Firth and Orkney Waters (The Crown Estate, 2011). However, only one of these proposed sites is operational to this date. The roll-out of wave and tidal energy developments in Scotland was slower than anticipated, and this delay has been attributed to the harsh environments the devices are exposed to, an unfavourable financial environment and a lack of policy support (Adams, 2019). Operational tidal energy extraction can be found in Shetland (NOVA), in the Pentland Firth (Meygen) and at test sites of the European Marine Energy Centre in Orkney (EMEC, 2022). The NOVA and Meygen turbines are seabed mounted Figure 1-4a.) and the device in place in Orkney is a floating platform (Figure 1-4b.). At the time of writing there were no operational wave energy converters in Scottish waters, but a prototype has been tested out in Orkney in 2021 (Wave Energy Scotland, 2021).

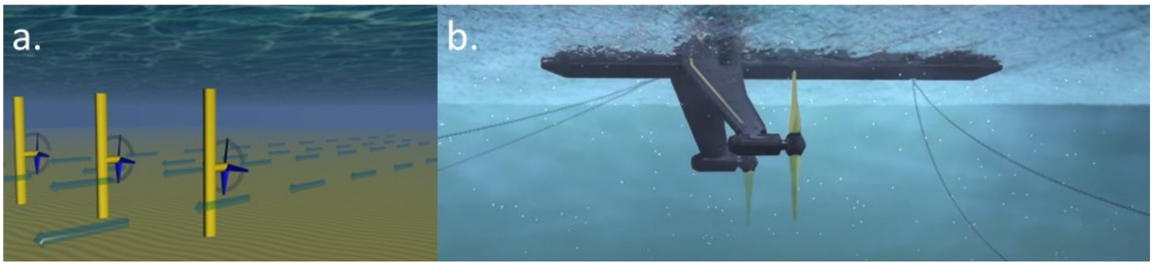


Figure 1-4 Illustration of different forms of tidal energy extraction technologies: a. seabed mounted turbines (source: Aquaret, 2012) b. floating platform (source: Orbital Marine Power Ltd)

1.3.2.2 Offshore wind farms

As well as wave and tidal energy, Scotland hosts an abundance of wind energy, which can be harvested with offshore wind farms (ABPmer, 2008). Offshore wind farms have a footprint in the airspace, in the water column and in the seabed where the turbines, and inter-array cables between the turbines, are located (KIS-ORCA, 2019, Figure 1-5, Figure 1-6). Six offshore wind energy projects are currently completed and operational: in the Solway Firth, Moray Firth, Firth of Forth and along the coast of Aberdeenshire (NatureScot, 2020). As well as that, seven projects are in development, and more projects are expected as part of the ScotWind leasing round (Crown Estate Scotland, 2021a; Marine Scotland Information, 2022).

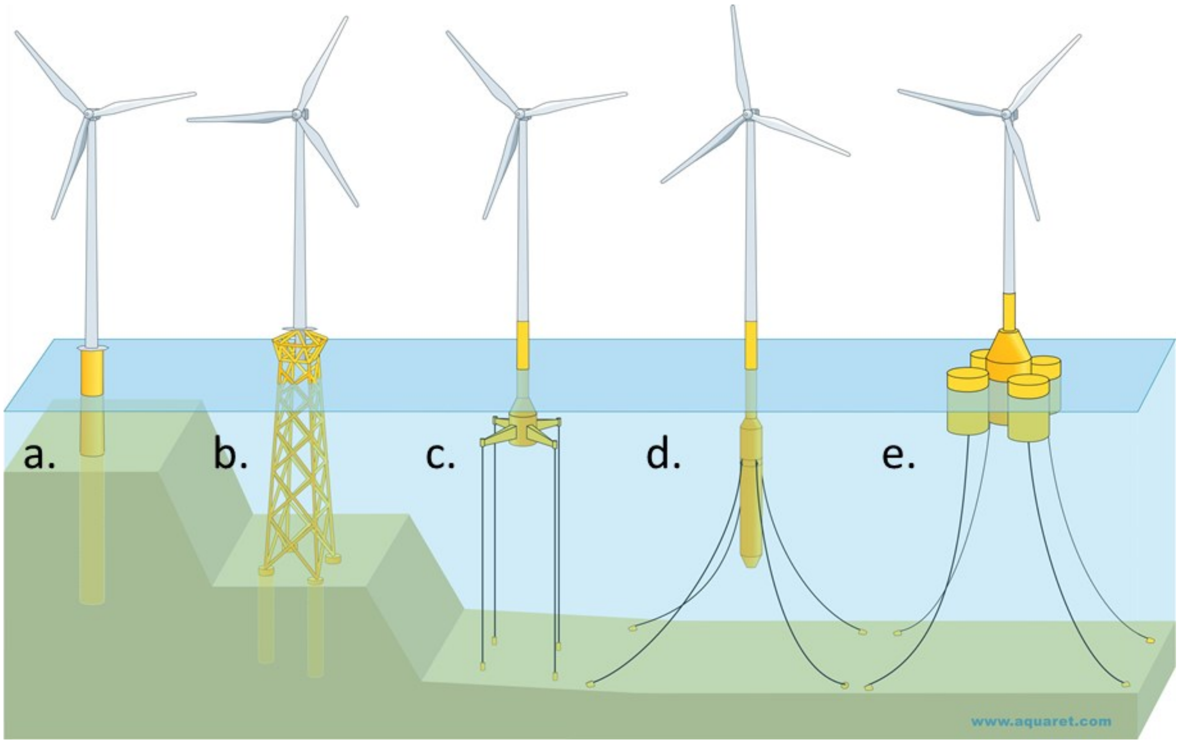


Figure 1-5 Fixed (a.-b.) and floating (c.-e.) foundation types for offshore wind turbines: a. monopile b. jacket c. tension-legged d. spar buoy e. semi-submersible (source: Aquaret, 2012)

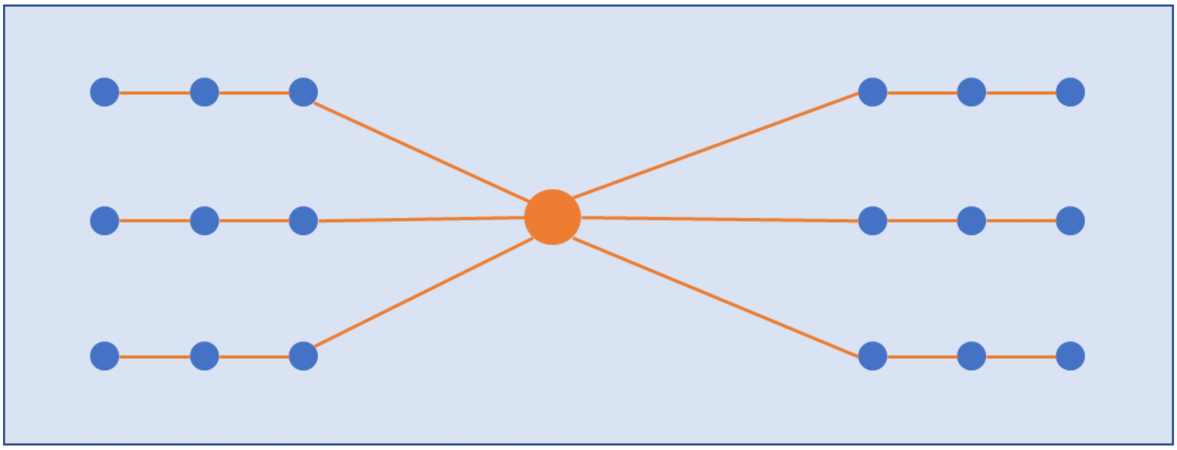


Figure 1-6 Aerial view of the turbine layout (blue circles), inter-array cables (orange lines) and a transformer platform (orange circle) of a fictional wind farm

While fixed turbines are limited to maximum depths of 40-60 metres (Figure 1-5a.-b.), floating wind turbines can be installed in deeper waters (Figure 1-5c.-e.). The UK Government has set a target to deploy at least 1 GW of floating wind capacity by 2030 (GOV.UK, 2020). In 2020, Marine Scotland's sectoral marine planning process for offshore wind identified 15 plan options, which have been made available for developers to apply for through Crown Estate Scotland's ScotWind leasing round (Figure 1-7). Ten of the awarded sites will be used for developing floating wind farms, six for fixed turbines, and one project will combine both (Crown Estate Scotland, 2022a). Further offshore, areas around offshore oil and gas sites are also being investigated for offshore wind farm development, specifically to decarbonise the offshore oil and gas industry, in deep areas which will require floating wind technologies (Scottish Government, 2021b, Figure 1-8).

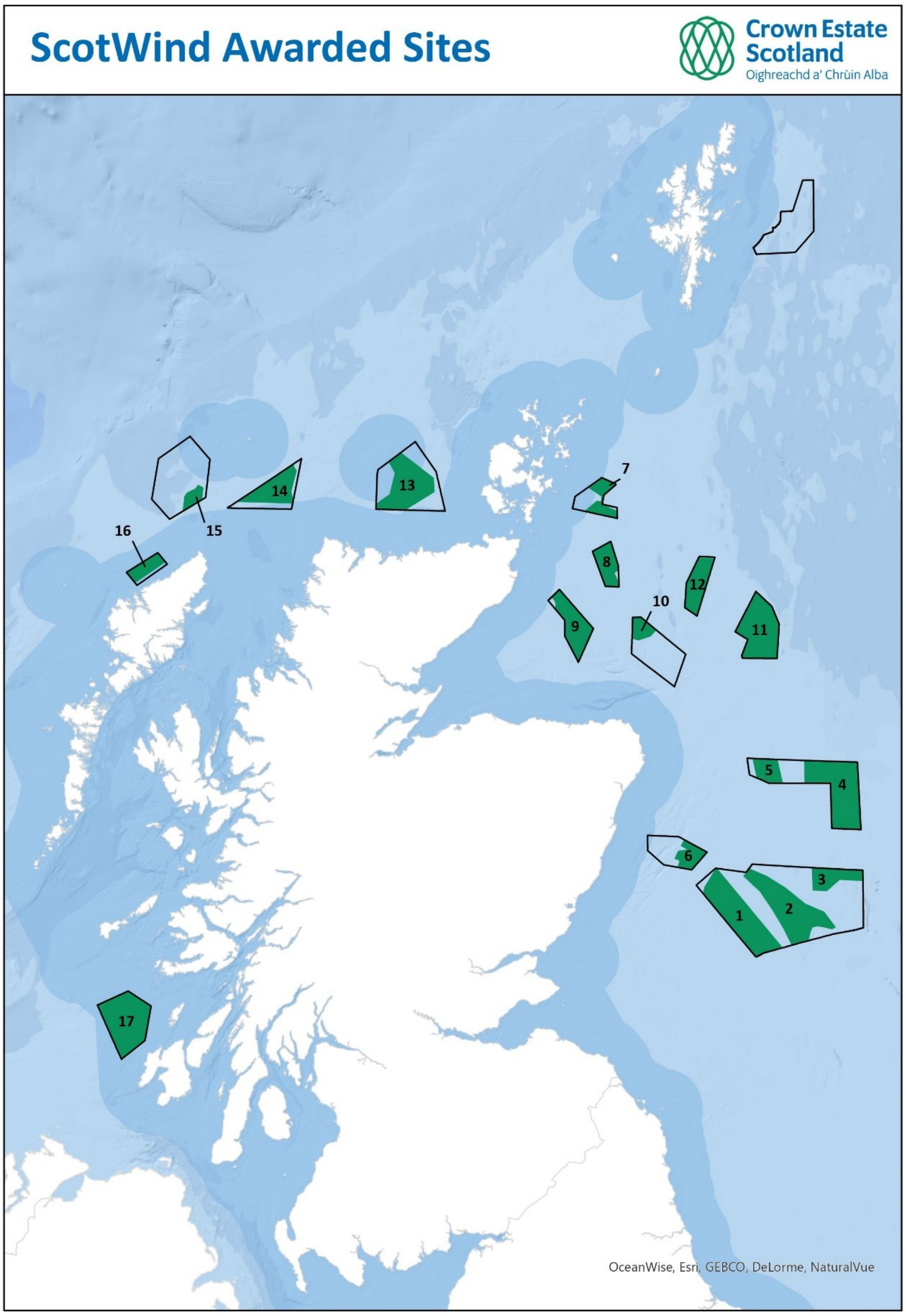


Figure 1-7 ScotWind sites (1-17) awarded by Crown Estate Scotland, within the Plan Options identified by Marine Scotland's sectoral marine plan (source: Crown Estate Scotland, 2022. Contains information from the Crown Estate Scotland licensed under the Open Government Licence v3.0)

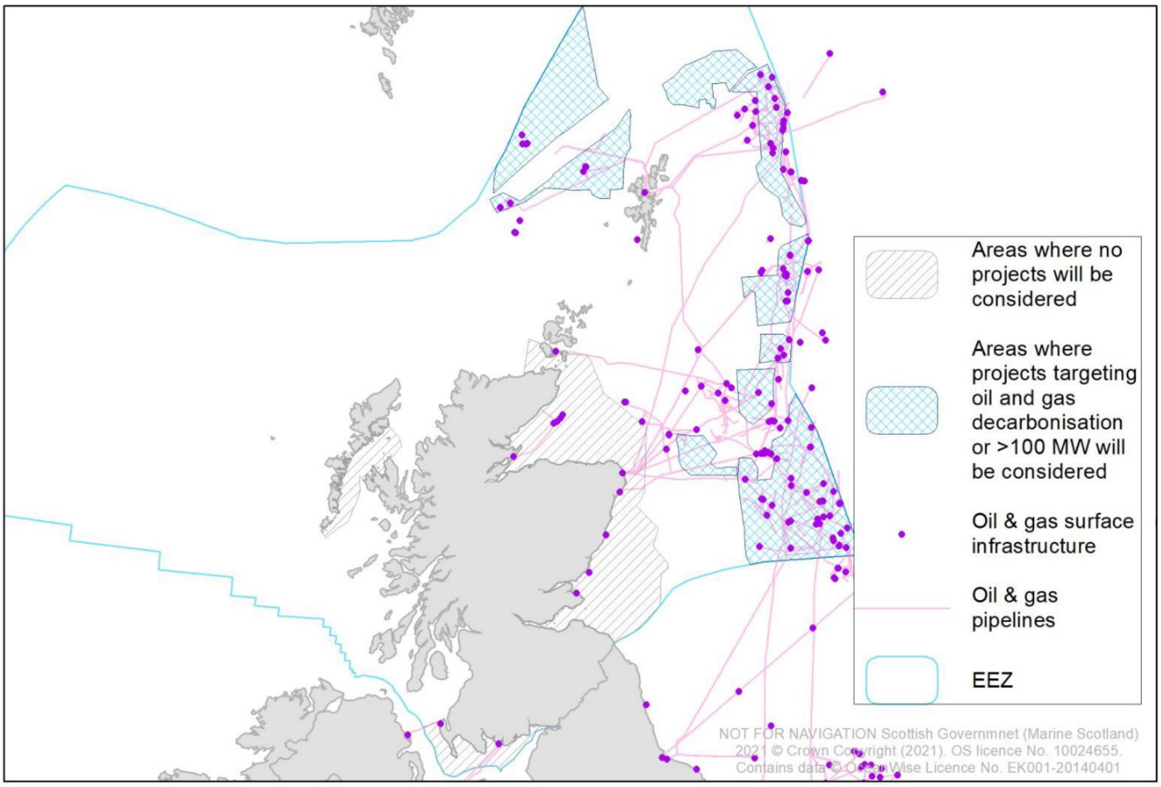


Figure 1-8 Areas under consideration for oil and gas decarbonisation (source: Marine Scotland, 2021. Contains information from the Scottish Government licensed under the Open Government Licence v3.0.)

1.3.2.3 Subsea cables for transport of electricity

The planned expansion of offshore wind projects will need to be paired with sufficient transmission infrastructure to transport electricity to consumers (SSEPD, 2015). Transmission cables are a type of subsea cable that have a higher voltage, and are used for long distance transportation of electricity (SHEPD, 2020).

In Scotland, three different types of transmission cables can be found: 1) export cables, 2) national transmission cables and 3) international transmission cables. The three types differ in their funding mechanism, amount of power transmitted (in megawatt) and purpose. Firstly, export cables transmit power generated from renewable energy developments to grid infrastructure on land (Ioannou et al., 2018). For example, the 588 MW installed capacity of the Beatrice Offshore Wind Farm in the Moray Firth gets transported via two export cables (BOWL, 2018). Next, national transmission cables transport electricity from areas with electricity generators (e.g. wind farms or hydropower) to other parts of the country that have a higher energy demand, ‘load centres’, such as densely populated cities (Munro, 2019). Such transmission cables tend to carry larger volumes of electricity than export cables. For example, the Caithness-Moray transmission cable can transmit up to 1200 megawatts, equivalent to the energy needs of up to 2 million people, which is over double the amount of power carried by the two export cables combined for the Beatrice Wind Farm project (NS Energy, 2019). Their expenditure is regulated by Ofgem (Ofgem, 2020). Ofgem (Office of Gas and Electricity Market) is an independent regulatory body for the UK's energy market, in place to protect consumers from abuse of the energy market e.g. overcharging bill payers (Munro, 2018; Ofgem, 2021).

Transmission cables that link different countries e.g. the UK and Norway allow an exchange of electricity, such as electricity generated by hydro-dams in Norway with electricity harnessed from wind energy in Scotland (Gullberg et al., 2014). Such interconnectors are not regulated by Ofgem and might be owned by a combination of state owned and municipal-owned power companies and can make use of differences in electricity prices between countries, to cover the costs of construction and operation (Gullberg et al., 2014).

As well as transmission cables for long distance transport, access to electricity for Scotland's 93 inhabited islands is secured by 112 subsea cables, some of which have been in place for over 50 years (SHEPD, 2018). Following inspection surveys, it was identified that a number of inter-isle cables were due to be replaced (SHEPD, 2015). All subsea cables SHEPD operates are found within 12 nm (nautical miles) in Shetland, Orkney, the west coast of Scotland and islands fringing the west coast (including the Outer Hebrides) (SHEPD, n.d.). In terms of the footprint of all types of subsea cables, Figure 1-9 illustrates three ways in which subsea cables can be found in the marine environment.

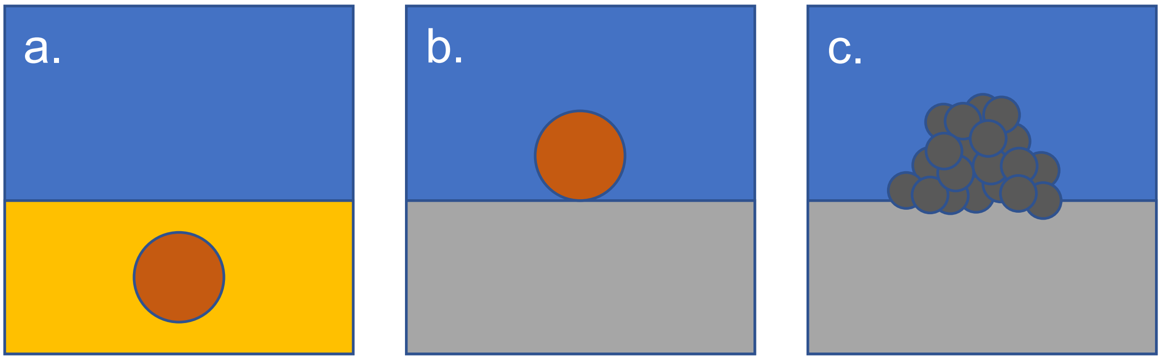


Figure 1-9 Seabed cross-sections illustrating the three main installation methods for subsea cables: a. burial b. surface-laying or c. rock protection

The number of transmission cables is projected to increase, with eight high voltage direct current (HVDC) links currently operational around the UK and 22 more links anticipated by 2027 (Scottish and Southern Electricity Networks, 2020, Figure 1-10).

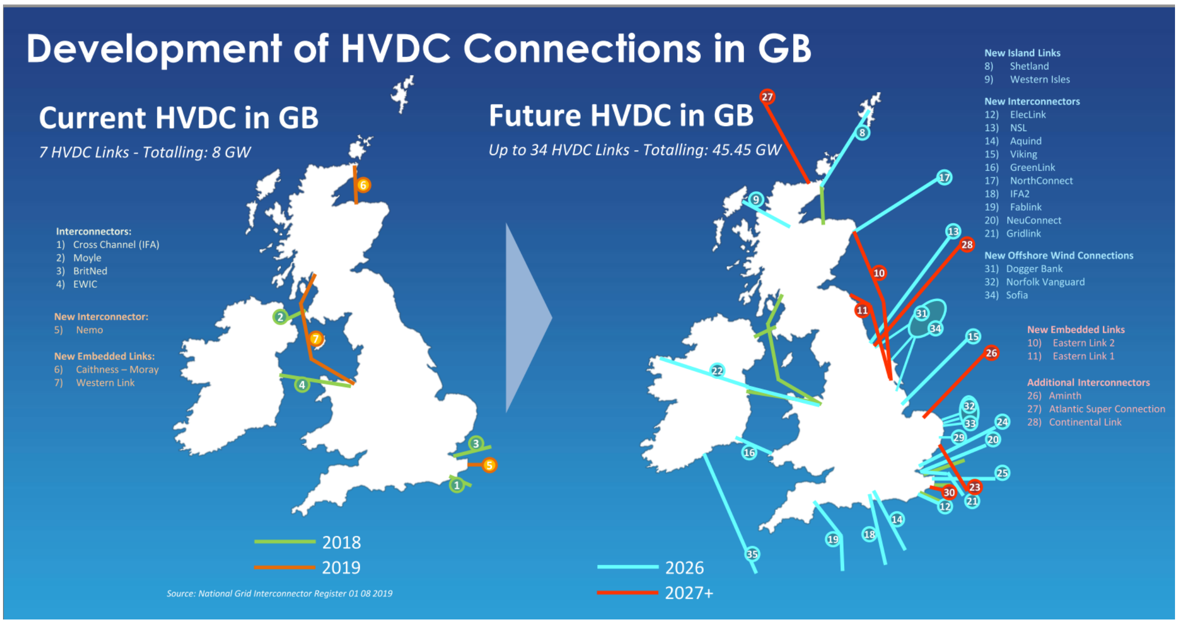


Figure 1-10 Estimated increase in high voltage direct current cables in British waters (source: The National HVDC Centre, 2021 and National Grid Interconnector Register 01 08 2019)

Tidal turbines, offshore wind farms and cables are all infrastructure related to electricity, which will become more prominent as we transition away from fossil fuels. These technologies have the potential to overlap and impact marine species and existing human activities (such as fisheries), as they have a footprint in the seabed as well as the water column. Throughout this thesis, the term ‘energy developments’ will be used to refer to both cable and renewable energy developments at sea. It does not refer to oil and gas developments.

1.3.3 Managing an increasingly crowded marine space

An increasing demand for ocean space can lead to increased competition between uses, which could lead to conflict (Ehler and Douvere, 2009; Jentoft and Knol, 2014; Pomeroy and Douvere, 2008). As a result, there is a need for multi-sector integrated management, considering ecological, economic, social and cultural needs. Consequently, a rise in demand for offshore renewable energy, as well as an increasingly crowded marine space, has in part triggered the development of numerous marine plans (Ehler, 2020; Ehler and Douvere, 2009; Jay, 2010; Johnson et al., 2016; Jones et al., 2013; Yates et al., 2018). Marine spatial planning is a method of organising the uses of marine space and interactions among them, and is perceived to be an ecosystem-based approach to marine management (Ehler, 2018; Ehler and Douvere, 2009; Katona et al., 2017).

Ecosystem-based management of marine space and resources acknowledges the complexity of ecosystems and aims to protect their structure, functions and processes. It integrates multiple perspectives (ecological, social, economic and institutional), taking a holistic approach that demands interdisciplinary knowledge. It is a spatially explicit management approach that is mindful of the need for decisions to take place at the appropriate scale (Delacámara et al., 2020; Ehler and Douvere, 2007; McLeod et al., 2005). The emergence of new uses of the ocean space requires decisions to be made around where they ought to take place. Approaching these decisions using an ecosystem-based management approach requires multiple objectives to be taken into account (Ehler and Douvere, 2009).

Siting novel marine energy developments from a marine spatial planning (ecosystem-based) perspective is different than approaching it from an engineering perspective, an economic, or an ecological perspective. Engineers will consider technical aspects such as the availability of the energy resource, suitability of the seabed substrate and proximity to existing cable infrastructure (e.g. Cavazzi and Dutton, 2016). For ecologists, the focus will lie on how the introduced structure will impact the ecosystem, which can be investigated via trophic web modelling (Alexander et al., 2016; Raoux et al., 2016). Economists might look at siting an energy development in terms of where is financially viable (Prässler and Schaechtele, 2012; Zaucha, 2019).

Marine spatial planning has to consider all of these approaches, which differ in their ontology, epistemology and theoretical perspective (Moon and Blackman, 2014). To combine these different perspectives in a holistic way, they can be considered as part of a social-ecological system. Social-ecological systems, according to the 'Resilience Dictionary' from the Stockholm Resilience Centre, are "*linked systems of people and nature*". This implies they are not seen as two separate entities that interact, but part of a holistic, unifying system (Berkes et al., 1998; Tett et al., 2013). Within this system, social and institutional aspects of resource allocation as well as engineering and environmental factors are taken into account (Martino et al., 2019).

Marine spatial planning of Scotland's Exclusive Economic Zone (EEZ), which extends up to 200 nm from the coast, is legislated through the Marine (Scotland) Act 2010 and the Marine and Coastal Access Act 2009 and is implemented through the National Marine Plan, published in 2015 (Scottish Government, 2015a). Scotland's National Marine Plan consists of a set of objectives and policies to enable an ecosystem approach to sustainable use and development in Scottish waters. The plan is enabled by the Marine (Scotland) Act for territorial waters (out to 12 nm) and by the UK Coastal Access Act for waters between 12-200 nm. The plan is compliant with the UK Marine Policy Statement. The Marine (Scotland) Act allows for the creation of Regional Marine Plans, which sit beneath the National Marine Plan. Unlike the national marine plan, regional marine plans are not a legal requirement under the Marine (Scotland) Act, but the Scottish Government have identified 11 Scottish Marine Regions which extend up to 12 nm from the Scottish coast, and if taken forward will be developed by Marine Planning Partnerships (Scottish Government, 2015b, 2010; UK Parliament, 1987).

There are several matters relevant to the National Marine Plan and the Regional Marine Plans that are reserved, meaning they are managed on a UK level and not devolved to Scotland. One such reserved matter is the generation, transmission, distribution and supply of electricity; however the planning of electricity infrastructure is devolved to Scottish Ministers. Moreover, approval from Scottish Ministers is required for the construction of new electricity infrastructure that generates more than 1 MW, under the Electricity Act 1989 (Torrance, 2019).

1.3.4 Marine spatial planning and a just energy transition

Scotland has committed to a just energy transition which puts "people, communities and places at the heart of our approach to climate change action" (Scottish Government, 2020a, p. 34). A change in society and economy as a result of transitioning towards net zero is inevitable, so the 'justness' of this change needs to be considered (Scottish Government, 2020a). One type of injustice mentioned in the report from the Just Transition Commission is the effect of decarbonising our energy system on electricity bills of households already suffering from fuel poverty (Just Transition Commission, 2021). To minimise this, mechanisms are in place to ensure investments in transmission infrastructure are cost-effective, through the regulator Ofgem (Ofgem, 2003). On the other hand, there is also the risk that introducing new developments in the marine space can lead to injustices for existing users of the sea, such as the loss of access to marine resources, social and cultural impacts of ocean development and exclusion from decision-making (Bennett et al., 2021a). Therefore, when planning for an expanding renewables and cables industry, sectors such as the fishing industry will need to be considered (Bennett, 2018; Hodgson et al., 2019).

Justice scholarship can provide a meaningful framework to evaluate the justness of the energy transition. Research on social justice, environmental justice, climate justice and energy justice have identified multiple dimensions of justice (Fraser, 2005, 1998; Jenkins et al., 2021, 2016; Rudolph et al., 2018; Walker, 2012). The following paragraphs gives a brief overview of how these dimensions have been defined.

Firstly, Nancy Fraser distinguished distributional from recognitional justice. Distributional justice relates to the fair distribution of impacts and benefits and can be regarded as the central tenet to social justice, but cannot be considered without acknowledging recognitional injustices (Fraser, 1998). Recognitional justice concerns the relative representation of groups in the decision-making process, and whether or not certain groups are underrepresented (Fraser, 1998; Rudolph et al., 2018). She later goes on to define a third dimension: representation justice, which concerns the inclusion of actors in the process of making decisions that will affect recognitional and distributional justice (Fraser, 2005).This has been defined as a dimension that includes procedural justice and cognitive justice (Blue et al., 2020).

Procedural justice is concerned with who is meaningfully involved in the decision-making process, and how different involved parties are included, not only by being physically engaged but through being represented with appropriate evidence in the process, such as with local knowledge (Haggett et al., 2020; Jenkins et al., 2016; Walker, 2012). Cognitive justice relates to how inclusive the process of generating meaning and knowledge is (Blue et al., 2020). Where procedural justice relates to tangible processes in place to facilitate participation, cognitive justice considers how justice is framed (Thew et al., 2020). This study will only consider procedural justice within this category but acknowledges that cognitive justice will also play a role in a just energy transition.

There is debate within energy justice scholarship on whether recognitional justice is separate from procedural justice, but for this study it is regarded as two distinct dimensions as in Jenkins et al., 2016, 2021. The distinction between procedural and recognitional justice is considered necessary for this study because it allows the consideration of underrepresentation of certain actors compared to others (Jenkins et al., 2021). Distributional, recognitional and procedural justice are considered the three core tenets to energy justice in Jenkins et al., 2016, which is defined as an emerging field which seeks to apply justice principles to the energy transition. A literature review by Jenkins et al., 2021 has found that the combination of considering distributional, procedural and recognitional dimensions was the most common theoretical approach found in studies. The definitions of the three types of justice used for this study as well as their sources are summarised in Table 1-2, and will be referred to throughout this thesis.

Table 1-2 Definitions of three justice aspects considered in this study

	Definition	**Sources**
Distributional justice	Fair distribution of impacts and benefits	Fraser, 1998; Walker, 2012
Procedural justice	Who is meaningfully involved in the decision-making process, either by being represented with appropriate data or by being physically present during decision-making	Haggett et al., 2020; Jenkins et al., 2016; Walker, 2012
Recognitional justice	Consideration of the potential underrepresentation of groups in the process	Fraser, 1998; Rudolph et al., 2018

For multi-objective decision-making, where conservation objectives are included to protect marine species, and economic objectives ensure economic viability, objectives that consider potential impacts to other users of the sea can be perceived to be objectives that ensure the 'justness' of an energy transition in the context of siting novel developments at sea. Therefore, marine spatial planning is an instrument that can aid in facilitating a just energy transition (Haggett et al., 2020).

1.3.5 The siting process

In this section, different interpretations of 'optimal siting' are discussed. Then, an overview is given of different stages of the siting process, including strategic macro-siting, site selection and project-level micro-siting. For the macro-siting stage, the sectoral marine planning process in Scotland is described.

The process that leads to the eventual allocation of a site for new energy infrastructure consists of complex interactions between individuals and groups, and has been termed 'the siting problem' (Keeney, 1980). This is referred to here as the siting process. The desired outcome of the siting process could be defined as finding the optimal location. The 'optimality' of finding that location (the decision process) can be analysed in two different ways. Firstly, the siting process can be considered optimal if it leads to the best location (Janssen, 1992; Simon, 1976). However, it is impossible to determine retrospectively whether the selected location was the best option compared to alternatives, when a multitude of factors informed the site selection (Edwards et al., 1984). The second way of regarding the optimality of a decision is whether the procedure used to reach it was optimal, i.e. the optimal consideration of the multiple objectives (Janssen, 1992; Simon, 1976). 'Optimality' can be interpreted in different ways. Optimal consideration of the objectives will be defined differently for different objectives. For conservation objectives, an optimal decision process could be one that ensures a net gain of biodiversity value in the area (e.g. SSEN Transmission, 2019). For economic incentives the siting process would have to ensure the chosen location is cost effective.

These different interpretations of optimal locations are measured in different ways. For example, a cost-benefit analysis can compare costs and benefits to different actors in monetary terms (Martino et al., 2019; SHEPD, 2019). To account for effects on ecosystem services, an ecosystem services trade-off analysis can be done by quantifying units of a suite of ecosystem services, using optimisation software such as MARXAN, by defining objective functions (Egli et al., 2017; Göke et al., 2018; White et al., 2012). Effects on species of siting a development in different locations can be modelled using trophic web modelling (Raoux et al., 2017). However, 'optimal siting' in the context of the need for a just energy transition requires a different approach than using monetary comparisons, ecosystem services or ecological modelling.

A study on the siting of nuclear waste argues that spatial implications of procedural justice, which will inherently influence distributive and recognitional justice as well, are understudied (Bell, 2021), and they have not been explicitly explored before in the context of siting energy developments at sea. This PhD thesis seeks to understand how spatial multi-objective decision support can facilitate a just energy transition.

Figure 1-11 Overview siting process

At present, the location of a renewable energy development at sea is not determined by a single decision; it will be embedded in a nested iterative process that starts with macro-siting and integrates further refinements at the micro-siting stage (Figure 1-11, Table 1-3). Macro-siting is where potential locations are reviewed at a strategic level, normally led by government, from which a set of suitable smaller-scale areas or sites (called plan options in Scotland) are identified. In Scotland, plan options (see Figure 1-7) are identified through the 'sectoral marine planning' process. Scotland's sectoral marine plans are designed to align with the objectives and policies of Scotland's National Marine Plan and wider Scottish Government policies (Scottish Government, 2020b).

Table 1-3 Overview of macro-siting, site selection and micro-siting for offshore energy developments (adapted from Kapetsky & Aguilar-Manjarrez, 2013)

	Macro-siting	**Site selection**	**Micro-siting**
Scale	Strategic (e.g. Scottish EEZ: 462 315 km^2)	Strategic (average area plan options: 854 km^2)	Local (example offshore wind farm area size: 131 km^2)
Purpose	Identify suitable option areas for commercial renewable energy development	Select an area (plan option) for an individual energy development with minimal consenting risk	Refine the assigned area and determine the specific layout
Executing entity	Governing authorities (usually)	Developer	Developer
Required resolution of data	Medium (kilometres)	High (100s of metres)	Very high (metres)
Results obtained	Distinct areas within which developers can select a site	Area selected for individual energy development (plan option)	Specific location and layout of the installation within the plan option

The scale of macro-siting is strategic, which can be on a supra-national, national or regional level (e.g. North Sea scale, Scottish scale, or Shetland scale). Siting at a strategic scale refers to long-term or overarching decisions, as opposed to operational decisions which are more short-term or localised in nature and relate to the site selection and micro-siting stages (Juneja, 2022; MSPglobal, 2021). Strategic siting is generally broad in scale and provides an overarching plan for a marine area, and there is great variation between different strategic scales. For example, the Scottish EEZ is 462 315 km^2 for national planning, whilst the average area of Scotland's Marine Regions, for strategic planning on a regional (subnational) scale, is 8 076 km^2 (Marine Scotland Information, 2021). There is also variation between nations, for example in comparison the Belgian EEZ is 3 454 km^2 (FPS Public Health, 2016).

The delineation of the plan options considers technical, environmental, industrial and socio-cultural features known to occur in Scottish waters. A steering group comprising of a diverse range of interested parties participated in the iterative process of narrowing down initial areas of search into discrete plan options, within which developers can apply for a lease from Crown Estate Scotland. In response to recent debates (e.g. Delaney, 2021), the term interested parties will be used instead of the term stakeholder. Throughout this thesis, interested parties refer to government agencies, representative bodies (such as associations), industries and individuals.

After strategic macro-siting, site selection is where a site is selected by a developer for an individual energy project within the designated plan options. Micro-siting is when the specific layout of the infrastructure is determined and the selected area is refined in an iterative process in consultation with interested parties (FLOWW, 2014). For this, more detailed local data is collected (Scottish Power Renewables, 2010). The average area size of the 15 identified plan options is 854 km^2 (Scottish Government, 2020b), whilst as an example, the size of the operational wind farm in the Moray Firth (Beatrice) is 131 km^2.

By splitting up the siting process into different stages, the complex nature of the problem with multiple scales and governance mechanisms is recognised in a nested, multi-tier approach as suggested by Ostrom, 2007 and Tweddle, Marengo, Gray, Kelly, & Shucksmith, 2014. It is important to keep in mind that the classification used in Table 1-3 may not be applicable to all consenting regimes, as some nations may allocate a developer to a site rather than having the developer select a site, such as in the Netherlands (CMS Legal Services, 2018). But, since the focus of this study is the Scottish consenting regime this classification will be used.

For subsea cables, which are necessary to transport energy from renewable energy generation areas to the consumer, the siting process starts with a cable route study, which investigates and proposes a route corridor. Through an iterative process based on desk analysis and data collection, this route corridor is refined and adjusted until specific locations have been decided upon, in consultation with interested parties (Det Norske Veritas AS, 2014, Figure 1-12).

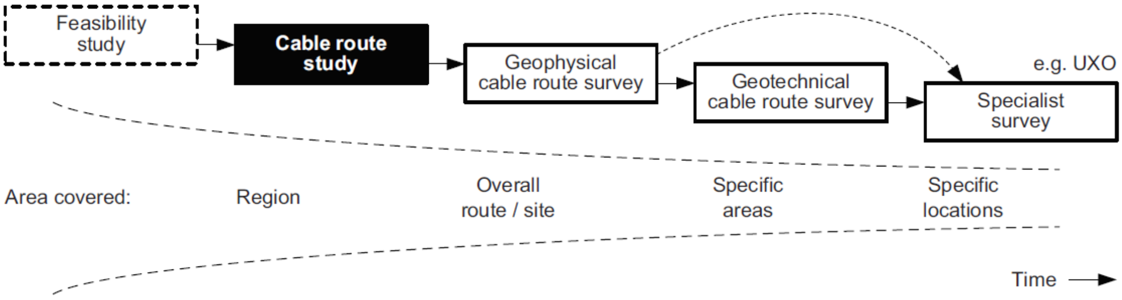


Figure 1-12 Schematic diagram of the cable routing process (Figure source: DNV-RP-0360 March 2016 edition, amended Oct 2021 - Figure 3-5 Methodical approach to studying a cable route (© DNV AS, 2021) DNV does not take responsibility for any consequences arising from the use of this content.)

1.3.6 The licensing process

This section starts with a brief overview of leases, licences and consents required before a developer can start construction. This is followed by an introduction to the process by which a development's environmental effects are assessed, the 'environmental impact assessment' (EIA) process. The different stages of the EIA process are described in detail.

The leasing of the seabed by the Crown Estate Scotland, such as for the latest ScotWind leasing round, has to comply with the National Marine Plan and with the spatial measures outlined in the sectoral marine plan (Crown Estate Scotland, 2020). A seabed lease is a contract between the developer and Crown Estate Scotland, valid for a specified number of years (e.g. 60), which is required before a developer can construct and operate renewable energy infrastructure. In return for the lease, the developer pays an agreed rent to Crown Estate Scotland (Crown Estate Scotland, 2020; Kafas, 2018a). For subsea cables, a lease is only required within 12 nm of the coast (Crown Estate Scotland, 2021b).

Developers holding a lease must also be granted a Marine Licence under the Marine (Scotland) Act before operations can start. To obtain a licence, the developer must demonstrate the project specifications adhere to the planning policies of Scotland's National Marine Plan (Scottish Government, 2018). For generating stations greater than 1 MW, a consent is also required under the Electricity Act (see Table 1-4). Licensing and consenting in Scotland takes a one-stop-shop approach where Marine Scotland's Licensing Operations Team (MS-LOT) act on behalf of Scottish Ministers and are responsible for granting both licences and consents (Scottish Government, 2018).

As per the Environmental Impact Assessment (EIA) Directive of 2014, projects falling under the category of Annex II (including transmission cables, the harnessing of wind power and hydroelectric energy production[1]) are subject to member state legislation regarding whether or not an EIA should be included in the consent application (European Commission, 2014). Table 1-4 summarises how the legislation in place sets out requirements necessary before a project can start.

Table 1-4 Licence, consent and EIA requirements for the different projects considered (EIA: Environmental Impact Assessment)

	Marine (Scotland) Act 2010 (within 12 nm)	**UK Marine and Coastal Access Act 2009 (out with 12 nm)**	**Environmental Impact Assessment (EIA) Directive EU (85/337/EEC)**	**Section 36 of the UK Electricity Act 2004**
Cable projects	• Licence required • Pre-application consultation (PAC) required • Need to adhere to national/regional planning policy	• Licence required for cable protection measures only (buried cables do not require a licence) • Adhere to national planning policy	No formal EIA required for subsea cables*	No consent required
Offshore renewable energy projects	• Licence required • Pre-application consultation required • Need to adhere to national/regional planning policy	• Licence required • Adhere to national planning policy	Formal EIA required for generating stations > 1 megawatt	Consent required for generating stations > 1 megawatt

* Even though no formal EIA is required for cable projects, most developers conduct a voluntary environmental appraisal (EA), which becomes binding through the licence

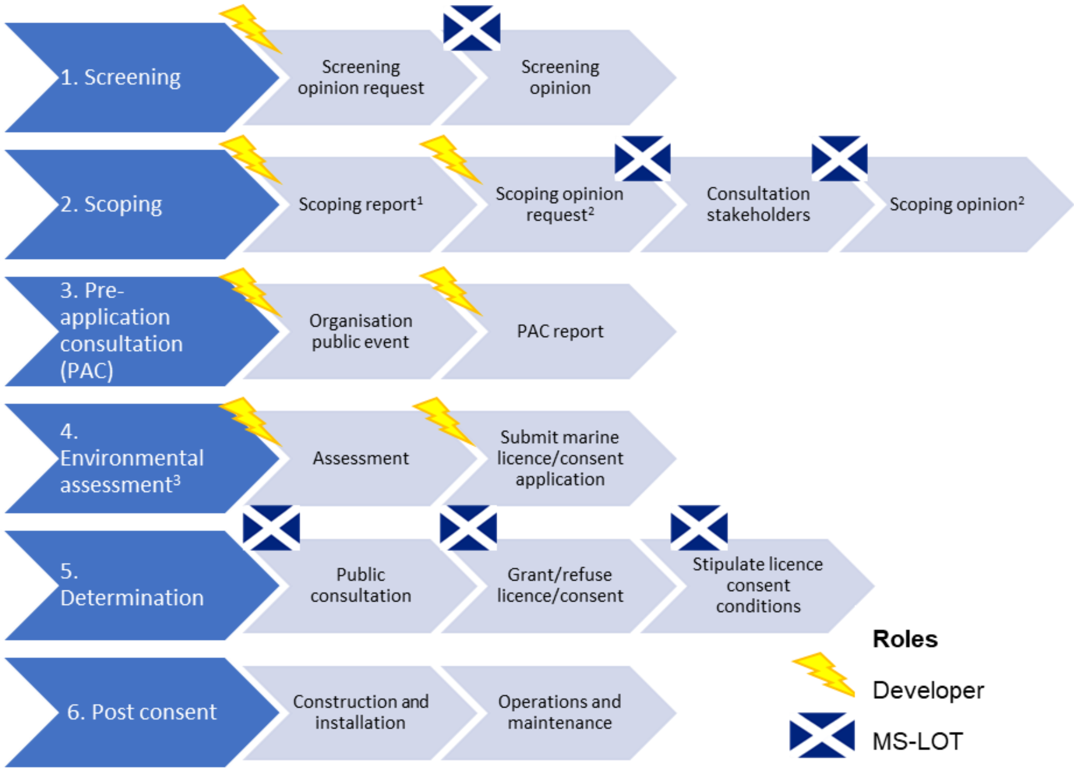
[1] Submarine electricity cables (cables that carry electricity from the substation to the consumer) do not fall under either Annex 1 or Annex 2. Transmission cables move electricity from a power plant to the substation and fall under Annex 2 (https://circuitglobe.com/difference-between-transmission-and-distribution-line.html)

An environmental impact assessment (EIA) is a process designed to examine and predict possible environmental effects of implementing a project, including socio-economic impacts (Glasson et al., 1999). In the UK it is documented in an 'Environmental Statement' (ES) which consists of different chapters, including a chapter on site selection. Impacts on other sectors would normally be included, and where relevant a chapter on the prediction of impacts on commercial fisheries would be expected. Even though siting decisions have been made prior to the EIA, siting is an iterative process so further refinements will be made during the EIA, for the micro-siting stage. These siting decisions will have to be justified in the ES. The impact assessment will predict impacts on various receptors of placing the development at a certain site. Even so, the site is usually described in broad terms to allow small-scale spatial adjustments to be made at a later stage, which is part of an approach called the 'Rochdale Envelope' (Wright, 2014a). Therefore, the siting of a development and the impact assessment of a development are two processes that happen simultaneously and should be considered together.

For cables which are found within territorial waters (within 12 nm from the coast) and renewable energy projects, under the Marine (Scotland) Act 2010, the installation and operation of subsea cables require a pre-application consultation (PAC). Pre-application consultation is the requirement of the developer to consult the public before submitting an application. This involves holding at least one public event where interested parties can comment on the proposed development. The ensuing report should summarise this public event and include any amendments to the design or location of the prospective development made based on the feedback received, or justify why some suggestions were not adopted (Marine Scotland, 2013).

Some transmission cables extend outside territorial waters, where a marine licence must be sought under the 2009 UK Marine and Coastal Access Act. Outside of territorial waters no licence is required for laying a power cable unless additional protection such as rock placement is needed (UK Government, 2009). As stipulated in Table 1-4, offshore renewable energy projects that generate more than 1 megawatt require a formal EIA (Environmental Impact Assessment) and a consent under Section 36 of the UK Electricity Act 2004.

Even though a formal EIA is not required for cable projects, Marine Scotland guidance states applicants should still consider the need for a "proportionate environmental assessment” (Marine Scotland, 2015). This can take the form of an “environmental appraisal” (EA) for transmission cable projects or an “environmental supporting information” (ESI) for the inter-isle cables. These environmental studies are subject to different regulations than an environmental impact assessment. Throughout this study, ‘environmental assessments’ will be the overarching term used to refer to EIAs, EAs and ESIs. Figure 1-13 gives an overview of the marine licence/consent process for renewable energy and cable developments.



[1] For studies not requiring an EIA, this may be called “Report identifying additional studies required”
[2] For studies not requiring an EIA, the equivalent of a scoping opinion may be called “Opinion on report identifying additional studies required”
[3] This may be a formal environmental impact assessment, an environmental appraisal, or environmental supporting information

Figure 1-13 Overview of the licensing/consenting process for offshore renewable and cable developments (not including the leasing process)

At the screening stage, the screening opinion from the licensing authorities will dictate whether or not an EIA is needed for generating stations smaller than 1 megawatt (Scottish Government, 2014a). During the scoping stage, developers will communicate which potential significant impacts should be considered in the assessment, and how, in a scoping report. This report is examined by the licensing authority, who will also consult relevant parties. Their feedback is published in a scoping opinion (or equivalent) (Scottish Government, 2018), see Figure 1-13. The scoping and pre-application consultation help to inform the environmental assessment, which can take between 2-5 years to conduct (Enablers Task Force, 2015). Once completed, the licensing authority (MS-LOT) and relevant parties assess the conclusions of the environmental assessment in the environmental statement. A licence/consent can be granted, or remaining objections can result in refusal, cancellation or delay of a project. At the post-consent phase, assuming the developer was granted a licence/consent as well as a lease, the project moves on to the construction and installation phase and then the operations and maintenance phase. The decommissioning phase and associated requirements are not within the scope of this study.

The different stages of the siting process outlined in Table 1-3 are not independent from the impact assessment process, and the two can feed into each other in both directions – for example spatial data that is important for micro-siting can inform environmental assessment. To date, the planning discourse has been focusing on spatial decision support at a strategic level (macro-siting), while planning at the EIA/micro-siting level has received little attention in this context, and has not been explored in detail so far (Arts et al., 2012; Jentoft and Knol, 2014; Power and Cowell, 2012; Smart et al., 2014). Therefore, this thesis addresses a gap in examining decision support during the siting process at both the strategic level and the project level.

1.4 Spatial multi-criteria decision analysis (MCDA) review

This section examines the role of multi-criteria decision support analysis (MCDA) in decision-making and presents the results of a pilot study which reviewed a set of existing MCDA tools that aim to inform multi-objective siting. Conclusions drawn from this pilot study informed the research questions to be addressed by subsequent chapters.

Multi-objective decision support is an approach that can integrate multiple interests when choices need to be made on where to site a novel development. It takes into consideration that a decision may need to satisfy more than one objective (Eastman et al., 1995). The aim of multi-objective decision support is to translate data into evidence that can be used to inform the decision problem (i.e. where to site a development) (Janssen, 1992). Figure 1-14 depicts the process of data being transformed into information that can serve as evidence. For decision support, the ‘knowledge’ stage could be seen as the decision-making stage. (Dammann, 2019; Dammann and Smart, 2019)

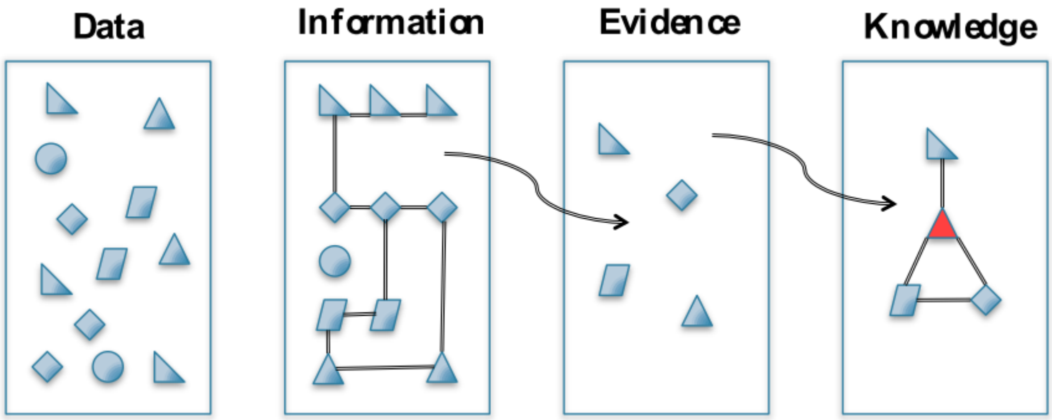


Figure 1-14 The difference between data, information, evidence and knowledge (source: Cahill et al., 2016, which was adapted from Ackoff's Knowledge Hierarchy)

To assist decision makers for the macro-siting, site selection and micro-siting stages in siting novel developments at sea such as renewable energy technologies, spatial multi-criteria decision analysis (MCDA) can be adopted as a decision support technique. Spatial MCDA is where a set of alternatives (e.g. different locations) are evaluated using a series of suitability criteria which are combined to form an overall suitability map (Keeney, 1992; Malczewski and Rinner, 2015). Two types of suitability mapping can be distinguished to assist blue growth aspirations: resource mapping to identify technical feasibility (e.g. BVG Associates, 2017; Weiss et al., 2018; Xu et al., 2020), and constraint mapping, which has the added aim of avoiding impacts on existing users and marine species in the area, often in a marine planning context, which will be the type of suitability mapping this PhD thesis will focus on (such as Davies et al., 2014; Tweddle et al., 2014). The consideration of marine species, as well as existing users and socio-cultural values, can allow MCDA to function as a tool to facilitate a just energy transition, for instance when siting novel renewable energy or cable developments in the marine environment.

Multi-criteria decision analysis allows large amounts of data to be summarised into a single suitability or constraint map, and advancements in technologies allow complex analyses to be used to inform decisions. There are different ways of combining data layers to present a single output map. A substantial array of tools to assist decision makers in siting offshore energy developments has already been developed, so it will be necessary to place the proposed approach in this context.

Therefore, this pilot study will review a selection of existing tools using a set of indicators, to understand how optimal siting is currently interpreted.

1.4.1 Methods

A selection of studies following a literature review in 2019 led to a set of 15 case studies (Table 1-7). This review could be typified as a narrative review with a convenience sample, as the search was not done systematically – rather a snowball sampling approach, where one study led to the discovery of another (Greenhalgh and Peacock, 2005; Sovacool et al., 2018). The reason for this unstructured approach is that it was found multi-criteria decision tools were used in academic papers but also in government reports and conference proceedings. Moreover, tools which used an optimisation routine (e.g. using MARXAN) to combine different layers of information did not refer to this approach as multi-criteria decision support, so the use of search terms was found to be of limited value. More systematic reviews on the use of decision support for marine spatial planning and for siting offshore wind (Coleman et al., 2011; Peters et al., 2020; Pınarbaşı et al., 2017; Stelzenmüller et al., 2013), terrestrial applications of spatial decision support (e.g. (Egli et al., 2017; Malczewski and Rinner, 2015; Roel et al., 2018) and non-spatial decision support literature (e.g. (Beinat, 1997; Janssen, 1992; Keeney, 1992) have also informed the formulation of research questions throughout this thesis.

To understand which types of evidence are considered in the spatial decision support tools, the included criteria layers were split up into themes. Each theme represents an objective, so that the inclusion of multiple objectives in the tools can be analysed. The themes used for this study were based on an existing set of themes used by Marine Scotland in their sectoral marine planning process: technical, industrial, environmental and socio-cultural themes (Marine Scotland Science, 2018, Table 1-5).

Table 1-5 Description of themes used to distinguish different criteria used in case studies (based on Marine Scotland Science, 2018)

Theme	Description
Technical	Criteria related to technical factors constraining a development such as bathymetry or distance from the coast
Industrial	Criteria related to the consideration of other industries such as fisheries and shipping
Environmental	Ecological features such as protected areas or the presence of important species
Socio-cultural	The consideration of recreational use or other non-monetary social/cultural values, for example national scenic areas

Existing research has pointed out gaps in marine spatial decision support, summarised in the form of five indicators in Table 1-6. The case studies (excluding the micro-siting tools) are analysed with the indicators to understand how they relate to the knowledge gaps. The micro-siting tools were not included in this analysis because the only micro-siting tools found during the review incorporated technical engineering variables only, therefore they were not designed to adhere to the indicators described in Table 1-6.

Table 1-6 Indicators that represent research gaps in marine spatial decision support

Theme	#	Indicator
Considering uncertainty	**1**	Incorporating uncertainty/risk
Engagement interested parties	**2**	Involvement of interested parties during process
	3	Could interested parties give feedback at data collation stage?
Spatial indicators	**4**	Considers spatial heterogeneity of values?
Socio-economic indicators	**5**	Considers socio-economic values?

1.4.2 Results and discussion

The socio-cultural theme is least represented in the case studies (7/15) (Table 1-7). This may be due to a lack of social data available, and uncertainty as to how socio-cultural data should be collected, analysed and presented (Copping, 2019). The most populated themes are the technical and environmental themes. With this imbalance, there is a risk that multi-objective decision-making is not considering the justness of the energy transition, which will depend on the inclusion of socio-economic and cultural values in the decision-making process. Moreover, the tools used for micro-siting only consider technical constraints (Table 1-7). The lack of consideration of the micro-siting case studies for environmental, industrial and socio-cultural needs could be explained in two ways. Firstly, it depends on the consenting regime – the scale at which a developer has 'room to move around' after a site was selected depends on the size of the leased area, which also may depend on the price per km^2 of leasing an area (Crown Estate Scotland, 2018). Secondly, it may be difficult to find micro-siting case studies that include other objectives in the academic field because the role of EIA in spatial planning is an understudied area of research (Smart et al., 2014).

Table 1-7 Overview of constraint layers included in 15 case studies focusing on the macro-siting, site selection and micro-siting stages, organised per theme (Environmental, Industrial, Socio-cultural and Technical)

Stage in the siting process	Governance level	Case study	Environmental	Industrial	Socio-cultural	Technical
Macro-siting	Supranational	Schillings et al. 2012	x	x		x
		Göke, Dahl, and Mohn 2018	x	x	x	x
	National	Marine Scotland Science 2018	x	x	x	x
	Regional	Magar, Gross, and González-García 2018	x	x		x
		Tweddle et al. 2014	x	x	x	
		White, Halpern, and Kappel 2012	x	x		x
		Ferguson and Cousineau 2018	x	x	x	x
		K. L. Yates, Schoeman, and Klein 2015	x	x		
		Grilli, Insua, and Spaulding 2013	x	x		x
Site selection	National	Chaouachi, Covrig, and Ardelean 2017	x		x	x
		Mytilinou, Lozano-Minguez, and Kolios 2018				x
		D. F. Jones and Wall 2016	x	x	x	x
	Regional	BOEM 2013	x	x	x	x
Micro-siting	Project level	Grilli et al. 2012				x
		Réthoré et al. 2014				x

Table 1-8 Gap analysis of existing approaches according to five indicators. Dark green (score =3) means the model scores well according to the indicator, light green (2) means partially and blank (1) means it hasn't considered that indicator.

Indicator	#1	#2	#3	#4	#5	References
Case study method						
Constraint mapping						(Marine Scotland Science, 2018)
Constraint mapping						(Schillings et al., 2012)
MARXAN						(Göke et al., 2018)
Bio-economic model						(White et al., 2012)
Constraint mapping						(Tweddle et al., 2014)
Constraint mapping						(Ferguson and Cousineau, 2018)
Ocean zoning						(Yates et al., 2015)
Windfarm siting index						(Grilli et al., 2013)
Resource assessment						(Magar et al., 2018)
Bayesian Analysis						(BOEM, 2013)
Multi-criteria siting						(Chaouachi et al., 2017)
Multi-objective						(Mytilinou et al., 2018)
Goal programming						(Jones and Wall, 2016)
Score	21	26	27	20	23	

Table 1-8 shows that spatial decision support for marine renewable energy developments is already a very advanced field, but that each tool has its limitations. The indicator that scored the lowest is the incorporation of uncertainty (#1). Even though the reviewed case studies all aim to reduce uncertainty in decision-making by providing decision support, 7/13 of the case studies did not mention uncertainty or how it was dealt with, which echoes findings of a previous study that conclude uncertainty is not always explicitly incorporated or mentioned in decision support (Milner-Gulland and Shea, 2017). For example, data quality is seldom addressed in GIS analyses (Green and Ray, 2002). Ignoring uncertainty can hinder effective decision-making (Milner-Gulland and Shea, 2017). Different types of uncertainty have different repercussions. For example, decision-making uncertainty "arises whenever there is ambiguity or controversy about how to quantify or compare social objectives" (Finkel, 1990) and can lead to delayed actions or highly risky or overly conservative decisions (Frederick et al., 1995; Rose and Cowan, 2003).

Decision-making uncertainty depends on how well the decision alternatives are communicated, and how clearly the different objectives are defined (Ascough et al., 2008; Milner-Gulland and Shea, 2017). It also depends on uncertainty related to the data used in the decision support tool, e.g. its precision or accuracy. When uncertainty of input data is not considered in subsequent data processing steps it can lead to the propagation of error (Chen et al., 2011). The way the data is collated also brings with it an inherent form of uncertainty in the form of decision rule uncertainty. Decision rule uncertainty refers to how input data can be translated into suitability values in different ways, e.g. how it is used to render alternatives either suitable or unsuitable, or something in between (Eastman, 2015). The degree to which uncertainty is recognised and taken into account during marine spatial planning varies (Collie et al., 2013; Stelzenmüller et al., 2015), and Maxim & van der Sluijs, 2011 highlight that especially qualitative aspects of uncertainty are not well considered in decision-making. This PhD will evaluate ways in which qualitative elements of uncertainty, such as decision-making and decision rule uncertainty, can be made more explicit in the siting process.

Overall, the engagement indicators (#2-3) scored well, so there are a lot of existing approaches to involve interested parties. Parties can be involved by being consulted on during the various stages of the process, and by being given the opportunity to verify datasets that are being used to make a decision (Shucksmith et al., 2014), facilitating procedural justice. However, despite efforts to consult interested parties, spatial decision support tools have been perceived to be a 'black box', highlighting a lack of transparency which is needed for participation by interested parties (Janßen et al., 2019; Rydin et al., 2018a). Chapter 2 of this PhD aims to address this by making the process more transparent with a step-by-step framework.

With regards to spatial theory on multi-objective decision support, when interests such as recreational use are incorporated in a model to inform siting of energy developments, they can be valued in a certain way. The way existing uses are valued may depend on local context and could be spatially heterogenous on a national scale. This can be considered by including a spatially variable method of valuing the various marine interests (Malczewski, 2011). Finally, as apparent in Table 1-8 as well as Table 1-7, socio-economic data is not always available or considered in decision-making.

There is no case study that adequately addresses all five indicators that represent current industry challenges, and this PhD thesis will aim to address these challenges throughout the different chapters. The limited number of tools identified at the project level indicate that planning discourse focuses mostly on siting at a strategic scale, and the licensing stage is overlooked and left to the responsibility of developers. Yet the licensing stage ultimately determines the success and acceptance of a project, so studying project-level case studies can inform knowledge gaps at a strategic scale. One of the challenges is the incorporation of socio-economic data in decision-making. An EIA review conducted for Chapter 3 will inform which socio-economic data is necessary to include in spatial decision support, with a focus on data characterising the fishing industry. Together, these studies should contribute to a better-informed siting of marine renewable energy developments, so that a more efficient and less costly licensing process can be realised with increased buy-in from involved parties, facilitating a just energy transition.

2 Applying value-focused thinking to decision support tools for siting offshore renewables

2.1 Aim of chapter

As outlined in Chapter 1, one of the dimensions of a just energy transition is procedural justice. Procedural justice can be hampered by decision-making processes that are not accessible to all interested parties (Jenkins et al., 2016; Slater et al., 2020), otherwise known as ‘black box’ situations (Janßen et al., 2019; Rydin et al., 2018a). This chapter presents a framework to increase the transparency of marine spatial decision support tools.

2.2 Background

Even though there is an increased availability of marine data that can support decision-making (Martín Míguez et al., 2019), the literature points to a gap between scientific outputs and decision needs, indicating necessary information may not be in the right format (Bolman et al., 2018; Janssen et al., 2013). The complexities associated with the interface between science and policy have been widely documented (van Enst, 2018 and references therein). Scientific outputs need to be translated into information, but can be interpreted in different ways when utilising this information to inform decision-making with tools (Cash et al., 2003), and this has been highlighted as a source of uncertainty (Maxim and van der Sluijs, 2011). A more explicit link is needed between the decision problem, input data, the decision-making process (where tools can be used) and decision outcomes, to assist in the interface between scientists and decision makers (such as policymakers), Figure 2-1. This can help progress an understanding of how policy is represented in spatial decision-making, similar to how for ecosystem services a framework has been developed to understand how ecosystem services are represented in siting decisions for marine protected areas (Potts et al., 2014).

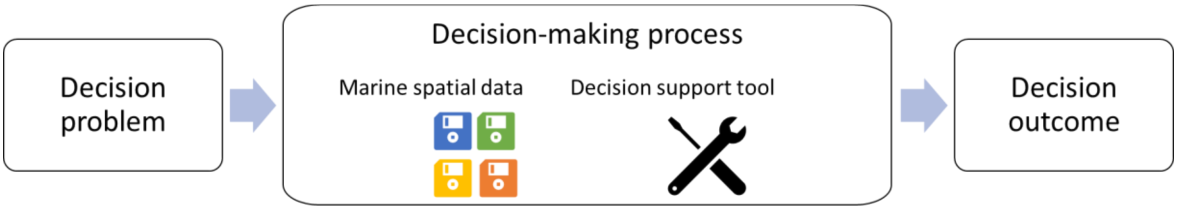


Figure 2-1 Diagram to illustrate how marine spatial data and decision support tools assist the decision-making process

Identified limitations to current marine spatial decision support include tools being perceived to be a “black box” (see Collie et al., 2013; Janßen et al., 2019; Trouillet, 2019) and the subjectiveness of mapping (Avila et al., 2021; Smith and Brennan, 2012; Tolvanen et al., 2019). For spatial decision support in general, the decision tool outcome, or ‘suitability map’, depends on the mapping method used (Lecours, 2017). The way in which information is presented cartographically is a subjective process and may influence how it is interpreted (Kitchin and Dodge, 2007; Shucksmith and Kelly, 2014). Lecours argues that this subjectivity can be made explicit by communicating which data is used, what its underlying uncertainties are, as well as providing a transparent workflow as to how it is included in the process (Lecours, 2017).

To address these potential shortcomings (subjectiveness of mapping not considered, black box issues) in decision support tools, this study introduces a procedural framework that makes the link between decision makers’ needs and site suitability tools explicit. The transferable and transparent workflow framework elicits user inputs at each step of the process. This provides increased transparency as to how existing marine users are represented within the decision support tool. As the timeline between initial site search studies at a strategic level and the eventual licence application by a developer can take over five years (Enablers Task Force, 2015), this framework allows decisions during the siting process to be documented, to facilitate continuity and transparency.

This study focuses on spatial multi-criteria decision analysis (MCDA) as a decision support tool, which assists in the evaluation of spatial alternatives (locations) a decision maker needs to choose between using criteria, as introduced in Section 1.4, and illustrated by steps 2-5 in Figure 2-2. Alternatives are the available options the decision maker must decide between (indicated with grid cells *a-i* in Figure 2-2). For conventional MCDA methods, the starting point is the alternatives that are available to the decision maker (alternative-focused thinking), but this approach assumes that all the relevant alternatives have already been identified, which could constrain the decision maker in making effective decisions, as some suitable alternatives may have been overlooked (Keeney, 1992). Bolman et al., 2018 argue there is a lack of consideration of the implications of the initial problem formulation phase of decision support tools. Therefore, the starting point of the proposed framework here is value-focused thinking (Keeney, 1992), which places emphasis on the initial phase of formulating objectives based on the values that play a role in the decision problem (Keeney, 1992) (indicated with the first step – objectives – in Figure 2-2).

A clear definition of the objectives is a requirement for effective decision support (Keeney, 2008). Multi-objective decision-making can be used to adapt an ecosystem-based approach to the siting process, and “balancing ecological, economic and social goals and objectives towards sustainable development” is a defining characteristic of effective marine spatial planning (Ehler and Douvere, 2009, p. 18). Objectives can be explicitly defined to ensure that future developments are economically viable, ecologically acceptable and socially just, a trichotomy known as the ‘triple bottom line’ (Halpern et al., 2013).

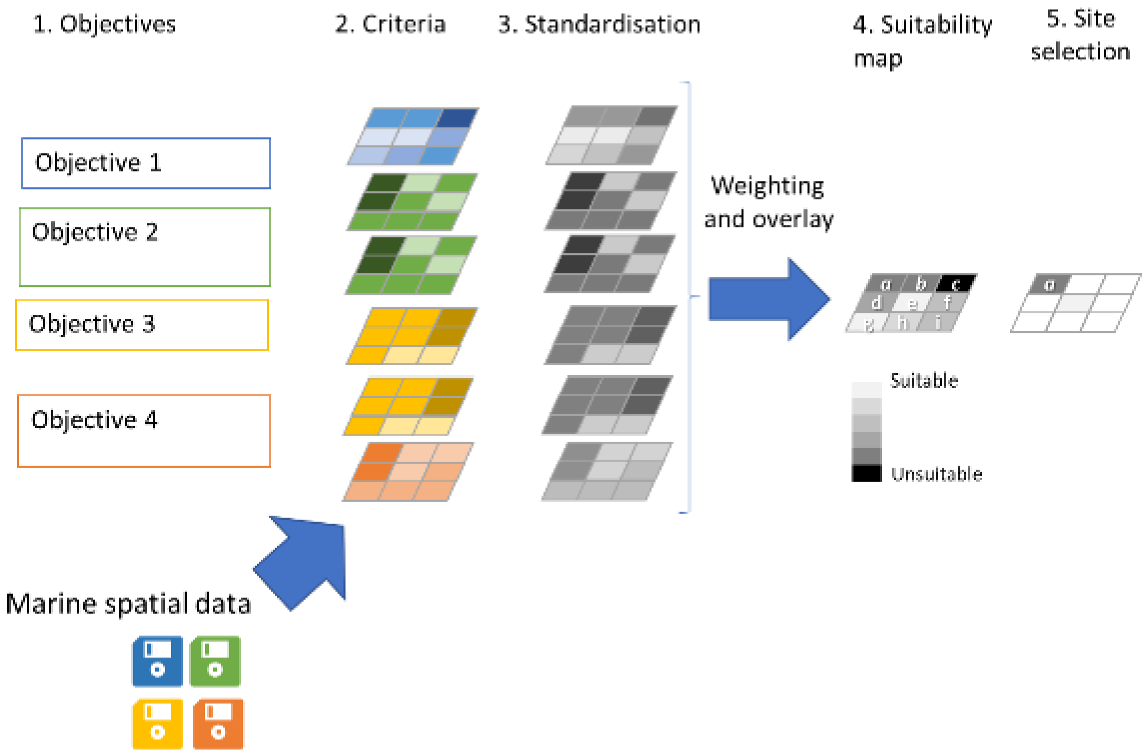


Figure 2-2 Overview of multi-criteria decision analysis steps: from the objective formulation step through to site selection. Alternatives a-I are indicated in step 4 are the alternative choices considered in the decision

The objective formulation step is followed by the step to identify criteria that can be used to compare alternative locations (step 2). Criteria, which can be derived from data, are then used to inform the achievement of objectives for each alternative (Keeney, 1992). The way decision support tools can inform a decision problem depends on how the objectives are defined, and how data is used to inform these objectives, in other words how criteria layers are constructed using the objectives from step 1 and marine spatial data (arrow feeding into the criteria step in Figure 2-2). The third step of standardising criteria layers will then also influence how criteria values are translated into suitability values.

Subsequent steps of tool development, such as weighting of the layers and overlay methods, are not addressed in this chapter because they have already received substantive research attention to date, e.g. sensitivity analyses of using different weights (Davies et al., 2014; Tweddle et al., 2014), involvement of interested parties in the weighting of the layers using the analytic hierarchy process (Abramic et al., 2021; Gregg, 2015; Roel et al., 2018; Saaty, 1980; Tuda et al., 2014), or innovative overlay methods such as multi-objective optimisation (Fox et al., 2019; White et al., 2012).

To develop the framework, value-focused thinking is combined with theories and approaches derived from existing decision support tools and decision support literature in both marine and non-marine contexts, including operational research. The framework consists of three steps (1-3 in Figure 2-2). The tool used to inform strategic siting of offshore wind energy in Scotland, called the "Opportunity and Constraint (O&C) Analysis" (Marine Scotland Science, 2018; Scottish Government, 2020b), was used as a starting point for the framework development, as it was the focus of a placement by the author at Marine Scotland Science in autumn 2019. The O&C tool was then analysed using the framework developed here, to gauge the utility of the framework. The framework was also applied to a spatial dataset on seabird distribution as a second case study, to understand how it can help improve transparency on how data is used in decision-making.

2.2.1 Opportunity and Constraint (O&C) Analysis tool Marine Scotland

In Scotland, siting of offshore wind energy is steered by the sectoral marine planning process (Scottish Government, 2014b). The 'Sectoral marine plan for offshore wind energy' (Scottish Government, 2020b) was informed by an "Opportunity and Constraint Analysis" tool (from here on referred to as the O&C tool). The method of the tool was based on the MaRS (Marine Resource System) tool developed by The Crown Estate UK, which was used to consider constraints informed by policy measures during siting of new developments (Moore and Moore, 2015). The tool grouped more than 20 different layers into technical, environmental, industrial and socio-cultural themes according to data type and user of the sea, and the four themes were combined to form an overall constraint level map (Figure 2-3, Marine Scotland Science, 2018). The included layers are listed in Table 2-1. Constraint levels can be considered the opposite of suitability levels, where higher constraint values reflect areas with a higher incompatibility with the proposed type of development, representing higher levels of consenting risk (Davies et al., 2014; Davies and Pratt, 2014).

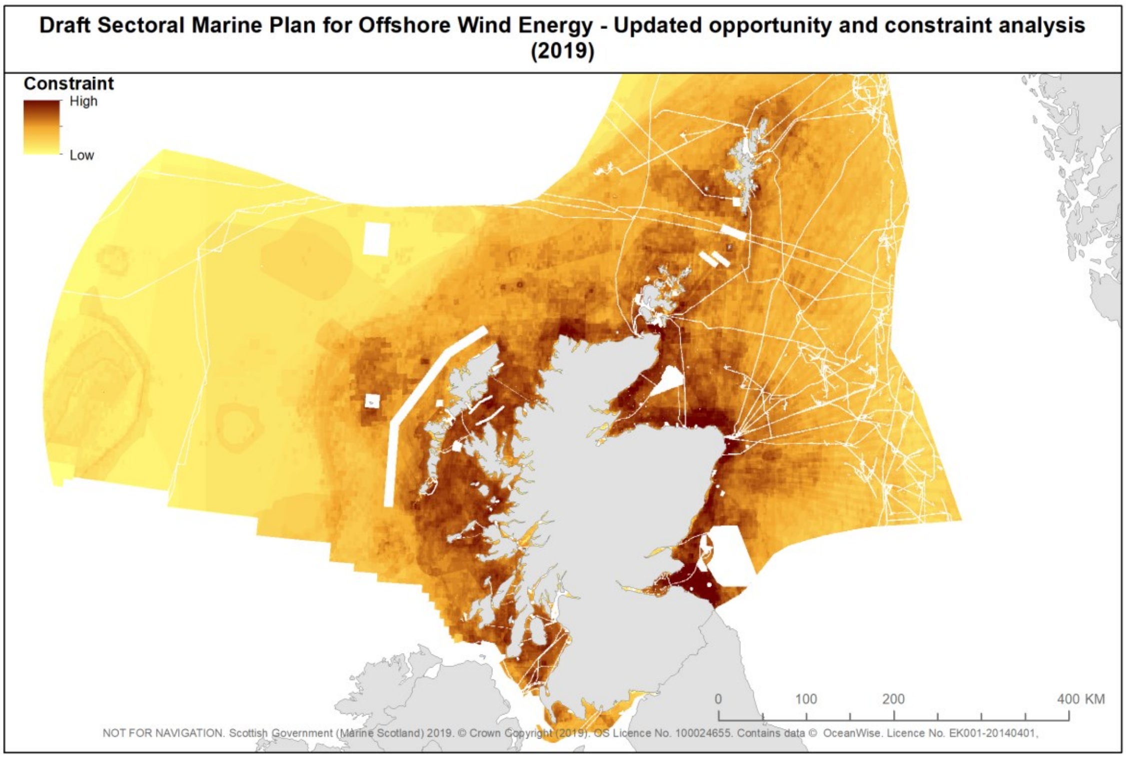


Figure 2-3 Output of tool designed to identify areas of search for offshore wind plan options (source: Marine Scotland, 2020, contains public sector information licensed under the Open Government Licence v3.0)

Table 2-1 Criteria included in the O&C tool

Data theme	Criteria layers included in the O&C tool 2018
Technical	• Bathymetry • Distance from electrical substations • Distance from key cable landings • Sediment • Slope • Wind energy
Environmental	• Cetacean density • Collected protected areas • Seabird distribution during breeding and winter season, combined with vulnerability indices • Nursery and spawning areas for commercial fish species
Industrial	• Shipping • Fishing • Helicopter routes • Military exercise areas • Radar interference areas
Socio-cultural	• Tourism and recreational use

Through an iterative process with multiple consultation and refinement steps, areas of search identified using the tool were then narrowed down into 15 plan options as published in the sectoral marine plan (Scottish Government, 2020b). These options dictate where developers can apply for a lease, for example for the 'ScotWind' leasing round launched in June 2020 (Crown Estate Scotland, 2020), for which leases were subsequently granted in 14 of these areas in January 2022 (Crown Estate Scotland, 2022b). As this tool is an implementation of MCDA that is intricately embedded in the decision-making process, unlike the 'neglected' examples mentioned previously, it provided a valuable case study to investigate how decision support tools can be more closely linked to the decision context. A workflow was created that articulated the approach taken at each step of the O&C tool building process, which provided the starting point for the framework development. Consequently, the framework was evaluated to determine how it could assist the auditability of future tools.

2.3 Methodology and results

The methodology of this study is presented in three distinct stages: 1) framework development 2) application of framework to the O&C tool 3) application of framework to the seabird dataset case study. Results are reported on at each respective stage of the methodology, to place them in their appropriate context.

2.3.1 Framework development

A literature review was undertaken to identify concepts that could be applied to the framework, including a review of existing marine spatial decision support tools adopting multi-criteria decision analysis (see Chapter 1), identifying relevant studies on terrestrial applications of spatial multi-criteria decision analysis, and reviewing literature in the field of operational research. During the placement at Marine Scotland in autumn 2019, the O&C tool was decomposed into a series of steps, so each step of the tool's method could be placed into the broader context of multi-criteria decision analysis literature, which enabled user inputs to be articulated with terms used in multi-criteria decision analysis, such as weighted linear combination (Malczewski and Rinner, 2015).

Decomposing the tool into a series of steps formed the starting point of the framework presented in this chapter. Even though the development of the tool comprised of additional steps, the framework focuses on the initial phase of identifying datasets and standardising them into constraint levels. During the

placement, the added value of explicitly linking national marine planning policy to the tool was also explored, which was the starting point of developing the first step of the framework.
The three steps of the framework are:

1. Objective formulation
2. Criteria formulation
3. Criteria standardisation

2.3.1.1 Step 1: Objective formulation

To assist in the formulation of objectives, the framework adopts a value tree approach, illustrated with the first case study – strategic siting of offshore wind in Scottish waters – in Figure 2-4. A value tree approach (also called objective trees, objectives hierarchies or hierarchic thinking) is a hierarchical representation of the objectives of a decision problem and the criteria that inform the achievement of the objectives (Beinat, 1997; Keeney, 1992; Saaty, 1980; Stelzenmüller et al., 2013).

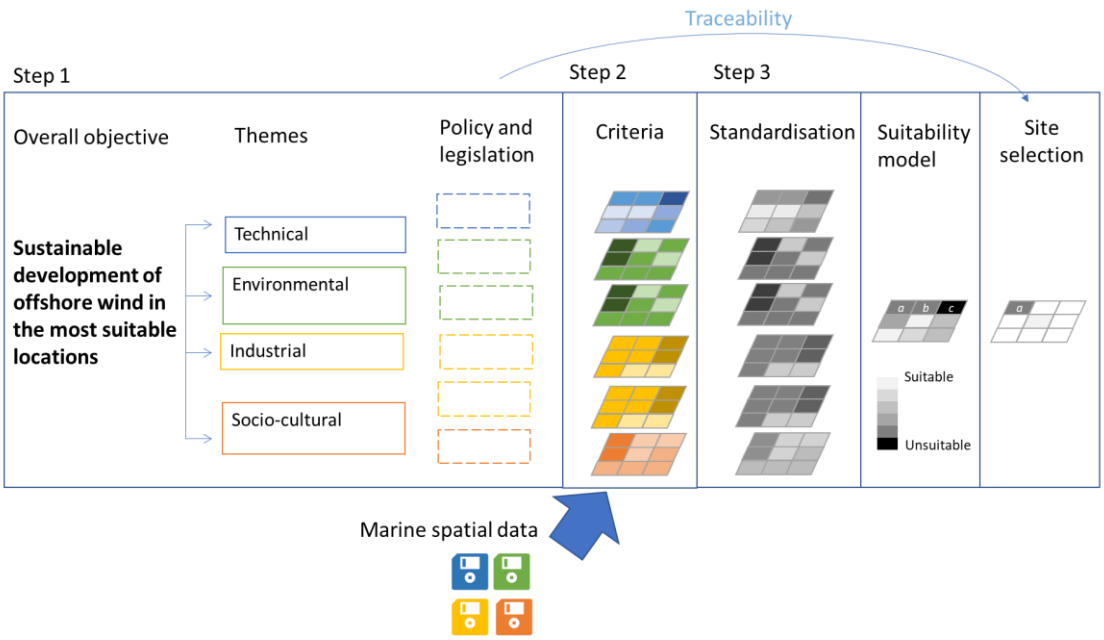


Figure 2-4 In this figure, the framework is applied to the case study of finding space for offshore wind in Scottish waters. The framework adopts a value tree approach and can enable transparency, traceability and replicability of the process.

The spatial decision problem that will be defined with objectives is subject to a multitude of legislative requirements, which are in place to avoid prospective developments impacting the environment. For example, if a project is predicted to have a significant effect on European sites (Special Protection Areas and Special

Areas of Conservation), the Habitats Regulations are a legal form of protection that can prevent the project from progressing if there is a risk that it will impact protected species or features (The Conservation (Natural Habitats, &c.) Regulations 1994).

This framework includes a step within the objective formulating phase where the user is required to consider what legislation is in place that could constrain the available alternatives for site selection. Figure 2-4 illustrates how this can improve traceability of the consideration of planning policies and legislation in the process, making a link between initial consideration during objective formulation and how that translates through to the final site selection step. Figure 2-5 summarises the first step of the framework where an overall objective is split up into themes, which are consequently linked with relevant policy and legislation requirements.

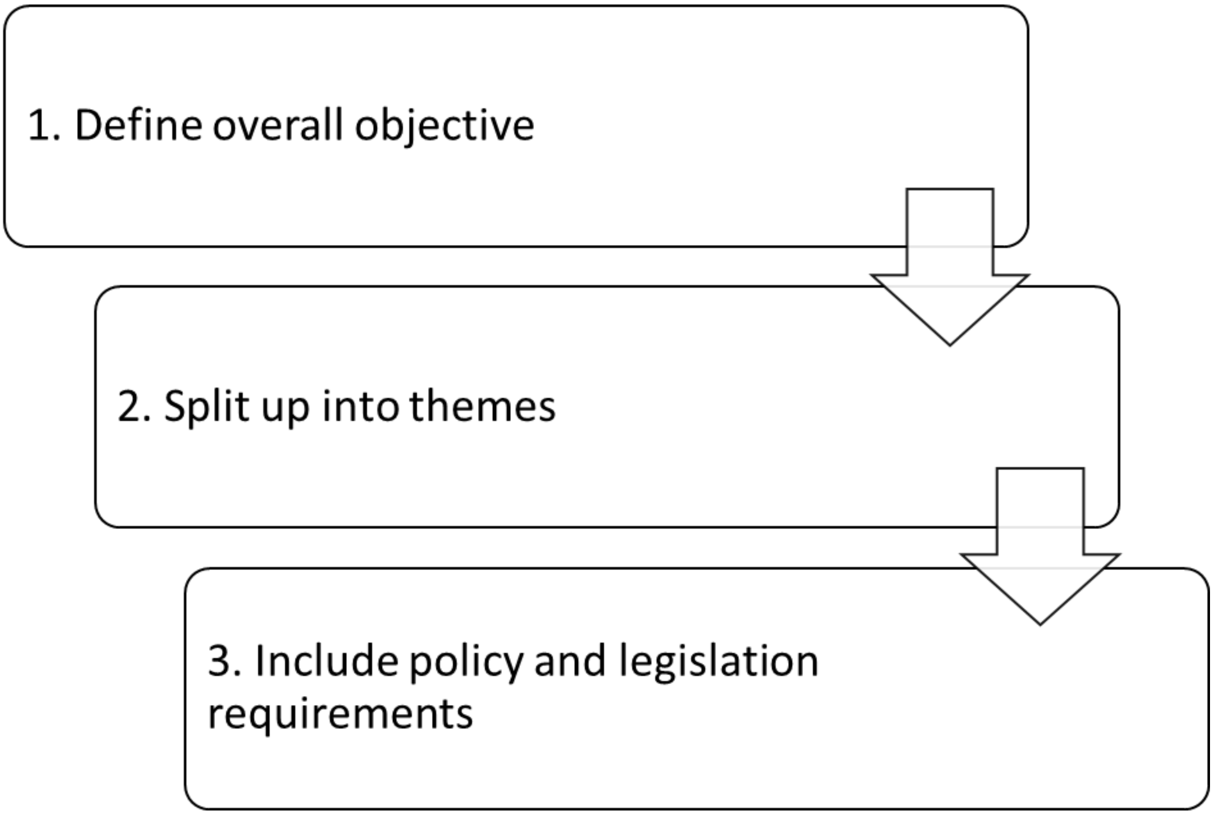


Figure 2-5 Key elements of the first step of the framework (adapted from Keeney, 1992)

2.3.1.2 Step 2: Criteria formulation

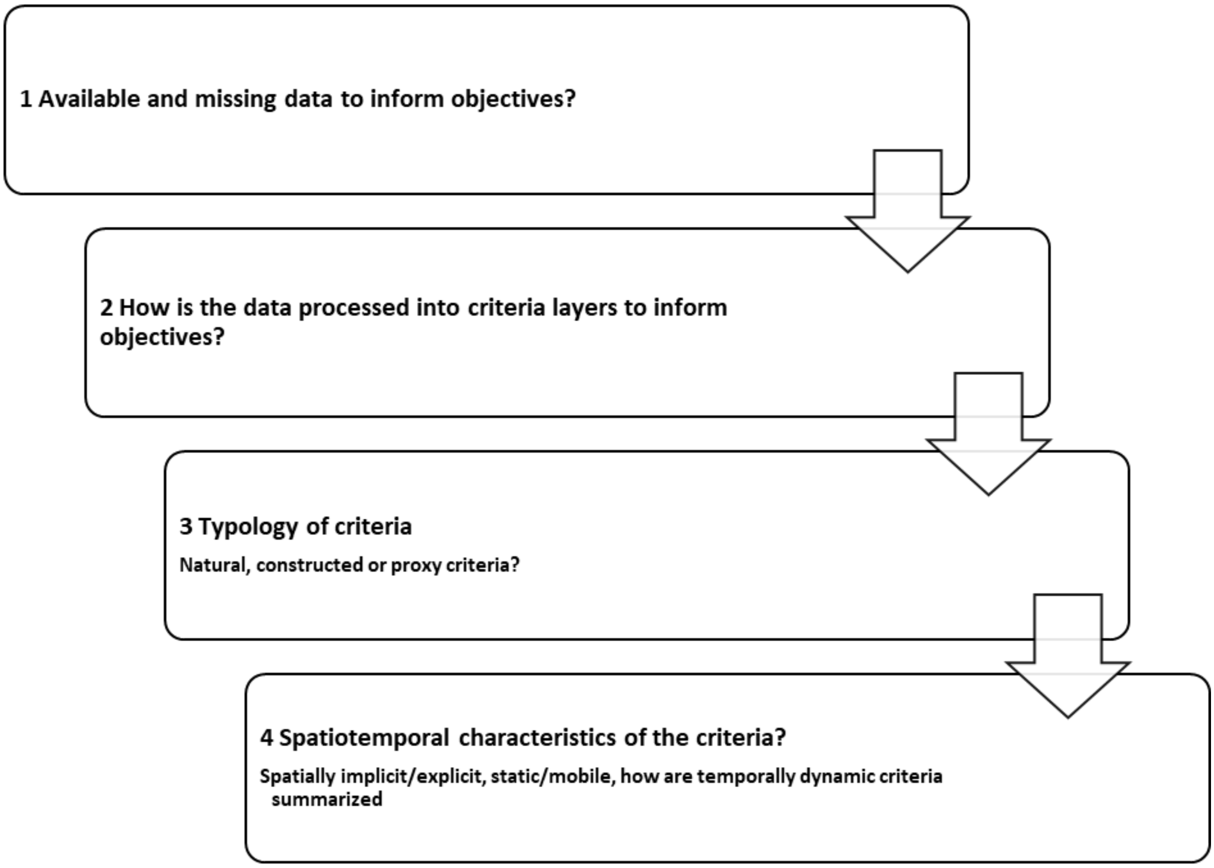


Figure 2-6 Summary of step 2 of the framework

Figure 2-6 summarises the second step of the framework which consists of identifying criteria that can measure the achievement of objectives for the different alternatives or locations (after the definition of an attribute in Beinat, 1997). By combining existing approaches of characterising criteria and data, this part of the framework is designed to aid the decision maker and interested parties in understanding how data can inform the formulated objectives. Keeney and Gregory have defined a hierarchy for criteria suitability, where the best criteria can directly measure the achievement of an objective in the field ('natural' criteria), while criteria that have a weaker link with the defined objective rely on proxy measures, as defined in Table 2-2 (Keeney and Gregory, 2005). Even though natural criteria are preferred, they will not be available for all objectives, so constructed or proxy criteria will also be a part of decision support.

Table 2-2 Types of criteria with definitions and examples

Criteria type	Definition (based on Keeney & Gregory, 2005)	Example
1. Natural	Objective can be physically counted or measured in the field using this type of criterion	The objective of favourable wind speeds can be directly measured at considered alternative sites
2. Constructed	Developed to directly measure the objective by creating a scale	If the defined objective is to minimise impact, a scale can be constructed to assign predicted levels of impact at alternative sites ranging from "severe" to "negligible"
3. Proxy	Indirectly measures the objective using an existing scale when there are no natural criteria available	If the defined objective is to "minimise bird strikes" in a wind farm area, a proxy criterion would be the number of birds present in that area

This criteria hierarchy is adapted from non-spatial decision support literature. To also consider spatiotemporal characteristics of the criteria, a workflow was created based on spatial decision support and marine spatial planning literature (see Figure 2-7). This workflow considers the spatiotemporal context of the decision problem, such as whether the included criteria are spatially implicit or explicit (Figure 2-7). A criterion is spatially explicit when its score depends on spatial location (Goodchild and Janelle, 2004), and spatial characteristics include location, distance, connectivity and direction (Malczewski and Rinner, 2015; Rinner and Heppleston, 2006). As well as spatial characteristics, temporal dimensions of the criteria are also included in Figure 2-7. The framework includes a step where the user must specify how temporally varying datasets are summarised into one static map to inform the decision. The static permanent criteria refer to fixed structures such as reefs, while semi-static criteria may move over time, such as spawning grounds, and might only be occupied for certain times of the year.

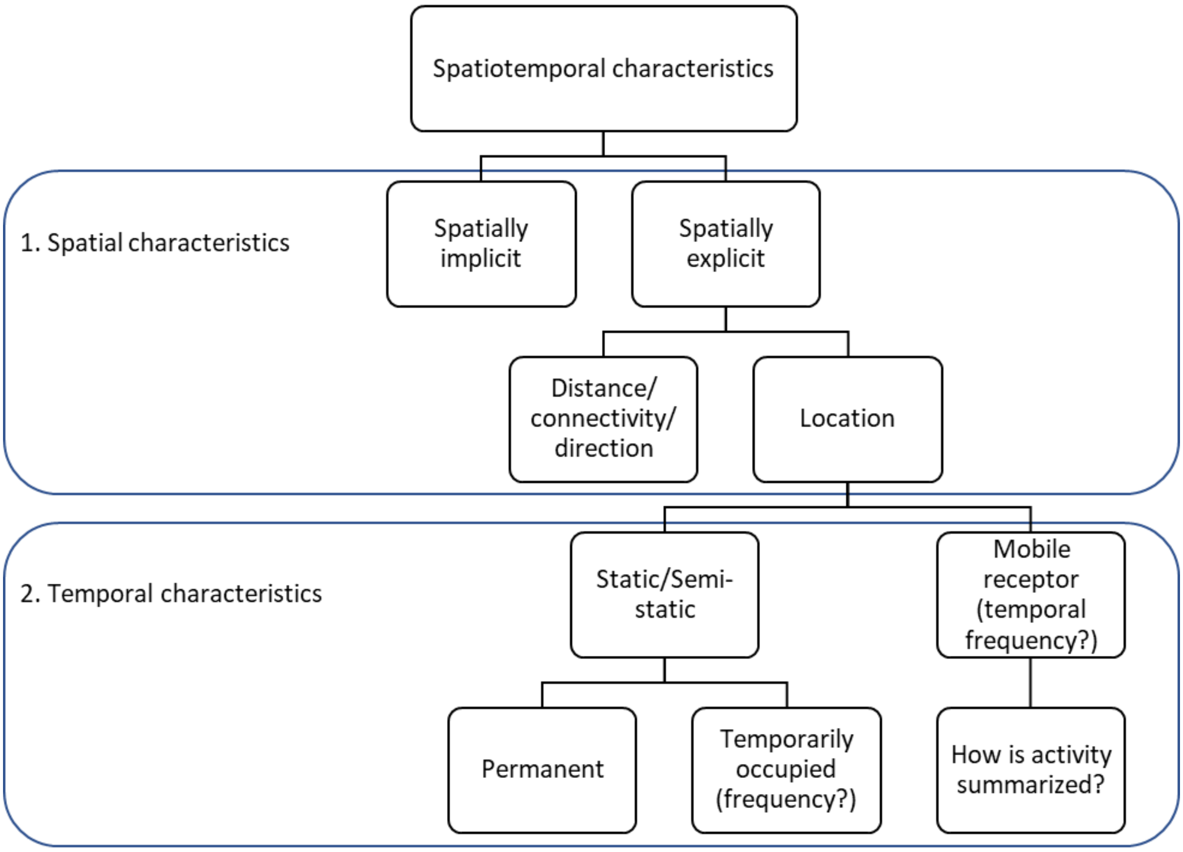


Figure 2-7 Workflow to characterise the spatiotemporal dimensions of the included criteria (spatially explicit characteristics derived from definitions in Goodchild & Janelle, 2004; Malczewski & Rinner, 2015; Rinner & Heppleston, 2006, and static characterisation and temporal characteristics derived from Holzhüter et al., 2019)

2.3.1.3 Step 3: Criteria standardisation

Criteria included in the decision support tool will have different units and scales, so the 'raw' input scores are standardised to a common suitability range for enabling comparisons (Malczewski and Rinner, 2015). The way in which an input score is translated into a suitability value can be characterised with a value function. For this framework, the value function is defined as a mathematical representation of how the criteria inform the achievement of the defined objectives, presented as a relationship between criterion value and suitability level (based on definitions from Beinat, 1997; Keeney, 1992; Malczewski & Rinner, 2015). The definition of a value-indicator used by Kenter et al., 2015 and Palola et al., 2022, the "measure of the importance of something", is also relevant, and interpreted here as the importance of a value in relation to locating a novel development, which the mapping tool aims to inform.

The link between criteria values and levels of suitability will depend on how the objectives are formulated. For an objective related to wind resource, if the objective is that wind resource needs to be between x and y m/s, a clear cut-off can be made between suitable and unsuitable areas. However, if the objective is formulated in a more ambiguous way, e.g. “maximise wind resource”, there will be more uncertainty related to the link between suitability and wind speed, as this objective can be interpreted in different ways. This is known as decision rule uncertainty (Eastman, 2015 and Robinson et al., 2002). For the framework, three categories of standardisation are proposed, corresponding with low, medium and high levels of decision rule uncertainty respectively (Figure 2-8).

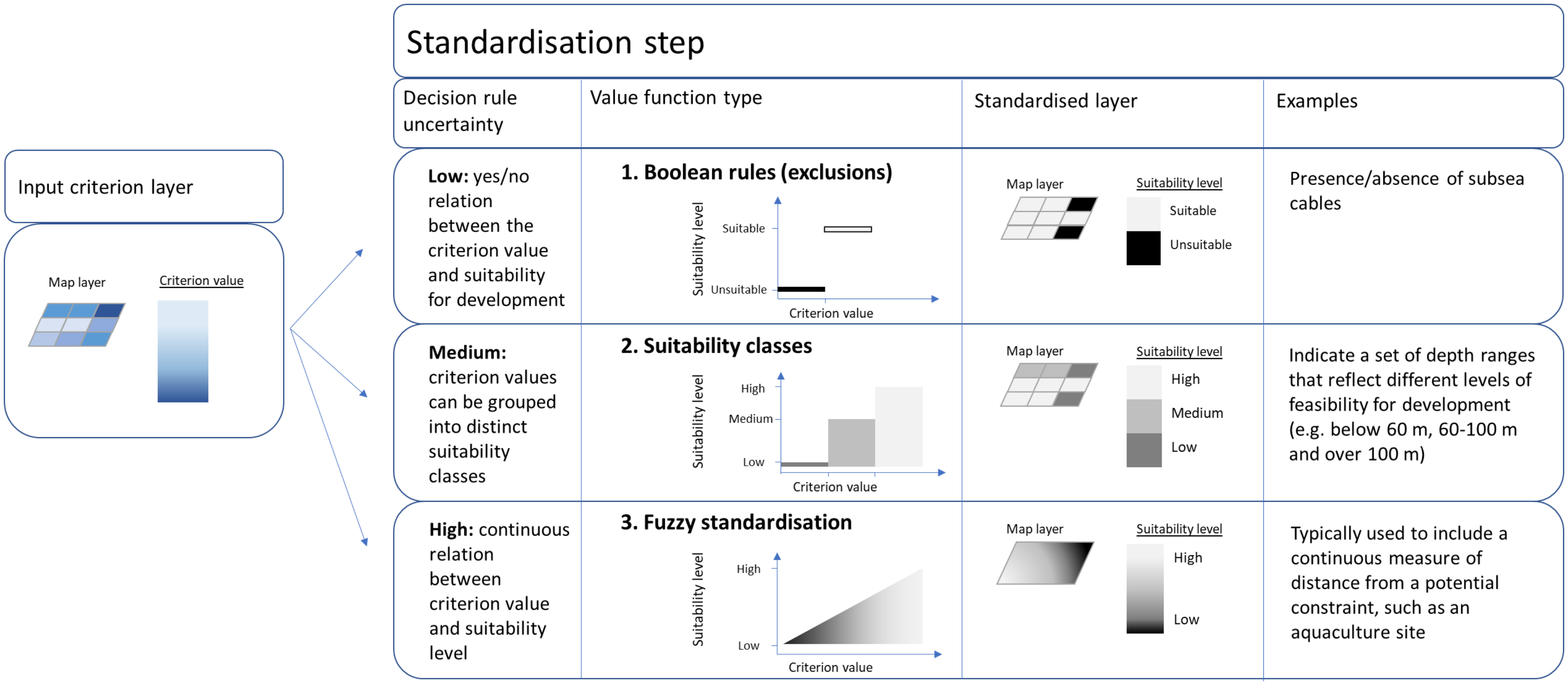


Figure 2-8 Standardisation techniques are grouped into three categories, according to uncertainty in the relationship between criterion and suitability level (decision rule uncertainty)

The first type, Boolean rules, defines a binary condition rendering an alternative either suitable (1) or unsuitable (0) (Eastman et al., 1995). This is illustrated on Figure 2-8, where two of the alternatives are rendered unsuitable, and the remaining 7 are standardised into suitable locations. A second approach, classification, is where different levels of suitability are defined based on the scores of the criterion, for medium levels of decision rule uncertainty (Figure 2-8). Class intervals can be defined in two ways: either using decision rules, e.g. defining cut-off levels for wind speed that reflect different levels of technical feasibility. Class intervals can also be obtained through statistical classification techniques to obtain suitability classes that reflect patterns in the data.

Statistical data classification aims to minimise variation within classes and maximise variation between classes (Dent et al., 2009; Smith, 1986). This simplifies the data, making it more accessible for interpretation and therefore, for inclusion in decision support (Dent et al., 2009; Janssen et al., 2013; Miller, 1956; Tufte, 2001).Types of statistical classification are explained in ArcGIS, 2019 and Bivand et al., 2020, and listed in Figure 2-9. Finally, for the highest category of decision rule uncertainty, a continuous level of suitability can be defined with fuzzy logic. Fuzzy logic originated as an approach to computing which allowed for “degrees of truth” beyond binary “true” or “false” approaches (Zadeh, 1965).

For the framework described in this study, fuzzy logic is used as a term to define value functions that allow for a degree of variation between binary options or discrete classes (Eastman, 2015), which is also the interpretation used in the ArcGIS environment (ESRI, 2016; Raines et al., 2010), although alternative interpretations exist (see Alassar et al., 2010; Teh & Teh, 2011). Figure 2-8 illustrates a linear function that translates a continuous input score into a continuous suitability level range. There are different ways of defining this continuous fuzzy value function, which are summarised in Table 2-3 (see also Raines et al., 2010).

Table 2-3 Overview of fuzzy approaches

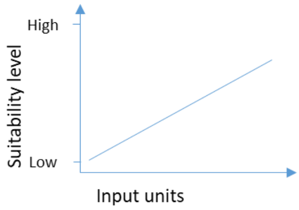
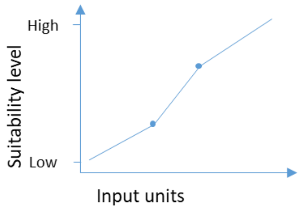
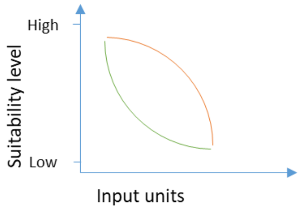
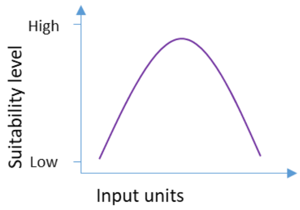
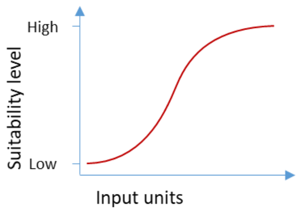
Shapes of curve		**Input parameters**	**Examples**
Linear		Min, Max	ESRI, 2016; Tweddle et al., 2014
Piecewise linear		Min, Max, Breakpoints	Stewart & Janssen, 2013
Concave/convex		Min, Max, Risk level (ρ)	(Ferguson and Cousineau, 2018; Malczewski and Rinner, 2015)
Bell-shaped		Min, Max, Midpoint, Spread/SD	ESRI, 2016; Gimpel et al., 2015
Sigmoidal		Min, Max, Midpoint, Spread/SD	Dias et al., 2020; ESRI, 2016; Gimpel et al., 2015

Figure 2-9 summarises the third step of the framework, which provides an overview of the different standardisation approaches that can be adopted, depending on the decision rule uncertainty.

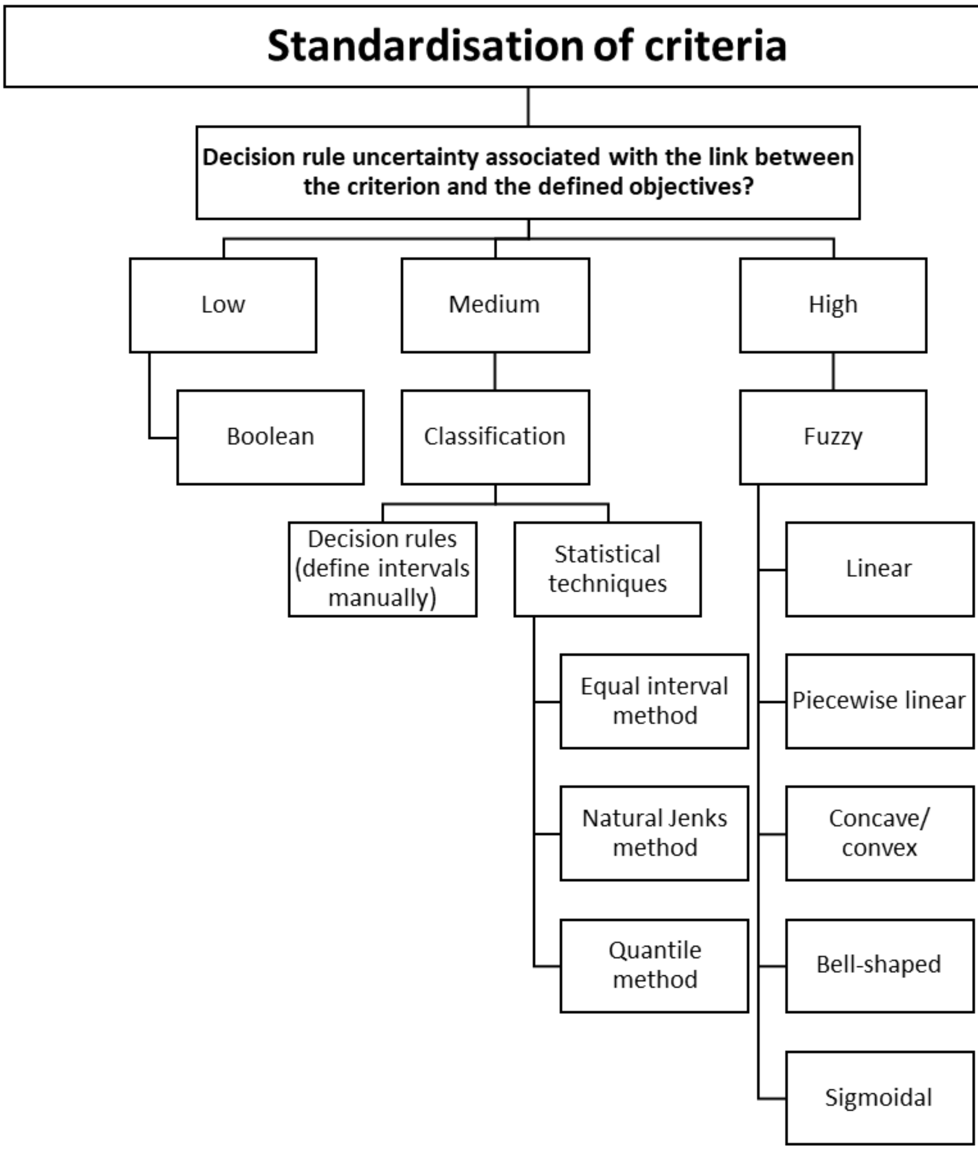


Figure 2-9 Overview of different approaches that can be taken to standardise criteria, based on decision rule uncertainty

2.3.2 Case study 1: Applying the framework to the Opportunity and Constraint (O&C) tool

As described in Section 2.3.1, the framework was developed based on a literature review on multi-criteria decision analysis and the existing method of the O&C tool. Table 2-4 (for step 1) and Table 2-6 (for step 2) document how the framework was then applied retrospectively to the O&C tool. This included defining objectives based on the criteria layers included in the tool. For step 1, the overall objective was defined as the first sector objective for offshore wind and marine renewable energy in Scotland's National Marine Plan: *"Sustainable development of offshore wind, wave and tidal renewable energy in the most suitable locations"* (Scottish Government, 2014b).

Table 2-4 Sources of information and methods used to apply step 1 of the framework to the O&C tool

	Sources of information	Method
Overall objective	National Marine Plan 2014[1]	Overall objective was defined based on the first sector objective for offshore wind and marine renewable energy
Themes	Scoping study 2018[2]	Themes derived from the scoping study (environmental, industrial and socio-cultural)
Policy and legislation requirements	Scoping study 2018[2], National Marine Plan 2014[1], legislative documents and guidance	Policies/legislation that underpin relevance of the included criteria in the scoping study were identified and used to formulate policy and legislation requirements. These were sourced from Scotland's National Marine Plan, legislative documents and guidance

Policy and legislation requirements were not defined for the layers included in the technical theme (e.g. wind speed, distance from substations) because they were not considered to be criteria that represented consenting risk. The three remaining themes in the 2018 scoping study (environmental, industrial and socio-cultural) were used to split up the overall objective. The policy and legislation requirements were formulated based on 1) the data layers included in the O&C tool, 2) policies in Scotland's National Marine plan (Scottish Government, 2014b), and 3) other legislative documents and guidance. Table 2-5 lists the policy and legislation requirements formulated for the tool using the methods explained in Table 2-4.

[1] https://www.gov.scot/publications/scotlands-national-marine-plan/, accessed 20/10/2021
[2] https://www.gov.scot/publications/scoping-areas-search-study-offshore-wind-energy-scottish-waters-2018/, accessed 20/10/2021

Table 2-5 Per theme, relevant policy/legislation is used to formulate policy/legislation requirements per dataset used in the O&C tool. NMP = National Marine Plan, followed by the names of the policies (e.g. “GEN 9”). HMR = Helicopter Main Route, MGN = Marine Guidance Note, CAP = Civil Aviation Publication

Theme	Policy, legislation and guidance	Policy and legislation requirements for tool
Environmental	"Comply with legal requirements for **protected areas** and **protected species**" (NMP, GEN 9)	Comply with legal requirements for **protected areas:** • marine protected areas (MPAs), • proposed MPAs, • Special Areas of Conservation (SACs), • Special Protection Areas (SPAs), • Sites of Special Scientific Interest (SSSIs), • Ramsar sites and draft offshore SPAs)
	Birds as protected species: s. 1(1) of the Wildlife and Countryside Act 1981, as amended by the Nature Conservation (Scotland) Act 2004 states it is an offence “to intentionally or recklessly: - Kill, injure or take any wild bird”	Do not kill or injure wild bird species
	Cetaceans as protected species: All cetaceans are on the European Protected Species list (Schedule 2 of the Habitat Regulations 1994) and under regulation 39 it is an offence to “injure or kill, … harass…., disturb” “such an animal”	Do not injure, kill, harass or disturb cetaceans
	"The following key factors should be taken into account when deciding on uses of the marine environment and the potential impact on fishing: The environmental impact on fishing grounds (such as nursery, spawning areas)” (NMP, FISHERIES 2)	Avoid environmental impact on nursery areas
		Avoid environmental impact on spawning areas

Table 2-5 (continued)

Theme	Policy, legislation and guidance	Policy and legislation requirements for tool
Industrial	"Existing fishing opportunities and activities are safeguarded wherever possible" (NMP, FISHERIES 1)	Safeguard existing fishing opportunities and activities
	"Navigational safety in relevant areas used by shipping now and in the future will be protected, adhering to the rights of innocent passage and freedom of navigation contained in UN Convention on the Law of the Sea (UNCLOS)" (NMP, TRANSPORT 1) (Article 15 of UNCLOS)	Protect navigational safety in areas used by shipping now and in the future
	"To maintain operational effectiveness in Scottish waters used by the armed services, development and use will be managed in these areas" (NMP, DEFENCE 1)	Maintain operational effectiveness of the armed services
	"Safeguard PSR" (PSR = Primary Surveillance Radar, source: CAP 764 guidance to help developers conform with the Town & Country Planning Safeguarded Aerodromes, Technical Sites and Military Explosives Storage Areas (Scotland) Direction 2003 (Scottish Planning Circular 2/2003)	Safeguard primary surveillance radar
	"There should be no obstacles within 2 NM either side of HMRs" (CAP 764 guidance to help developers conform with the Town & Country Planning Safeguarded Aerodromes, Technical Sites and Military Explosives Storage Areas (Scotland) Direction 2003 (Scottish Planning Circular 2/2003)	Do not obstruct HMRs and 2nm either side
Socio-cultural	"The extent to which the proposal is likely to adversely affect the qualities important to recreational users, including the extent to which proposals may interfere with the physical infrastructure that underpins a recreational activity" (NMP, R&T 2)	Avoid adversely affecting qualities important to recreational users

For the environmental theme, the general policy on natural heritage (GEN 9) from Scotland's National Marine Plan was deemed the most relevant, along with the planning policy related to spawning and nursery areas (FISHERIES 2) (Table 2-5). Bird and cetacean species are also protected by legislation that is not exclusive to the marine environment, through the Wildlife and Countryside Act 1981 and the Habitat Regulations. For the maritime shipping and military defence datasets that were included, specific planning policies were relevant (Table 2-5). There were also data layers included that were not explicitly mentioned in the National Marine Plan, related to the footprint offshore wind farms have in the air space: radar interference and helicopter routes were included as data layers. The need to consider these constraints is specified in a policy and guidelines document by the Civil Aviation Authority, to make sure developers conform to the Town & Country Planning Safeguarded Aerodromes, Technical Sites and Military Explosives Storage Areas (Scotland) Direction 2003 (Scottish Planning Circular 2/2003).

After formulating policy and legislation requirements (see Table 2-5), step 2 used criteria typology to examine the link between the requirements and the data layers included in the O&C tool, as described in Table 2-6. The results from applying the criteria typology are found in Table 2-7.

Table 2-6 Sources of information and methods used to apply step 2 of the framework to the O&C tool used for siting offshore wind in Scottish waters

	Source of information	**Method**
Criteria typology	Scoping study by Marine Scotland Science, 2018 and references therein	Criteria were classified as natural, constructed or proxy using the typology defined in *Table 2-2*, based on how they informed the achievement of the policy and legislation requirements formulated in *Table 2-5*
Spatio-temporal characteristics	Scoping study by Marine Scotland Science, 2018 and references therein	Spatiotemporal characteristics of the criteria were documented using the workflow from *Figure 2-7,* based on the data type as well as on the information available about the datasets in the 2018 scoping study

Table 2-7 Classifying the relationship between the policy and legislation requirements and the criteria, for the environmental, industrial and socio-cultural themes

Theme	**Policy and legislation requirements for tool** (source: Table 2-5)	**Criteria layer** (source: Marine Scotland Science, 2018 and references therein)	**Criteria type**
Environmental	Comply with legal requirements for MPAs, proposed MPAs, SACs, SPAs, SSSIs), Ramsar sites and draft offshore SPAs	Locations of protected areas (MPAs, proposed MPAs, SACs, SPAs, SSSIs, Ramsar sites and draft offshore SPAs)	Proxy
	Do not kill or injure wild bird species	Vulnerability to collision of seabirds during the breeding season	Constructed
		Vulnerability to collision of seabirds during the winter season	Constructed
	Do not injure, kill, harass or disturb cetaceans	Overall cetacean density distribution created from individual species distribution maps (#/std hour x 1000)	Proxy
	Avoid environmental impact on nursery areas	Probability of encountering aggregations of fish in the first year of life	Proxy
	Avoid environmental impact on spawning areas	Number of overlapping spawning areas for 11 commercial species	Proxy
		Spawning area preference of cod	Proxy
		Probability of encountering spawning haddock	Proxy

(continued)

Theme	Policy and legislation requirements for tool (source: Table 2-5)	Criteria layer (source: Marine Scotland Science, 2018 and references therein)	Criteria type
Industrial	Safeguard existing fishing opportunities and activities	Monetary value fishing in £ (amalgamated VMS and Scotmap)	Proxy
	Protect navigational safety in areas used by shipping now and in the future	Annual mean for 2015 of the # of vessels in the first week of each month	Proxy
	Maintain operational effectiveness of the armed services	Locations of military exercise areas	Proxy
	Safeguard primary surveillance radar	Radar interference that would be caused by wind turbines with tip heights of 200 m above sea level	Natural
	Do not obstruct HMRs and 2nm either side	Locations of Helicopter Main Routes	Natural
Socio-cultural	Avoid adversely affecting qualities important to recreational users	Activity density map for combined coastal and sea-based tourism and recreational activities	Proxy

The environmental theme had six proxy criteria and two constructed criteria (Table 2-7). For the industrial theme, two natural criteria were identified in relation to the defined impact-related requirements. The radar interference layer was classified as a natural criterion because radar interference as a form of impact could directly be represented as a criterion layer using a modelled map that indicated where interference is likely (NATS, n.d.). The socio-cultural theme was represented by a proxy criterion. Criteria that represented the location of the receptors as well as information that informed how the policy and legislation requirements could be achieved, such as vulnerability to collision, were considered constructed criteria. For example, the seabird layers were included in the spatial tool as 'weighted' receptor maps, depending on the relative sensitivity of different bird species using weights derived from (Furness and Wade, 2012). Criteria that represented only the location of a receptor/receptor activity, and not how that informed the policy and legislation requirements, were considered proxy criteria.

Spatiotemporal characteristics of the included criteria layers are documented using the method described in Table 2-6, and reported on in Table 2-8. The scoping document was consulted to understand the spatiotemporal characteristics of the included criteria (Marine Scotland Science, 2018).

Table 2-8 Characterising the spatiotemporal elements of the datasets per theme

Theme	Criteria layer (source: Marine Scotland Science, 2018 and references therein)	Spatial characteristics	Temporal characteristics	How is mobile data summarised
Technical	Bathymetry	No	-	-
	Distance from electrical substations	Yes (distance)	Static (permanent)	-
	Distance from key cable landings	Yes (distance)	Static (permanent)	-
	Sediment type	No	-	-
	Slope	No	-	-
	Wind resource	No	-	-
Environmental	Locations of protected areas (MPAs, proposed MPAs, SACs, SPAs, SSSIs, Ramsar sites and draft offshore SPAs)	Yes (location)	Static (permanent)	-
	Vulnerability to collision of seabirds during the breeding season	Yes (location)	Mobile (seasonal)	Combined at sea densities for all included seabird species for the breeding season, based on records from 1980-2004
	Vulnerability to collision of seabirds during the winter season	Yes (location)	Mobile (seasonal)	Combined at sea densities for all included seabird species for the non-breeding season, based on records from 1980-2004
	Overall cetacean density distribution created from individual species distribution maps (#/std hour x 1000)	Yes (location)	Mobile (unknown)	Collation of all sightings of the 10 most common species from 1979-1997

Table 2-8 (continued)

Theme	Criteria layer (source: Marine Scotland Science, 2018 and references therein)	Spatial characteristics	Temporal characteristics	How is mobile data summarised
Environmental	Probability of encountering aggregations of fish in the first year of life	Yes (location)	Semi-static[1] (seasonal)	-
	Number of overlapping spawning areas for 11 commercial species	Yes (location)	Semi-static[1] (seasonal)	-
	Spawning area preference of cod	Yes (location)	Semi-static[1] (seasonal)	
	Probability of encountering spawning haddock	Yes (location)	Semi-static[1] (seasonal)	
Industrial	Monetary value fishing in £ (amalgamated VMS and Scotmap)	Yes (location)	Mobile (unknown)	5-year average from 2007-2011
	Annual mean for 2015 of the # of vessels in the first week of each month	Yes (location)	Mobile (unknown)	Mean monthly shipping density for 2015
	Locations of military exercise areas	Yes (location)	Static (unknown)	-
	Radar interference that would be caused by wind turbines with tip heights of 200 m above sea level	Yes (connectivity)	Static (permanent)	-
	Locations of Helicopter Main Routes	Yes (location)	Static (unknown)	-
Socio-cultural	Activity density map for combined coastal and sea-based tourism and recreational activities	Yes, location	Mobile (unknown)	Combined activity density collected with a survey from August-October 2015

[1] Spawning and nursery grounds are subject to change location (Aires et al., 2014) so they are classified as semi-static

The spatiotemporal characteristics of the included criteria are described in Table 2-8. The technical theme comprised of a combination of spatially implicit and explicit criteria, and the explicit criteria represented static features. All other themes were represented with spatially explicit criteria that included static, semi-static and mobile criteria. All static and semi-static criteria were classified as permanent, except for the spawning grounds which are known to occur seasonally. Two criteria layers that were classified as permanent in fact represented activities that are not permanent, and the temporal frequency of the space use is unknown (military exercise areas and helicopter main routes). Seasonality of seabird occurrence was considered, and for the other mobile receptors, temporal frequency of space use is unknown. Mobile data was summarised in different ways. For the bird, cetacean and recreational criteria all sightings/activities were collated in one layer, while for fisheries and shipping, an average was taken.

In relation to the third step, the O&C tool consists of criteria layers that were standardised into low, medium and high constraint classes, using either decision rules or statistical classification techniques, depending on the characteristics of the dataset (Table 2-9). For example, for the protected areas layer in Marine Scotland's O&C tool the assigned constraint levels depended on the type of protected area: European sites which have a higher level of protection were given the highest constraint level (3), and national/regional sites a medium constraint level (2) (Marine Scotland Science, 2018). In contrast, for the shipping density layer a statistical classification was used (quantile classification), and the intervals were adjusted so that the extent of high density shipping presence was not exaggerated in the layer, as reported in the method described for the O&C tool in the Marine Scotland Science scoping report (Marine Scotland Science, 2018).

Table 2-9 Standardisation techniques adopted by the O&C tool (source: Marine Scotland Science, 2018)

Theme	Criteria layer (source: Marine Scotland Science, 2018)	Classification technique
Technical	Bathymetry	Decision rules
	Distance from electrical substations and key cable landings	Decision rules
	Sediment type	Decision rules
	Wind resource	Decision rules
Environmental	Locations of protected areas	Decision rules
	Vulnerability to collision of seabirds	Statistical (natural breaks) + manual adjustment
	Overall cetacean density distribution created from individual species distribution maps (#/std hour x 1000)	Statistical + manual adjustment
	Probability of encountering aggregations of fish in the first year of life	Statistical + manual adjustment
	Number of overlapping spawning areas for 11 commercial species	Statistical (equal interval)
	Spawning area preference of cod	Decision rules
	Probability of encountering spawning haddock	Statistical + manual adjustment
Industrial	Fishing value	Statistical (quantile)
	Shipping density	Statistical (quantile) + manual adjustment
	Locations of military exercise areas	Decision rules
	Radar interference that would be caused by wind turbines with tip heights of 200 m above sea level	Decision rules
	Locations of Helicopter Main Routes	Decision rules
Socio-cultural	Activity density map for combined coastal and sea-based tourism and recreational activities	Statistical

2.3.3 Case study 2: The use of bird tracking data in decision support at project level

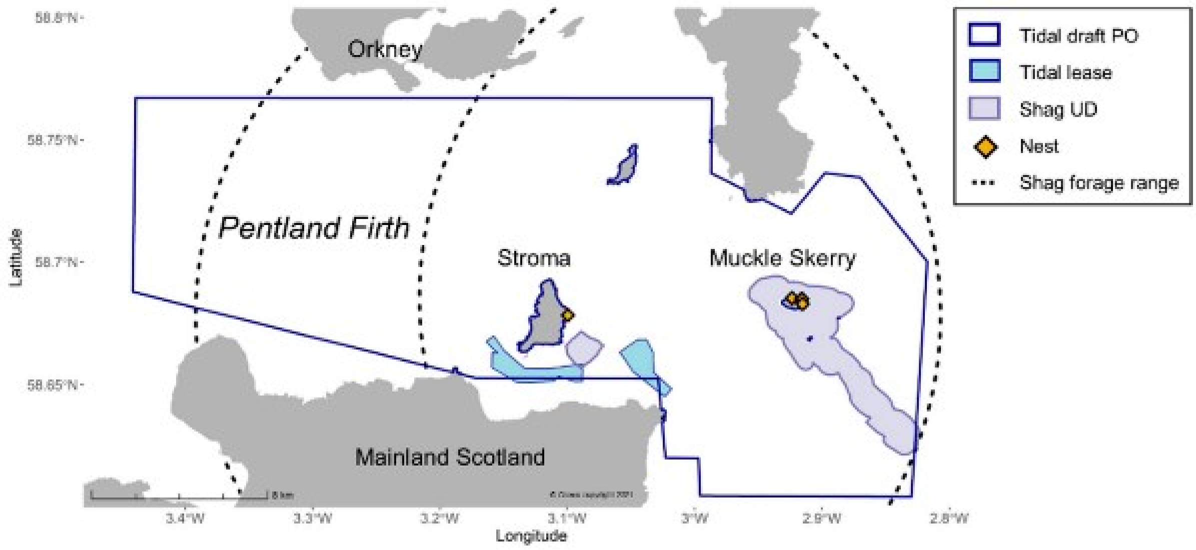


Figure 2-10 Space use polygons (utilisation distributions (UD)) created using bird tracking data (source: Isaksson et al., 2021)

The second case study aims to evaluate how space use polygons (UDs or utilisation distributions) derived from bird tracking data (see Figure 2-10) can inform the siting of tidal energy developments. Tidal stream environments such as the Pentland Firth have potential to host renewable energy generation (Neill et al., 2017), but are also used by seabirds for foraging (Furness et al., 2012). Animal movements can be tracked at fine spatiotemporal scales (location within a few metres, recorded every second) using telemetry equipment such as GPS devices attached to an individual (Dujon et al., 2014; Kays et al., 2015). In combination with other attached devices such as time-depth recorders, information on specific behaviours such as diving can also be collected alongside location (Halsey et al., 2007; Schreer and Testa, 1995). Information on behaviour is necessary to inform consenting risk, as it will determine what potential interaction the individual may have with the proposed development (Isaksson et al., 2020). At project level, to minimise spatial overlap with protected species, data on location of individuals is commonly used to make density maps. For example, the intensity of space use by razorbills is represented by the number of GPS points within a grid cell (Figure 2-11b). Another wind farm project considered the percentage of spatial overlap between proposed development sites and individual bird tracks (Seagreen, 2018). However, these two types of data processing have been criticised due to a lack of consideration of patterns in behaviour (Christel et al., 2013). These examples do not consider species-specific behaviours, such as the difference between foraging, flying or resting.

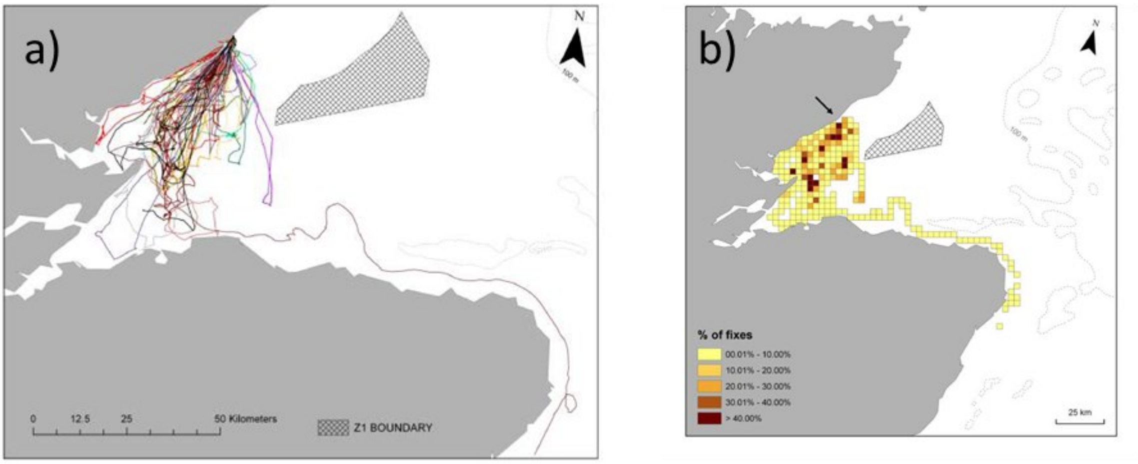


Figure 2-11 a) GPS tracks of razorbill trips b) Intensity map of space use by razorbills calculated with the GPS tracks (source: Telford, Stevenson, MacColl Wind Farms and associated Transmission Infrastructure Environmental Statement, Technical Appendix 4.5 C (https://www.morayeast.com/application/files/5915/8014/0760/Appendix-4-5-C-Seabird-Tracking-Modelling.pdf))

For this study, GPS tracks as well as depth recordings from a tagged European shag (*Phalacrocorax aristotelis*) in the Pentland Firth, converted into space use polygons (see Isaksson et al., 2021, Figure 2-10), were used as the input data (step 2) and then linked with defined objectives (step 1) and standardised into suitability values (step 3). Spatial decision support has previously been developed by Marine Scotland to guide tidal development in the Pentland Firth, however this draft guidance developed in 2013 was never formally adopted (Scottish Government, 2013). This data could be used to inform a revision of the draft plan option, or micro-siting within the draft plan option, to minimise impacts on a protected species (Isaksson et al., 2021).

Objectives were defined in relation to the bird tracking data set by integrating policy and legislation requirements with objectives specific to the receptor (Figure 2-12).

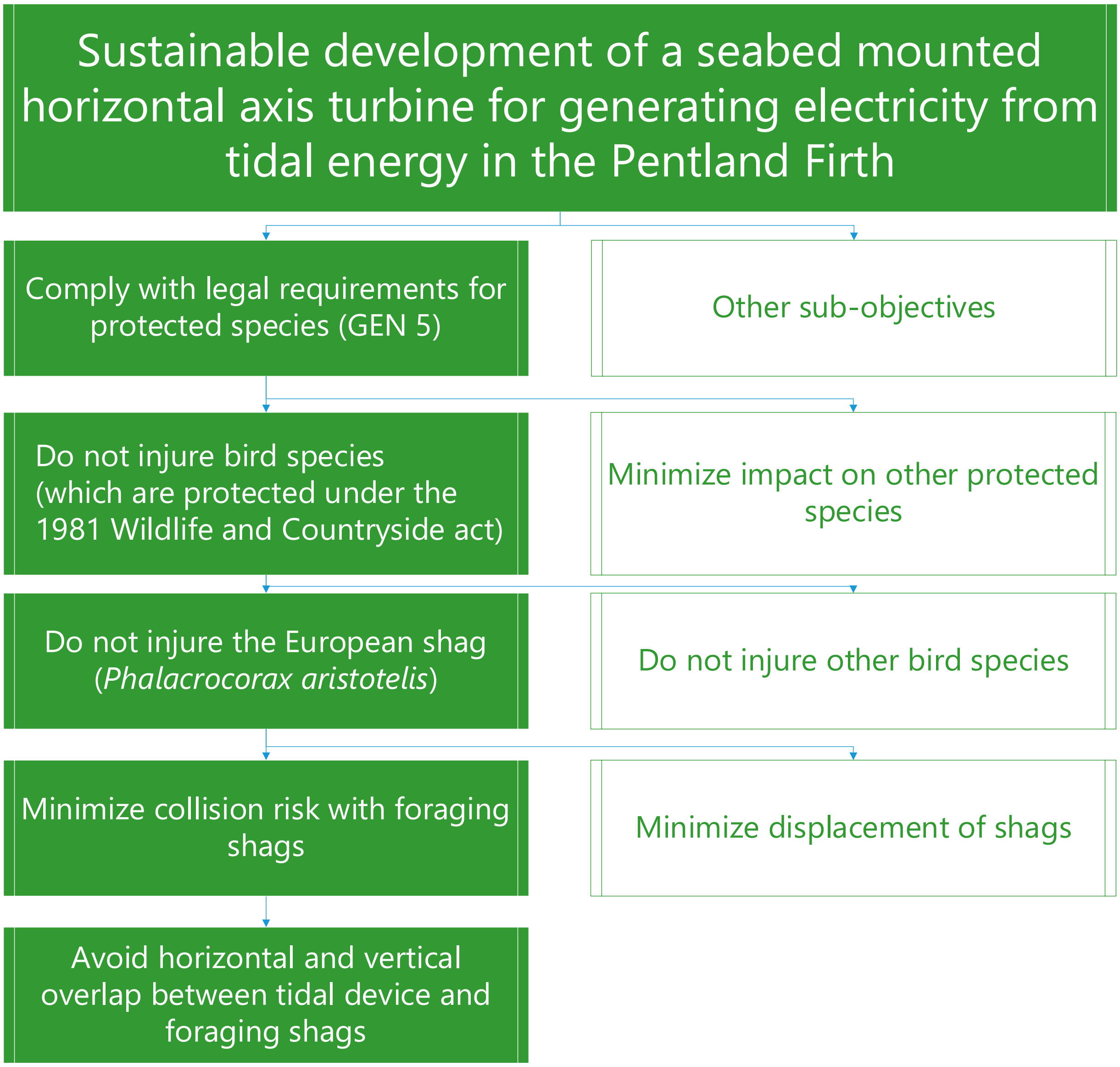


Figure 2-12 Objectives and sub-objectives defined for step 1 of the framework applied to the bird tracking case study

By using a combination of shaded boxes and outlined boxes, the objective tree in Figure 2-12 articulates the context of the decision by making it clear which objectives are informed by the dataset and which objectives are not represented with the data. For the next step, the framework was used to create a clear workflow of how the tracking data could be translated into a criteria layer to be included in a decision support tool, including a description of spatiotemporal data characteristics and the representativeness of the dataset.

Table 2-10 Criterion, criterion type and spatiotemporal characteristics are described as part of applying the framework to the bird tracking data

Objective (as defined in Figure 2-12)	Avoid horizontal and vertical overlap between tidal device and foraging shags
Criterion	Locations of utilisation distribution polygons of a foraging adult shag individual for the sampled time period (source: Isaksson et al., 2021)
Criterion type	Natural
Spatial characteristics	Spatially explicit (location)
Temporal characteristics	Mobile (temporal frequency known for 10.8-hour timespan in breeding season)
How is mobile data summarised	Space use for 10.8 hours is represented with biologically meaningful 95% utilisation distribution polygons

Table 2-10 describes the spatiotemporal characteristics of the data and how they were summarised. The recorded at risk (foraging) behaviour by the individual was represented with 95% utilisation distribution polygons. These polygons are calculated using the input data and represent 'active' areas of use for the individual (Ford and Krumme, 1979). For this application of utilisation distribution polygons, the polygons represent active areas of use specifically for at-risk foraging behaviour (the workflow is explained in Isaksson et al., 2021). Table 2-8 from case study 1 indicates that space use of mobile receptors can be summarised in different ways. Therefore, a chart was put together for the bird tracking data (see Figure 2-13) to indicate the representativeness of the summarised data. For example, the data only represents foraging behaviour and not flight.

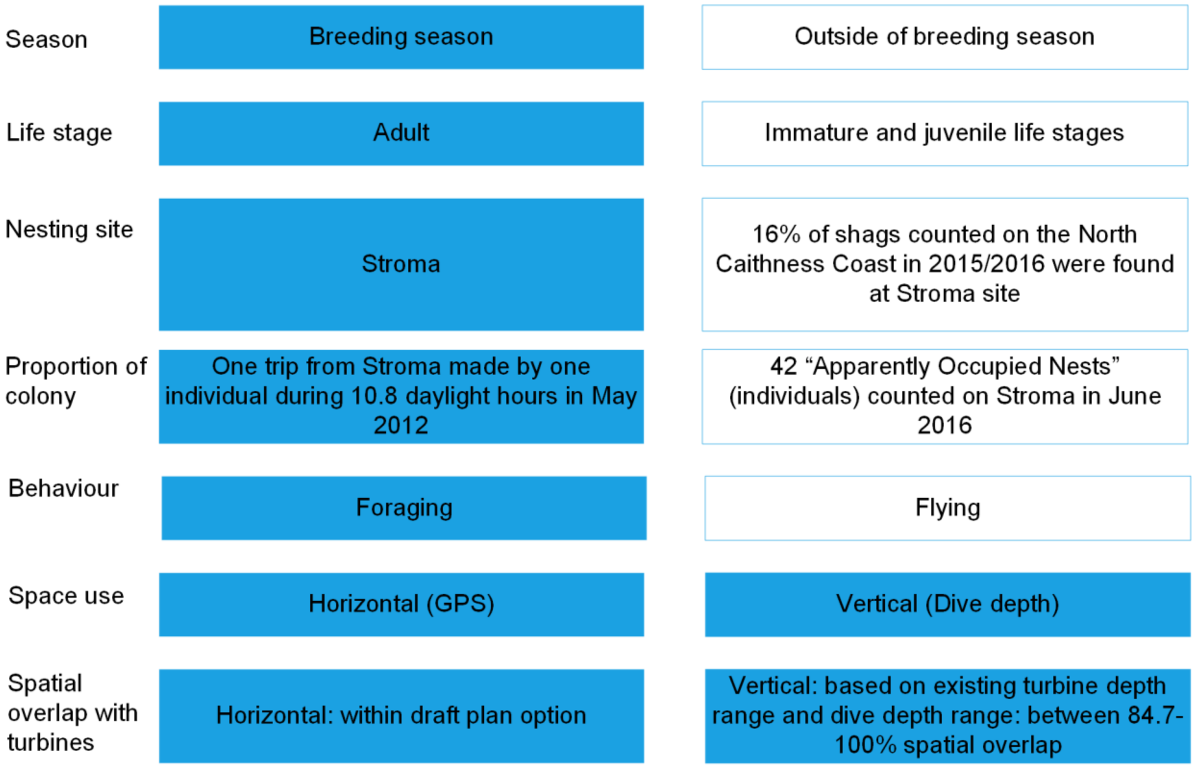


Figure 2-13 Representativeness of the bird tracking data. Filled boxes indicate the dataset fulfils that characteristic, outlined boxes indicate the dataset does not represent that characteristic. Information sources: Isaksson et al., 2021; Swann, 2018. Source calculation vertical overlap: dive depth range of input dataset for the shag individual and Meygen turbine specifications (MeyGen, 2012)

To include the bird tracking dataset as a criteria layer, a standardisation technique was chosen based on the objective formulation “Avoid horizontal and vertical overlap between tidal device and foraging shags”. As that dataset has direct measurements of the vertical and horizontal positions of the tracked shag individual, and there is 84.7-100% chance of spatial overlap of the dives with the depth range of turbines (Figure 2-13), there is a moderate degree of certainty that placing the turbine within those areas the shag forages in could lead to a spatial overlap, therefore a Boolean approach to standardisation was adopted. This decision process led to the constraint layer as shown in Figure 2-14. Even though Figure 2-8 suggests a Boolean approach is binary where all alternatives are either suitable or unsuitable, the lack of data on the space use of other shags led to the decision not to depict the rest of the area as suitable, but only highlight the areas that would be unsuitable for tidal development.

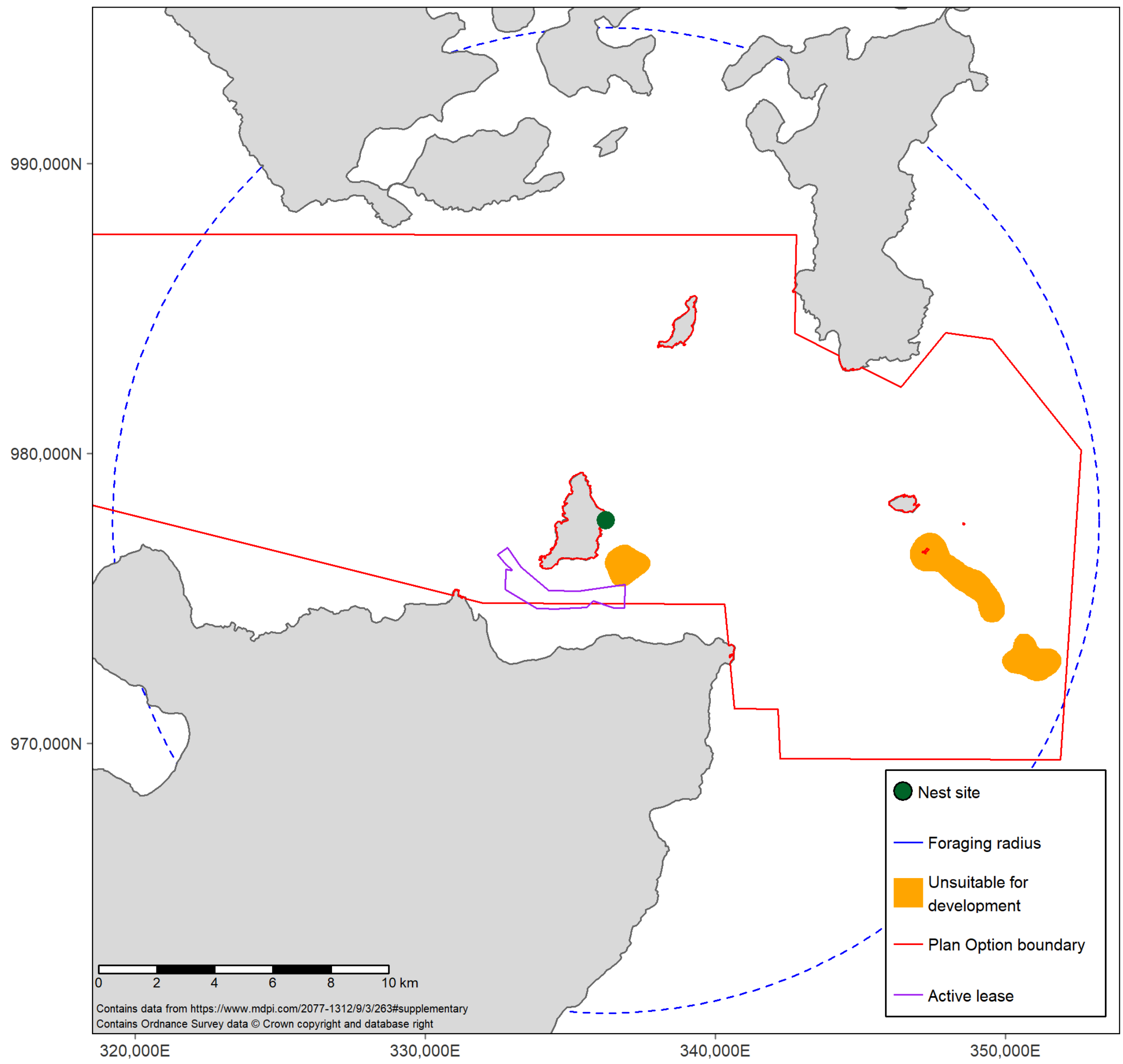


Figure 2-14 Constraint layer for tidal devices based on available shag tracking data processed into utilisation distributions by Isaksson et al., 2021 (source forage range: Thaxter et al., 2012)

2.4 Discussion

The framework was constructed to improve integration of spatial decision support tools and data into decision-making, and to make the link between planning policy and siting decisions more explicit. It is intended that the framework will enable the siting process to be more transparent, defendable and traceable, from its inception at strategic level until final site selection at project level. The framework has the potential to be used to inform and articulate siting decisions in statutory assessments e.g. strategic environmental assessments (SEA) and environmental impact assessments (EIA), and for communicating decision support tools developed within the academic realm so that they can more readily be applied in practice. The framework could also be used to communicate tool development between clients (e.g. developers) and consultants (e.g. tool makers).

Application of the framework was demonstrated at two scales: strategic level and project level. The aim of the first step of the framework was to integrate an objective formulation step into the spatial decision support process, providing a link between objective formulation, policy requirements and how data layers represent policies in place, which is currently frequently ignored in decision support tool formulation (see conclusions in Peters et al., 2020). Placing the method of the O&C tool into the framework made the link between policy and legislation requirements and the tool clear, as well as how the spatiotemporal characteristics of different receptors were represented in the tool.

By linking the datasets used in the tool with planning policies, it became apparent that while Scotland's National Marine Plan is the main document used to inform spatial planning in Scotland, there is a range of policy, legislation and guidance documents in place that inform the siting of marine developments. For example, guidelines developed by the aviation authority for helicopter routes, or more specific legislation related to bird species that applies to both marine and terrestrial contexts. Slater & MacDonald point out that effective marine spatial planning has to take into account the legislative context beyond MSP requirements (Slater and MacDonald, 2018). Moreover, Greenhill argues that the implementation of marine planning policies are constrained by pre-existing and rigid management tools (Greenhill, 2020). Therefore, when aiming to reduce consenting risk with spatial decision support, the user will need to look beyond the national marine plan when identifying constraints, which emphasises the importance of the objective formulating phase of the framework, which is in place to ensure the tool developer considers these instruments (policy, legislation, guidance) explicitly before gathering data for the criteria layers.

The objective tree (see Figure 2-4) allows non-spatial information to be considered and documented in the siting process, including policies and legislation. Accounting for this information at the objective formulation phase allows the consideration of other sectors at an early phase to be defendable and enables the decision context to be explicitly articulated. The explicit consideration of legislation in spatial decision support is also apparent in Shetland's GIS tool, where the assigned constraint levels for criteria were based on restrictions that have been put in place through legislation and policy in the past (Tweddle et al., 2014). For the protected areas layer in Marine Scotland's O&C tool, the assigned constraint levels depended on the type of protected area (Marine Scotland Science, 2018). This illustrates that as well as informing the objective formulation phase, legislation can also play a role in the later standardisation step of the workflow. Additionally, the vulnerability indices applied to the seabird layers in Marine Scotland's tool also took into account the different protection levels of the considered seabird species (Furness and Wade, 2012), so legislation can be incorporated in all steps of the framework.

The criteria typology, documentation of spatiotemporal characteristics and adopted standardisation technique elucidate how the included criteria inform the achievement of objectives. This transparent workflow can articulate inherent subjectivity in the mapping process, as suggested by Lecours, 2017. If the step-by-step framework is presented along with the final suitability map from the tool, it can allow a clear link between the outcome of the decision support tool and the individual datasets that were used to construct it, overcoming the concern that some decision support tools are perceived as a black box (Collie et al., 2013; Janßen et al., 2019). The publication of spatial decision support that informed the INTOG regions in Scottish waters already combines the illustration of some of the criteria layers with information on which class intervals were used, indicating increased transparency of the siting process is already becoming more commonplace (Scottish Government, 2021b).

The use of a criteria typology that distinguishes between natural, constructed and proxy criteria has been used before in environmental and marine decision support (Bennett et al., 2021b; Karjalainen et al., 2013), and can be used to elucidate how the link between criteria and objectives can vary. All the objectives linked with Marine Scotland's O&C tool related to avoiding risk of impact. Risk of impact not only depends on the location of a potential receptor but also on the sensitivity of the receptor, and the predicted magnitude of the effect of the proposed development (Glasson et al., 1999), which rely on a wide range of information sources as well as expert judgement (Figure 2-15).

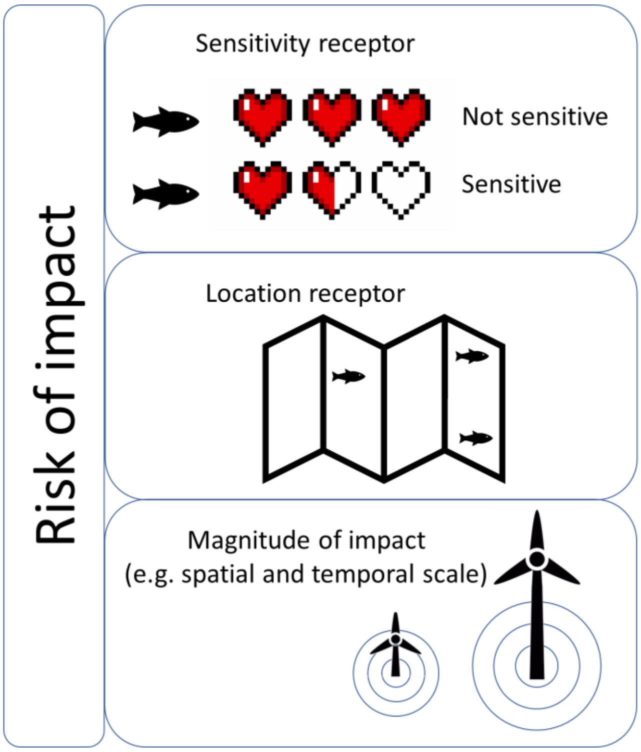


Figure 2-15 Risk of impact depends on multiple sources of information

For the case study focusing on Marine Scotland's O&C tool, over 70% of criteria were identified as proxy criteria, as they only considered information on the location of the receptor and not on receptor sensitivity. For example, knowing the locations of the nursery areas will only partially avoid environmental impact on nursery areas. Impact also depends on the sensitivity of the receptor (fish species) and the predicted magnitude of the potential impact (Figure 2-15). A 'natural' criterion for this objective would be a map of predicted risk of impact on nursery areas by wind farms across Scottish waters, but this information is not available in a spatial format at strategic level, particularly as impact will vary depending on the wind farm array design and any adopted mitigation measures. In contrast, at project level, this type of data is more readily available such as the bird tracking data processed to represent at risk behaviours as presented in the second case study. But at project level, the scope of changing location is already more limited than at a strategic level.

Generally, the included proxy criteria only represented information on the location of receptors, without considering other non-spatial factors that also influence the potential risk of impact on the receptor. In the industrial theme and socio-cultural theme, fisheries and recreational use were also included using proxy criteria that indicate the location of the activities. Safeguarding fisheries and protecting areas important to recreational users also depend on non-spatial contextual elements. For example, in Shetland's Marine Plan, as well as including the location of recreational activities, it was considered whether or not they are spatially adaptable (Shucksmith et al., 2014).

Criteria that represented the location of the receptors as well as their sensitivity, such as vulnerability to collision, were considered constructed criteria. Combining spatial distribution and sensitivity of a receptor, as was done for the seabird collision layer in the first case study (Table 2-7), indicates higher criterion suitability than 'receptor mapping' (see Figure 2-16), and in spatial decision support this combination has also been adopted for spawning grounds in the German Bight (Gimpel et al., 2013). Accounting for sensitivity of species by weighting species-specific layers with sensitivity indices is another way of including non-spatial information into spatial decision support. Modelled impacts, or 'impact mapping', as was included for radar interference, could also be included for other receptors using existing models, such as the FINLA model for fisheries displacement (Kafas, 2018a).

At project level, a review of environmental statements by Willsteed et al., 2018 identified that modelling methods were applied to differing degrees for different types of receptors, for example modelling was commonly applied for predicting underwater noise impacts but rarely for predicting habitat loss (Willsteed et al., 2018). This variability in how different receptors are considered is also reflected in the different ways in which impact for different receptors were represented in the O&C tool. Findings from applying the framework indicate that as well as the criteria typology from Keeney & Gregory, 2005, criteria suitability specifically for impact-related requirements can be characterised on a scale that ranges from 'receptor mapping' to 'impact mapping' (Figure 2-16). A recent European review of current practice highlighted there is more scope during the planning of renewable energy developments to develop methods that translate data on the abundance of species (receptor mapping) into sensitivity indicators (sensitivity mapping) (European Commission, 2020a).

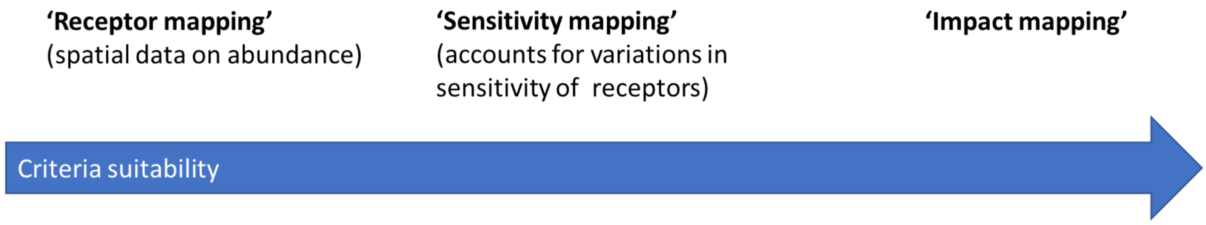


Figure 2-16 Visualisation of the gradient between 'receptor mapping' and 'impact mapping' in terms of criteria suitability

Policies and legislation related to avoiding impacts can be interpreted in different ways, as discussed in Floor et al., 2016. A lack of specificity in the wording of national planning policies has been raised as problematic for regional planning in Scotland (Greenhill et al., 2020). In this study, this lack of specificity led to difficulties in measuring the achievement of policy and legislation requirements using the data that is available to characterise Scottish waters. Attempting to formulate policy and legislation requirements that align with the included layers of the O&C tool gave an indication of how 'mappable' planning policies are that are currently in place.

It was found the policies could be interpreted in different ways. For example, the requirement to "safeguard existing fishing opportunities and activities" was represented in the O&C tool as a layer with fishing value that was standardised into low, medium and high constraint classes, while at a subsequent stage in the sectoral marine planning process, the fishing industry used a different approach to standardisation and presented a map with discrete polygons to represent which areas they wanted developers to avoid (Scottish Government, 2020c). A lack of data as well as a lack of consensus on how fisheries should be represented with data was identified as a barrier to more prescriptive policy for the fishing industry in England's East Inshore Plan (Management Organisation, 2014), as pointed out by Shucksmith et al., 2020. Moreover, contrary to the policy for protected areas and species, the fisheries-related policies in Scotland's National Marine Plan are not underpinned with legislation.

As it was found that planning policies could be interpreted in different ways and underpinned with different data, this framework could be used to 'test' future planning policies to ensure they are specific enough to be integrated into spatial decision support and therefore by implication their utility in consenting decisions. Scotland's sectoral marine plan options, that were informed by the O&C tool discussed in this chapter, are an example of clear spatial policy guidance for developers (Scottish Government, 2020b). Another example of spatially explicit policy at a regional level can be found in Shetland, where the spatial tool developed to inform the siting for renewable energy developments is directly integrated into planning policy. Different conditions within the policy apply to different constraint levels (Shetland Islands Marine Planning Partnership, 2021; Tweddle et al., 2014).

Criteria included in the strategic-level O&C tool mostly related to locations of receptors of potential impact, which were either static, semi-static or mobile receptors. Space use of mobile receptors was summarised in different ways. For example, a five-year average was taken for fisheries, while for shipping, an average of 12 months of data was taken. For the bird and cetacean species, multiple decades of data were considered. When summarising the presence of a marine user with a static map to be included in a spatial decision support tool, consideration should be given to whether it is more appropriate to take the average 'presence' over multiple years, distinguish between seasons or highlight extremes, as expressed in a consultation response by a statutory consultee for a proposed offshore wind project (MOR Ltd, 2010).

Another consultee in response to this wind project expressed that fisheries data averaged over multiple years should be treated with caution, due to changes in fishing patterns at finer temporal scales (MOR Ltd, 2010), which has been in addressed in a recent guidance document (Marine Scotland & Brown and May Marine, 2022). Through a review of the representation of fisheries in marine planning processes, Trouillet identified a lack of consideration of intra- and inter-annual variability of fishing activities (Trouillet, 2019). This framework makes these decisions explicit, to allow greater understanding of temporal components of the data, the importance of which is highlighted in Shucksmith & Kelly, 2014. Even though proposed developments may be static structures which do not move in time, they will require construction, installation and maintenance, all of which have temporal components.

Guidance specifically on how to consider dynamic users in marine spatial decision support is currently limited. Conventional approaches to summarising bird tracking data with the use of ‘plain density maps’, as depicted on Figure 2-11, has been criticised in the literature (Christel et al., 2013). Space use polygons that were calculated based on seabird behaviour (see Isaksson et al., 2021) are presented here as a novel approach to representing the activity of a mobile bird species in spatial decision support. Tracking data is becoming increasingly available and is often the most accurate way of determining spatial overlap between animals and potential impacts (Hays et al., 2019 and references therein).

Research has been undertaken on how tracking has been adopted into conservation policy and management (Hays et al., 2019), and on its potential for being used in marine spatial planning (Lennox et al., 2019), but barriers to adoption of tracking data into decision-making have been identified (Ogburn et al., 2017). This study demonstrates a concrete potential application of tracking data for informing the siting of proposed developments at sea, and the framework could ease the integration of novel data into decision-making. A combination of an objective tree, a spatial constraint layer and a qualitative indication of representativeness of the data can complement the quantitative measures of representativeness reported in (Isaksson et al., 2021). This method of presenting the bird tracking data for inclusion in spatial decision support could be adopted for other mobile users e.g. for representing fishing interests.

In the context of the siting of novel developments at sea and considering existing marine features, species and users, the value functions as presented in Figure 2-8 and Table 2-3 can be used to represent anticipated trade-offs. Quantitative trade-off analyses between proposed wind energy developments or aquaculture sites and existing species and sectors using bioeconomic modelling have allowed a quantitative maximisation of defined objectives (Lester et al., 2018, 2013; White et al., 2012). During multi-criteria decision analysis, when standardising layers of existing marine uses to inform the siting of a novel development into common constraint levels, an implicit assumption is also made regarding the anticipated trade-off between an existing feature and the proposed development, even if this is not quantified. Visualising this assumption in a graphical format using value functions, as was done for Figure 2-8 and Table 2-3, can allow novel research into these trade-off relationships to be considered when choosing a standardisation technique for a specific layer, in dialogue with interested parties. The implications of how layers are standardised using different techniques are further explored in Chapter 5. Similar to findings presented here, value functions have been demonstrated to help represent non-monetary values as well as differences in values by different actors in Palola et al., 2022.

For the bird tracking case study, the representativeness characterisation in Figure 2-13 highlights missing information such as data on more individuals and on juvenile shags. Despite these limitations, the presented data provides more locally relevant detail than the foraging radius (see Figure 2-14), which is a single figure calculated based on the behaviour of shag individuals in varying settings. This study demonstrates the potential of integrating data from animal-borne telemetry and biologging into constraint layers, when data on more individuals is available than included in this study, and for multiple years and across seasons. Elements of subjectivity in the data processing that were not reported on as part of this framework include the choice to use occurrence distribution rather than a home range distribution when calculating the space use polygons, as well as how foraging behaviour was classified (see discussion of this in Isaksson et al., 2021).

Applying step 3 to the bird tracking data identified a limitation in the framework, as a Boolean approach was deemed the most appropriate but not in its binary form – i.e. the presence data was considered unsuitable for development, but the absence data could not be seen as indicating suitable sites for development, due to limitations in the representativeness of the data. Therefore, a further adjustment to the framework could make this distinction explicit, so that in Figure 2-8 a fourth option could be formulated that caters for this situation that distinguishes between decision rule uncertainty related to available data and decision rule uncertainty associated with missing data. This fourth option would be relevant for other data types as well because generally the marine environment is data poor, therefore an absence of data does not mean an absence of risk. This would allow a distinction from the consideration of other data types that adopt a ‘true’ Boolean approach based on known data across the study area, e.g. the exclusion of cables and pipelines (e.g. Davies et al., 2014), or the exclusions of areas where energy resource is too low for feasible harnessing (e.g. Neill et al., 2017). A further iteration of Figure 2-8 is presented in Figure 2-17 to include this finding.

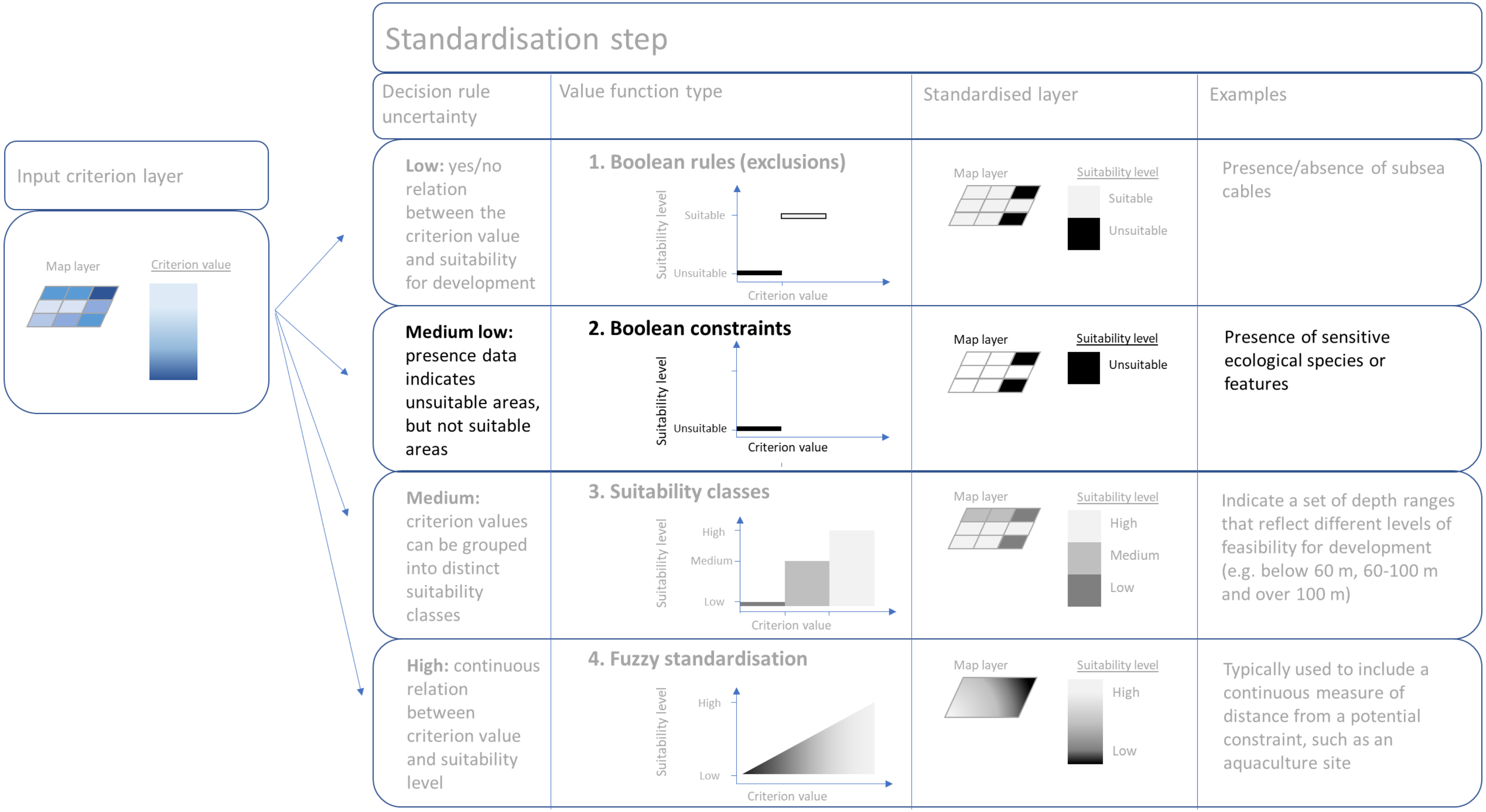


Figure 2-17 Modification of step 3 of the framework based on findings in this study: inclusion of a fourth method (Boolean constraints)

Testing the framework with the two case studies gave insights into its applicability, and how it can make the siting process more transparent. This allows comparisons between consecutive iterations of a tool, or with other tools that have similar aims. It makes it clear that subjective user inputs and decisions are required throughout the process and that different interpretations of the objectives and spatial data are possible, and a transparent workflow can make this process more accessible to all interested parties. The objective formulation phase can help to ensure that tool developers consider policy and legislation at an early phase, before populating the tool with data layers.

2.5 Limitations of study

A limitation of this study is that the retrospective application of this framework to Marine Scotland's existing O&C tool relied on the judgement of the author of this study. The author defined the policy and legislation requirements based on the literature, classified the criteria into natural, proxy or constructed types, described the spatiotemporal characteristics of the included criteria and the adopted standardisation techniques based on publicly available information. Future applications of this framework would benefit from a collaborative approach to this classification, or from a third-party review. To further evaluate whether this framework enhances transparency in decision-making, a follow-up study is suggested that investigates whether interested parties perceive the framework to aid transparency or not, to make a connection between interested parties and policy implementation. The method for such a study could be based on that developed for the CORPORATES project (Slater et al., 2020).

To increase the accessibility of the process for interested parties, a further iteration of the framework could also include an interactive tool which visualises how changes made in user inputs throughout the process will influence the resulting suitability map, such as different standardisation techniques, or different ways to summarise the spatial data used.

2.6 Conclusions

This framework allows an explicit link to be made between legislation and spatial decision support and illustrates how policies can be interpreted in different ways. The project level case study demonstrated the steps required to integrate novel data into spatial decision support, and how the data addresses information needs related to planning policies and legislation developers need to adhere to. Testing the framework on an existing tool (Marine Scotland's O&C tool) has led to some insights including the challenge of mapping the planning policies that need to be adhered to with the spatial decision support, such as avoiding impact. The exercise also highlights that planning policies within the National Marine Plan are not the only instruments that influence the siting of developments, and it allowed an evaluation of how implementable planning policies in place are for guiding spatial decisions. It also brings out the process of how data can be translated into information, for example how abundance data of seabird species can be combined with vulnerability indices to provide a form of estimation of receptor sensitivity, or how bird tracking data can be represented in the process using space use polygons.

Existing or future marine spatial planning tools can benefit from this framework because it enables an auditable and transparent decision-making process for interested parties, offshore renewable energy developers at project level, and planning authorities at a more strategic level, providing a clear overview of approaches that could be used e.g. fuzzy and classification standardisation techniques. Linking objectives (such as policy and legislation requirements) directly with datasets could also identify data gaps that can guide future marine data collection efforts.

Concepts from value-focused thinking, such as the emphasis on objective formulation and the evaluation of criteria to inform those objectives, have been adopted by other studies in relation to environmental impact assessment or socio-economic monitoring of fisheries, illustrating that even though they were not developed specifically for environmental or marine decision-making, they are still relevant, and can help with the framing of the decision problem and provide guidance for future decision support (Bennett et al., 2021b; Karjalainen et al., 2013).

3 Evaluating the current use of fisheries data during project planning of energy developments

Chapter 2 identified three steps for including criteria layers in spatial multi-criteria decision analysis. This chapter concerns the data gathering step (step 2), with a focus on data that represents the interests of the fishing industry.

3.1 Introduction

As identified in Chapter 1, the growing number of industrial energy projects at sea need to consider existing users of the marine space. One ubiquitous and long-standing user of the sea is the fishing industry (Jentoft and Knol, 2014; McConnaughey et al., 2020). With the anticipated increase in offshore wind farms and transmission cables (see Chapter 1), potential interactions between fisheries and these emerging sectors are expected to intensify, and it has caught the attention of decision makers at European, North Sea and national levels, as reflected in recent publications. For example, the European Parliament Committee on Fisheries (PECH) commissioned a review of the effects of offshore renewables on fisheries (Stelzenmüller et al., 2020). Similarly, the European Commission requested a technical study and a review of the available knowledge and information on the effects of offshore wind farms on fisheries and aquaculture (Dupont et al., 2020; Van Hoey et al., 2021).

At the North Sea level, advice by the North Sea Advisory Council on "The Development of Offshore Windfarms and Fisheries Interactions" was formulated, expressing the need for a better representation of fishing activity in marine planning, including for the anticipated increase in transmission cables (interconnectors) (NSAC, 2020). In Belgium, the 2020 edition of the marine spatial plan includes the requirement for marine developments to undertake an assessment of predicted impacts on the fishing industry (FOD Volksgezondheid, 2020). In June 2021, the UK published a policy brief on offshore wind farms and fisheries, and the National Federation of Fishermen's Organisations (NFFO) has called for the need for fisheries to be more explicitly included in the marine planning system, also specifying potential interactions with inter-array cables (APPG on Fisheries, 2021; NFFO, 2021). Finally, a literature review as well as guidelines for developers were commissioned by The Crown Estate (UK) and Marine Scotland (Marine Scotland & Brown and May Marine, 2022; Marine Scotland & Xodus, 2022a, 2022b).

As elaborated on in Chapter 2, the way in which fisheries are considered during the siting process of a new energy development is influenced by the type and availability of evidence that is being used to represent them. In contrast to the more ‘mappable’ spatially and temporally stable sectors such as aquaculture, the spatiotemporally dynamic nature of the fishing industry complicates reaching an understanding of the value of fisheries to an area of interest (Trouillet, 2019). This is illustrated in Figure 3-1, where a comparison is made between a. the discrete locations of aquaculture sites and b. live positions of a moving vessel equipped with AIS.

Figure 3-1 a. Aquaculture sites found around Shetland and the North of Orkney (source: Aquadat/NMPi, Open Government Licence (OGL)) b. Track from a fishing vessel over the course of 24 hours, colour range shows changes in speed (source: screenshot from the openly available site www.marinetraffic.com)

Figure 3-1b. illustrates that spatial data to understand fisheries activities can have a high resolution, even showing when the vessel slowed down, but the data does not include information on fisheries-specific activities – e.g. whether it was out fishing or not and what it may have landed. In contrast to the availability of high resolution data depicting vessel movements, details of the locations of fish landings are communicated using ICES rectangles, which are approximately 30 nautical miles by 30 nautical miles in size (GOV.UK, 2021; Marine Scotland, 2016). Data is reported at a broader scale than the size of proposed projects, therefore it cannot inform siting decisions at finer spatial scales.

To overcome this loss of information when landings are reported at such a coarse scale, high resolution vessel tracking data obtained via the vessel monitoring system (VMS) has been processed so that the landings from one ICES square are attributed to the fishing vessel activities recorded by the VMS (see Figure 3-2). VMS records a ‘ping’ every two hours to depict the location, speed and course of the fishing vessel, which can be used to determine when the vessel is engaged in fishing. Another type of vessel movement data is AIS which is publicly available (while raw VMS data is government-held) and higher in spatial resolution, but it requires more processing (Shelmerdine, 2015).

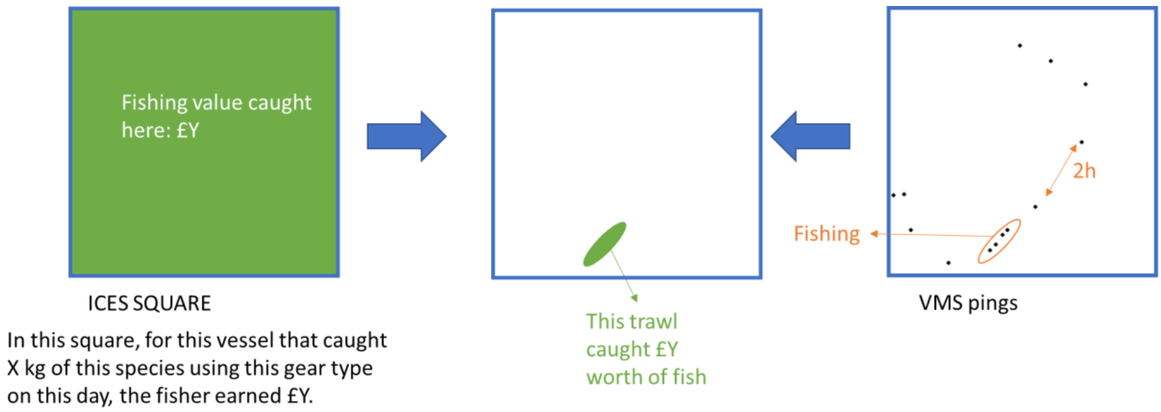


Figure 3-2 Illustration of how VMS data is linked to ICES square landings

Another issue with vessel movement data is that only vessels larger than 12 m are equipped with a VMS, whilst most inshore fishing fleets are smaller than 12 m (in 2020, 25% of vessels registered in Scotland were over 10 metres in length and 75% were shorter than 10 metres, (Marine Scotland, 2021)). AIS is only required for vessels over 15 m (Table 3-1). In Scotland, initiatives have been set in place to increase data availability on smaller vessels lacking AIS or VMS equipment, i.e. those <12 m and 12-15 m. For the Scotmap project, 1090 fishers were interviewed between 2011-2013 to collect data on the spatial patterns of fishing vessels under 15 m in length (Kafas et al., 2017, 2014), and the Scottish Inshore Fisheries Integrated

Data System (SIFIDS) project focused on developing low-cost alternatives to VMS for small-scale fisheries such as inshore fleets (Mendo et al., 2019c).

Table 3-1 AIS and VMS requirements for fishing vessels

	Under 12 m	12-15 m	15-18 m	18-24 m	Over 24 m
AIS			Required since 2014	Required since 2013	Required since 2012
VMS		Required since 2012	Required since 2005	Required since 2005	Required since 2005

Sources: MCA, 2020, MMO, 2014, 2019, European Commission, 2003

As well as understanding the fleets' spatiotemporal footprint, socio-economic data also plays a role in characterising fisheries space needs (Janßen et al., 2018; Trouillet, 2019; Trouillet et al., 2019). Socio-economic data refers to the relation between economic activity and social life, such as employment, infrastructure, services and health (Kruse et al., 2009). Such type of data is needed to understand the value of a fishing area for onshore communities, such as for employment, tourism, the reliance of processing plants on landings, or upstream businesses such as shipyards (Billing et al., 2018; Brookfield et al., 2005; Ross, 2013; St. Martin and Hall-Arber, 2008).

Understanding the spatiotemporal footprint of fishing vessels, as well as the socio-economic value their activities represent, can be challenging to characterise (Bennett et al., 2021b). Yet, the way in which potentially affected fisheries are considered in decision-making has procedural justice implications (Jenkins et al., 2016). As an increasing number of energy projects in Scottish waters have now progressed to the post-consent phase, there is a vast array of publicly available information on the siting and impact assessment processes of various types of proposed developments. This provides the opportunity to explore how the energy industry currently considers the complexity of the fishing industry when integrating fisheries data into project planning. This chapter will assess:

1. What fisheries data were included?
2. How was it used in the project planning and impact assessment process?
3. To what extent did the data represent the affected fisheries?

3.2 Methodology

The impact assessment and licensing process for energy projects, which is explained in Section 1.3.6, is informed by fisheries data, including socio-economic characteristics. The use of fisheries data by 21 Scottish case studies dating between 2011-2020 was analysed using an evaluation framework developed for this study. The evaluation framework was composed using guidance documents aimed for developers as a starting point, which were assumed to reflect best practice. The evidence base on commercial fisheries used by project developers was scored using the framework, to identify whether data needs were met, and if not, how data collection efforts can be prioritised to meet data gaps. Quantitative data collection using the evaluation framework was complemented with insights from interviews with a range of individuals. Responses from interviewees that may be more value-based than the quantitative framework allowed a more in-depth analysis of the research questions. This combination of two independent methods is known as a mixed methods approach with a convergent design, and can be used to identify similarities and differences in results collected using different methods, to answer the same research questions (Creswell and Creswell, 2018; Robson and McCartan, 2016). Section 3.2.1 outlines the development of the evaluation framework and is followed by an introduction of the case studies (3.2.2) and interview methods (3.2.3).

3.2.1 Evaluation framework

A framework was developed to evaluate the evidence base on the fishing sector used during siting and impact assessment of the case studies. The framework focuses on two receptors: fish and shellfish species, and commercial fisheries (Table 3-2). In environmental assessments, ‘fish and shellfish species’ and ‘commercial fisheries’ are usually considered as two distinct receptors to which two separate chapters in an environmental statement/environmental appraisal are devoted to, albeit with a recognition of interactions between them. The evidence base for the commercial fisheries receptor is divided into subcategories under the headings of fleet composition, spatiotemporal patterns and socio-economics. Data quality is evaluated for both receptors, and impact assessment is only assessed for the commercial fisheries receptor (for which guidance documents were available).

Table 3-2 Scope of the evaluation framework (indicated by crosses)

Category	**Fish and shellfish**	**Commercial fisheries**			
		Overall	Subcategories		
Theme #			Fleet composition	Spatiotemporal patterns	Socio-economics
1. Evidence base	X	X	X	X	X
2. Data quality	X	X			
3. Impact assessment		X			

Since no framework exists yet to specifically assess the use of fisheries data in the environmental impact assessment, a framework developed by Willsteed et al. 2018 for evaluating impact assessments in environmental statements of offshore wind farms for ecological receptors (not including fisheries) (Willsteed et al., 2018), as well as fisheries-related guidance documents intended for use by developers (Blyth-Skyrme, 2010; FLOWW, 2014; Seafish and UKFEN, 2012), were used to develop a set of indicators that were organised into categories (see App 3.1 for full framework).

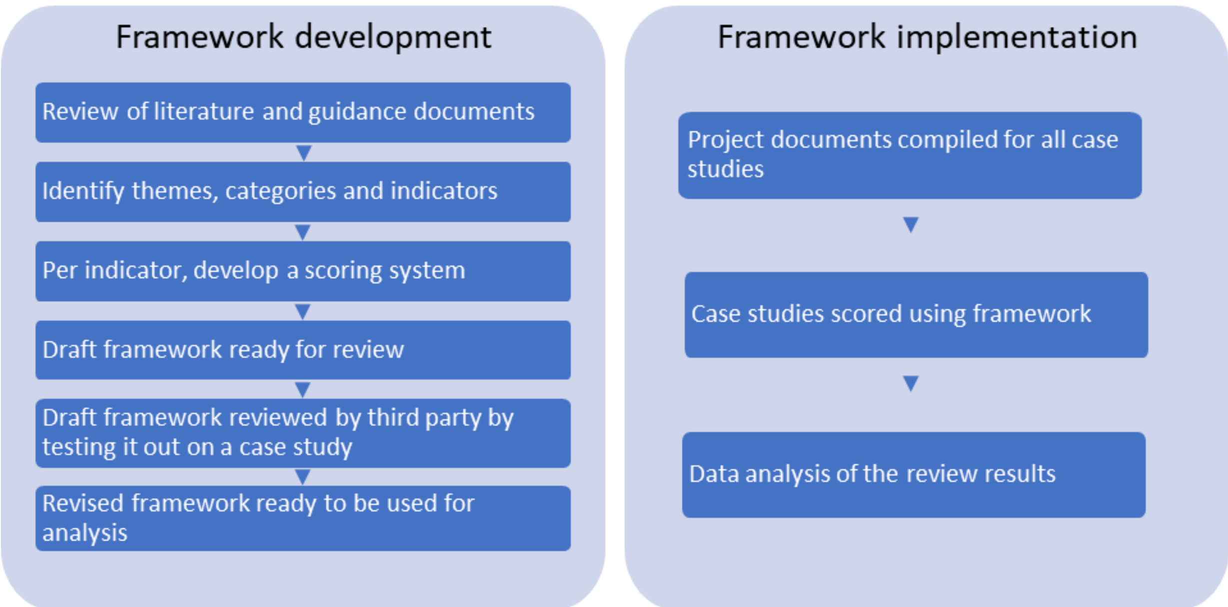


Figure 3-3 Workflow for developing and implementing the framework, based on the approach taken by Willsteed et al., 2018

Figure 3-3 gives an overview of the steps taken to develop and implement the evaluation framework. Literature on the interactions between renewable energy projects and the fishing industry as well as guidance to help developers liaise with fisheries were reviewed, and they guided the formulation of three themes, four categories and 40 indicators. The themes were used to group different aspects of fisheries data, and categories distinguished between types of data. The indicators consisted of a combination of yes/no indicators and indicators for which a scoring system was developed (App. 3.1). The indicators were formulated by going through the literature and existing guidance documents aimed for improving practice (Batts et al., 2017a; Blyth-Skyrme, 2010; FLOWW, 2015, 2014; Seafish and UKFEN, 2012; Shelmerdine et al., 2017), and reformulating recommendations into indicators to assess whether guidance was being adopted (see App 3.2 for references used per category/indicator of the framework). A pilot case study was used to test the framework, scored by two different researchers independently and then compared. The pilot study identified the need for a mid-point score option (as was adopted in Willsteed et al., 2018), when two aspects of a case study would lend themselves to two different scores for the same attribute. After amendments in the wording of the indicators and the inclusion of the possibility of assigning a mid-point score, a final framework was adopted for the analysis.

Theme 1: Evidence base

The evidence base was evaluated for the 'Fish and shellfish' receptor, as well as for 'Commercial fisheries' for which three subcategories were formulated: fleet composition, spatiotemporal patterns and socio-economics. For the fish and shellfish receptor, the evaluated evidence base included data that was used to represent fish and shellfish species during siting and impact prediction, such as the locations of spawning and nursery grounds of fish species. The referenced sources for all the case studies were grouped into categories to obtain a general understanding of what type of sources were used, and the number of references per category was recorded. The same approach was used for the commercial fisheries receptor.

For the commercial fisheries subcategory 'Fleet composition', the way in which vessels using the study area were characterised was evaluated. The subcategory

‘Spatiotemporal patterns’ included indicators which assessed how the time-varying space use of the fishing industry was included, such as with spatial data on effort and landings. The aim of the ‘Socio-economics’ category was to assess the inclusion of social and economic data such as employment, income and knock-on effects on the fish processing industry. Table 3-3 gives a brief description of each category of the framework. All indicators of the framework and their scoring can be found in App. 3.1.

Table 3-3 General description per (sub)category of the indicators included for evaluating the evidence base of the case studies

Category	Description indicators
Fish and shellfish	Whether or not natural variability was considered for the different considered species
Commercial fisheries: Fleet composition	Whether home port of the vessels active in the project area (and surroundings) was specified
Commercial fisheries: Spatiotemporal	Spatial and temporal resolution and extent of the considered vessel activity is scored
Commercial fisheries: Socio-economics	Whether or not income and employment data are considered, jobs/businesses in the supply chain or processing sector costs and earnings

Theme 2: Data quality

The data quality indicators were formulated based on data confidence assessments, which evaluate the reliability of datasets used in a study with a set of independent indicator that represent different aspects of data quality (Crowther and Gray, 2016; Marine Management Organisation, 2013; Pedersen Weidema and Suhr Wesnaes, 1996; Shucksmith et al., 2014). Existing data confidence assessments, which were not focused on analysing the use of fisheries data, were reviewed to inform the indicator formulation (see Table 3-4). The defined data quality indicators were organised into a pedigree matrix to form a multi-criteria evaluation of the underlying evidence base of the case studies (see Table 3-5).

Table 3-4 Existing literature reviewed to inform the development of the four data quality indicators

Application	**Source**
Introduces pedigree matrix method (including scoring and visualisation using radar diagram)	(Funtowicz and Ravetz, 1990; Van Der Sluijs et al., 2005)
Assessment of data quality needs for ecosystem-based marine spatial management	(Issaris et al., 2012)
Assessment of quality of evidence used in decision-making by the Marine Management Organisation	(Marine Management Organisation, 2013)
Assessment of data confidence of the datasets incorporated into the Shetland Islands' Marine Spatial Plan	(Shucksmith et al., 2014)
Assessment of the evidence base of the monitoring and evaluation of spatially managed areas	(Stelzenmüller et al., 2015)
Assessment of data quality of data included in the Irish Marine Atlas used to assess a proposed offshore wind farm	(Crowther and Gray, 2016)

Four data quality indicators were included: a) evidence, b) recognised uncertainty, c) timeliness and d) spatial dimensions (Table 3-5). They were used to score data sources found in the project documents for the two receptors: fish and shellfish and commercial fisheries. The 'Evidence' attribute is adapted from previous assessments of uncertainty associated with the evidence used in decision-making (Issaris et al., 2012; Stelzenmüller et al., 2015). It aims to capture the capability of the data source to inform the decision-making, where a data source that consists of measured and locally verified data scores higher than data sourced from large-scale datasets not visibly cross-validated.

The aim of including the 'Recognised uncertainty' attribute was to understand how uncertainty is dealt with when data was used during project planning, with the scores aiming to make a distinction between ignorance (where uncertainty is not acknowledged) and recognised ignorance (where uncertainty is identified and/or quantified (Bijlsma et al., 2011; Funtowicz & Ravetz, 1990; Shucksmith et al., 2014; Vanessa Stelzenmüller et al., 2015). 'Timeliness' was used to measure the data vintage of the sources used and the 'Spatial dimensions' attribute analysed whether the data included spatial characteristics such as location and extent (Shucksmith and Kelly, 2014).

Table 3-5 Pedigree matrix for data quality. Scores can be assigned from 0-3 for four variables

	Attribute	***0***	***1***	***2***	***3***	***Based on***
A	**Evidence (E)**	Data source not mentioned	Data from an authoritative source (e.g. ICES) but not visibly verified by local sources	Data visibly verified with local sources (score of 1.5 for verification with a non-local source)	Measured (not modelled) and locally verified data	Issaris et al., 2012; Stelzenmüller et al., 2015
B	**Recognised uncertainty (U)**	Data limitations and uncertainties not mentioned	Acknowledged data limitations and uncertainties	Quantified data limitations and uncertainties	Compounding error from analysing multiple datasets with (known) uncertainties acknowledged	Bijlsma et al., 2011; Funtowicz and Ravetz, 1990; Shucksmith et al., 2014; Stelzenmüller et al., 2015
C	**Spatial dimensions (S)**	Unknown or uncertain extent and location details	Neither location nor extent are identifiable to a reasonable degree of accuracy	Location or extent accurately identified, but not both	Both location and extent accurately identified	Shucksmith et al., 2014
D	**Timeliness (T)**	Older than 10 years/not mentioned	Older than 5 years	Older than 2 years	Within last two years	Shucksmith et al., 2014

Theme 3: Impact assessment

The impact assessment category of the evaluation framework used a guidance document composed by Seafish and UKFEN to score impact assessment techniques (Seafish and UKFEN, 2012). Indicators were identified based on a review of the guidance compiled by Seafish and UKFEN (UK Fisheries Economics Network) for financial and economic impact assessments of fishing industry receptors (Seafish and UKFEN, 2012), the guidance document from the COWRIE project (Blyth-Skyrme, 2010) and the FLOWW guidance (FLOWW, 2014). The FLOWW guidance, "FLOWW Best Practice Guidance for Offshore Renewables Developments: Recommendations for Fisheries Liaison", was put together by the Fishing Liaison with Offshore Wind and Wet (FLOWW) Renewables Group. Chaired by The Crown Estate, this group was set up in 2002 and includes representatives from around the UK (FLOWW, 2014). To assess the relevance of this guidance to the projects, reference to each of these guidance documents was also recorded for each case study, but not included in the data analysis (Indicator 0 in App. 3.1).

For all three themes (evidence base, data quality and impact assessment), a scoring system was used with values ranging from 0-3 or 0-4. For indicators that were not deemed relevant for particular case studies, e.g. potential re-employment when no impacts on employment are predicted, there was the option of scoring 'not applicable'. Detailed description and scoring of the indicators can be found in App. 3.1. For the data quality analysis, scores were assigned per dataset and different numbers of datasets were included per study. To enable comparisons between case studies, the maximum score per case study was calculated. Data analysis was undertaken in R (R Core Team, 2021). Radar diagrams were constructed with the pedigree matrices using the 'fmsb' package in R (Nakazawa, 2019). The median and inter-quartile range was used to calculate a representative score per sector, because the scores are ordinal data and had a skewed distribution. Plots for the spatiotemporal indicators were made using the 'ggplot2' package in R (Wickham, 2016). Scores were summarised per indicator, per vessel length and per sector. The mean and standard deviation were used as summary statistics here as the sample size ($\mathrm{n} = 772$) was deemed large enough for parametric statistics.

3.2.2 Case study selection

A case study protocol was developed based on case study methodology literature (Tellis, 1997; Yin, 2003). The unit of analysis across case studies was the consideration of fisheries throughout the project life cycle. A list of all consented projects in Scottish waters within the relevant sectors was compiled, based on the Marine Scotland Licensing Operations website[5] (consulted throughout 2020) for the transmission cable, tidal and offshore wind projects, and on the SSEN projects page[6] (consulted May 2019) for the cable replacements. Irrelevant projects were eliminated based on the criteria listed in Table 3-6. For each criteria the reason for elimination is justified.

Table 3-6 Criteria used to select case studies

	Criteria	***Justification***
1	Identifiable interaction of the project with the fishing industry	A case study is not relevant if fisheries impacts are scoped out of any environmental assessment.
2	Impact assessment should be publicly available	Without the impact assessment documentation (environmental statement or equivalent) there is not enough information available to compare with other case studies.
3	Project completion after 2010	After the implementation of the Marine (Scotland) Act 2010
4	Commercial-scale fixed offshore wind projects only (>100 MW)	Avoid imbalance of offshore wind case studies compared to other sectors

Only commercial-scale offshore wind case studies (as opposed to demonstration projects) were selected because these represented the most recent projects at the time and avoided an imbalance of the number of offshore wind case studies compared to the other sectors. Commercial-scale projects are defined as generating at least 100 MW of electricity (Scottish Government, 2020b). This process of elimination led to a selection of 5-6 case studies per sector, and 21

[5] http://marine.gov.scot/mslot-all-application-and-project-documentation
[6] http://news.ssen.co.uk/submarinecables/information/

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case studies in total. For the offshore wind and tidal projects, the impact assessment of the export cables was also included.

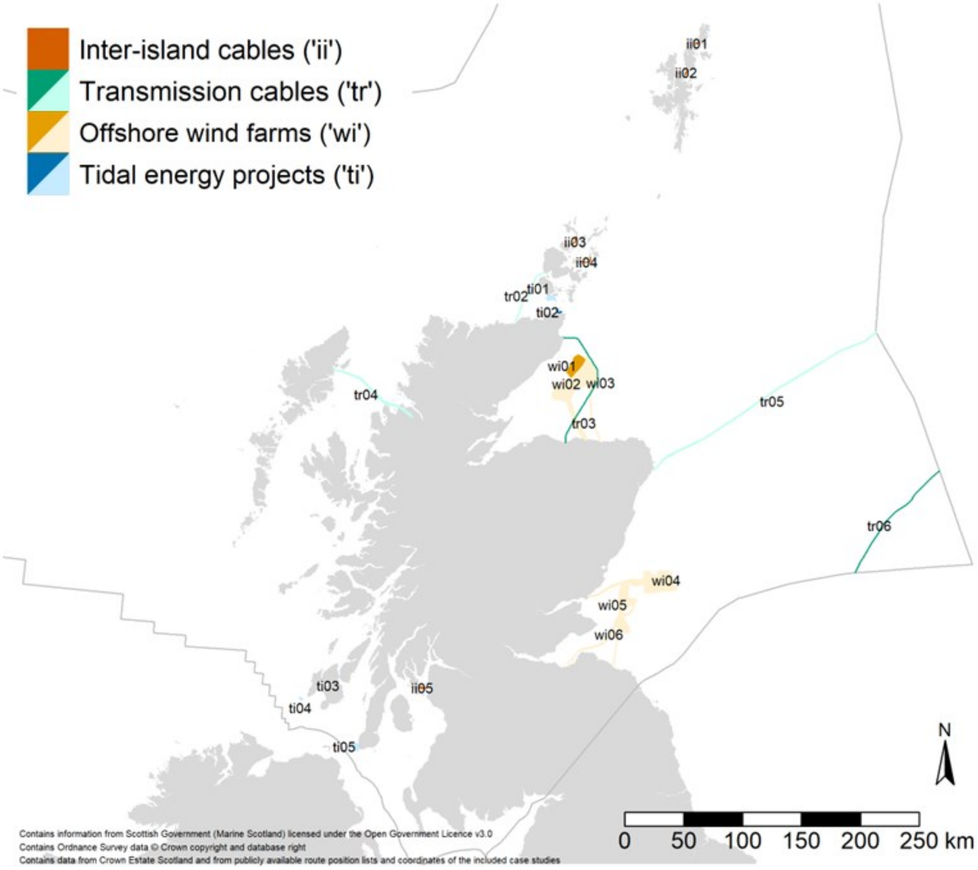

Figure 3-4 Included case studies, with incomplete projects in a lighter shade (as of October 2021). Inter-island cable, transmission cable, offshore wind farm and tidal energy projects were given codes which are indicated at the locations of the projects

The project planning phase of the 21 case studies occurred at different time frames and concerned different locations in Scottish waters. Spatial variation in case studies can enhance an understanding of the role different spatial contexts play, and temporal variation in case studies allow differences between time periods to be identified (Sovacool et al., 2018). However, an analysis of case studies that vary in space and time can make it difficult to make general conclusions (Sovacool et al., 2018). Care was taken to be conscious of the differences in time period and location when interpreting results. For earlier case studies, not all documentation was available online. Consideration was given to important milestones that could affect the inclusion of fisheries data, i.e. whether project documents were published before or after the publication of the FLOWW guidelines or the implementation of Scotland's National Marine Plan which occurred in 2014 and 2015 respectively (FLOWW, 2014; Scottish Government, 2015a). The FLOWW guidelines are in place to improve the consideration of fisheries during project planning, so project documents preceding 2014 could not have benefited from these guidelines (FLOWW, 2014). Scotland's National Marine Plan includes policies that developers should align with during project planning, e.g. considering fisheries and fish habitats (Scottish Government, 2015a). During the interpretation of the results, results were only generalised across case studies when they were seen to be relevant to all case study types.

Per case study, project documents were compiled, and in some instances this included more than one environmental statement for the same project. This occurred when developers had to apply for a new licence, for instance if changes were made in the siting or design of the project that had already obtained a licence previously. The documents listed in Table 3-7 were used to score the various aspects of the case studies using the evaluation framework, and the evaluation focused on fish and shellfish and commercial fisheries data mentioned in the documentation.

Table 3-7 List of documents consulted for the analysis

Document	Section
Scoping report*	Planning/site selection
	Fish and shellfish
	Commercial fisheries
	Shipping and navigation
	Socio-economics
Environmental statement* - Main document	Planning/site selection
	Fish and shellfish
	Commercial fisheries
	Shipping and navigation
	Socio-economics
Environmental statement* - Appendices	Commercial fisheries technical report
	Navigational risk assessment
	Cable burial risk assessment
Fisheries Liaison Mitigation Action Plan (FLMAP) (for cable case studies)	
Commercial Fisheries Mitigation Strategy (for offshore wind farms)	

* Or equivalent for case studies not requiring a formal environmental impact assessment

If additional information was required, other chapters or documents were also consulted. Fish and shellfish species, commercial fisheries, shipping and navigation and socio-economics chapters were included in the analysis because they all address potential effects on the fishing industry. Fish and shellfish species may be affected by the proposed developments including through changes in the electromagnetic field (Gill et al., 2020; Hutchison et al., 2020). Commercial fisheries chapters address potential impacts specific to the commercial fishing industry, and the shipping and navigation chapters are included because proposed developments may have potential impacts on navigational safety (Gill et al., 2020). Fisheries-specific impacts include loss of access to fishing grounds and displacement effects. Finally, potential socio-economic knock-on effects include impacts on fisheries-dependent shore-based industries of changes in the fishing activity as a result of proposed projects (Kafas, 2018b). These potential impacts all relate to sector-specific planning policies that must be adhered to under the Marine (Scotland) Act 2010, as specified in Scotland's national marine plan (TRANSPORT 1, FISHERIES 1-3 (Scottish Government, 2014b)).

3.2.3 Semi-structured interviews

As well as analysing documents related to the case studies, a series of interviews were conducted, which were informed by a mapping exercise to identify the relevant parties involved in the process.

3.2.3.1 Identifying the interested parties

Interested parties were mapped out to identify relevant interviewees for this study. The method was based on a 2021 study by Schupp et al, which identified three interest groups: offshore wind interests, commercial fisheries interests and the regulator (Schupp et al., 2021). For the purposes of this study, the interest group representing the regulator was broadened to encompass other roles of government, as well as subdividing the group representing fisheries interests as illustrated in Figure 3-5. Throughout this study, the three main categories will be referred to most often, but the subdivisions were used during the recruitment of interviewees to ensure a balance of perceptions. In total 20 participants were interviewed, between January to September 2020. This consisted of six interviewees from the cables or renewable energy industry, six participants from the government and eight fisheries interviewees. The participants from the fishing industry were either fisheries representatives or fishers themselves, representing both large-scale and small-scale fisheries. Two face-to-face interviews were conducted prior to the onset of the COVID 19 pandemic, after which all interviews were held online. This may have influenced the composition of interviewees: it posed challenges in terms of reaching out to potential interviewees, as this could only be done by e-mail or phone. On the other hand, it did not limit the study to interested parties based in locations accessible to the author (who was based in Shetland), which has reduced geographical bias in selecting interviewees.

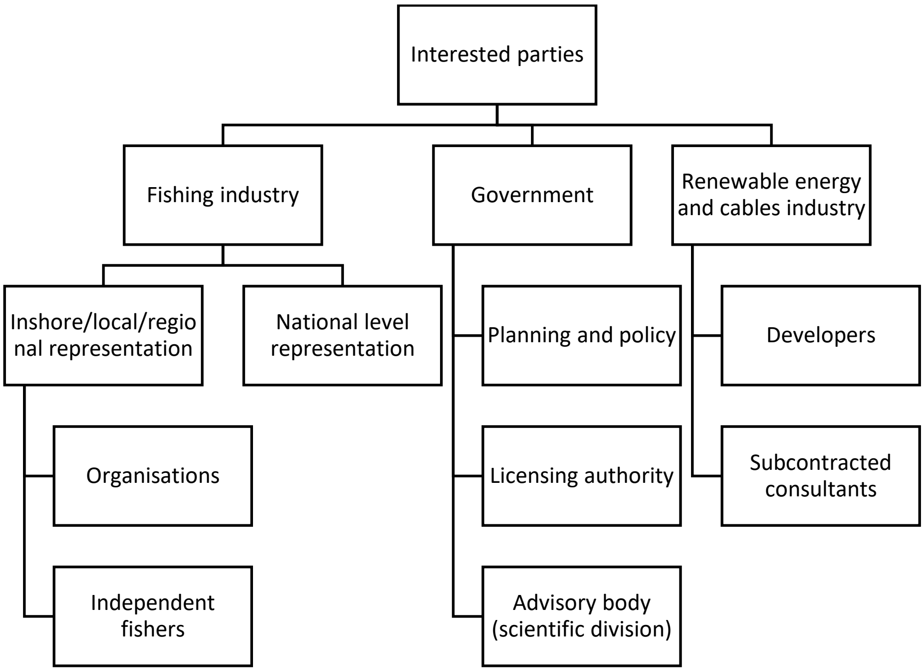

Figure 3-5 Map laying out the actors involved in the process of considering fisheries interests during offshore energy projects

3.2.3.2 Interview method

To determine how different parties may have different perspectives on the consideration of fisheries during the project life cycle of energy developments, semi-structured interviewing using an interview guide was considered the most appropriate option. Semi-structured interviews are not confined to a fixed set of questions and are used to gather in-depth information to understand underlying motivations and attitudes (Bernard, 2006). Individuals that had experience with the chosen case studies were selected where possible, to allow a triangulation with the results obtained from evaluating the project documents using the evaluation framework. Some interviewees were familiar with multiple case studies, while others could give detailed insights on a specific case study. The interviews added depth and context to the findings from applying the evaluation framework.

To recruit participants, both snowball and purposive sampling was used. Snowball sampling is a process where initial contact with some participants leads to contact information for more participants (Edwards and Holland, 2013). To avoid any bias towards any one interest group over the others, the snowball sampling was initiated with purposive sampling to ensure each group was equally represented. Purposive sampling is when individuals are deliberately selected to represent certain groups (Neuman, 2014). For this study, participants were interviewed in relation to their profession, also called expert or elite interviewing (Bogner et al., 2009; Edwards and Holland, 2013). One of the challenges with this type of interviewing is that participants may be constrained as to what information they can share (Edwards and Holland, 2013). To overcome this challenge, as much as possible, for larger organisations a combination of someone leading the project and someone active 'on the ground' was invited, to have access to a more comprehensive perspective. The interview guides varied in wording according to the type of interviewee but aligned with the same overarching themes (see version per interest group in App. 3.3). The questions are summarised across interest groups in Table 3-8.

Table 3-8 Interview guide across interest groups

1. Role of fisheries data to represent fishing interests during the site selection of a project/avoidance of impacts?
2. What do you think about the data sources used in the fisheries characterisation and how their limitations are acknowledged?
3. Was sufficient data on inshore fisheries included?
4. Is there any data missing you think could be included?
5. Do you think there would be value in having more data available on the link between the affected fishing fleet and onshore buyers and processors?
    - If yes, at what stage in the project could this be relevant?

3.2.3.3 Anonymising the interviews

The results based on the selected case studies (for the textual analysis as well as for the interviews) were presented in an anonymised format. Case studies and interviewees were only identifiable per sector and interest group (fisheries, government or energy industry). The results were shared with the interviewees to ensure they are content with the level of anonymisation and recording accuracy (see App. 3.4). The study received ethical approval from the University of the

Highlands and Islands ethics committee, and the documents that were submitted for the ethics application can be found in App. 3.4. The sequence of conducting the interviews and analysing the case studies was organised so that small-scale developments and locally represented participants were analysed/interviewed first, while large-scale developments and participants active in decision-making at a national level were analysed/interviewed last. Individuals active at a national level were more relevant to interview once all case studies had been analysed – as they had experience with the widest range of case studies.

3.2.3.4 Processing and analysing interviews

All interviews were transcribed from audio recordings by the interviewer (IW). Interview transcripts were coded based on the themes and categories of the evaluation framework, so that results from the two methods could be triangulated (e.g. "Evidence base – Socio-economics", see App. 3.2). NVivo 12 software (QSR International Pty Ltd., 2018) was used for coding the interviews. In terms of complementing the case study documentation with interviews, the participants were not familiar with all considered case studies, and especially for older case studies, participants may no longer recall specific experiences or potentially relevant details. Moreover, it was more challenging to find interested parties to interview that were involved in older projects as they may have moved positions since their involvement. Therefore, the interview results reflect general views on the elements of the framework rather than feedback on specific projects.

3.3 Results

Fisheries activities are a complex use of the marine space, which is why a framework was developed in this study to evaluate how different aspects of fisheries space use are considered during project planning. Findings reveal insights into how fisheries are represented, in addition to perceptions on this from interviews. The results are reported per theme (evidence base, data quality, impact assessment) after reporting on which guidance documents were used by the case studies.

3.3.1 Guidance used

The FLOWW guidance, "FLOWW Best Practice Guidance for Offshore Renewables Developments: Recommendations for Fisheries Liaison", (FLOWW,

2014) was the most widely referenced document with all developments conducting assessments after its publication in 2014 referring to it (14/14 case studies). As the FLOWW guidance was specifically developed for renewable projects, cable projects referred to this guidance in the context of “where applicable”. Of the pre-2014 impact assessments, 2 of the 7 case studies referenced an earlier guidance document by the FLOWW group (BERR, 2008). The Seafish and UKFEN guidance, “Best Practice Guidance for Fishing Industry Financial and Economic Impact Assessments” provides guidance on how to assess socio-economic impacts (Seafish and UKFEN, 2012). As it was specific for impact assessments, it was only relevant for case studies for which an environmental appraisal (EA) or environmental impact assessment (EIA) was carried out after its publication in 2012 (14/21). It was referenced in 8/14 case studies, and 5/8 of these case studies were offshore wind farm projects. “Options and opportunities for marine fisheries mitigation associated with windfarms”, a report that was part of the COWRIE project (Blyth-Skyrme, 2010), was published in June 2010 which pre-dates all the environmental assessments considered and was used by 7/21 case studies. It was developed specifically for wind farms, which is reflected in its use: it was mentioned by two thirds of the wind farm case studies but only 20% of the non-wind farm case studies. References to guidance documents are summarised in Table 3-9.

Table 3-9 References to guidance documents in the case studies

Guidance document	References in case studies
FLOWW, 2014	14/14
Seafish & UKFEN, 2012	8/14
Blyth-Skyrme, 2010	7/21
BERR, 2008	2/7

3.3.2 Evidence base

In total, 322 references to data sources (for both the fish and shellfish and commercial fisheries receptors) were identified in the project documents of the case studies, from a diverse range of sources, which complement each other. As all case studies were situated in Scottish waters, there was some overlap of sources used. For the fish and shellfish receptor, these sources were used to obtain information about the location of fish and shellfish species, and their spawning and nursery grounds. For this, scientific studies and surveys were used as sources, as well as landings data held by the government and primary data collection (Table 3-10). The contribution to the evidence base of projects of a series of related scientific reports and academic papers on the spatial whereabouts of spawning and nursery grounds in UK waters is demonstrated by how all case studies referred to at least one of them(Aires et al., 2014; Coull et al., 1998; Ellis et al., 2012, 2010; González-Irusta and Wright, 2016a, 2016b). As well as that, there were projects that conducted their own surveys, such as trawl surveys to obtain more detailed information about spawning grounds, feeding grounds and nursery grounds in the project area. This allowed more precise information on the receptors to be considered.

Table 3-10 Data sources identified for the fish and shellfish receptors

Category	Type of source	Number of citations
Scientific	Scientific reports	60
	Academic papers	4
	Data from scientific projects	4
	Book chapters	3
Government	Data from government surveys	14
	Government-held fisheries data (e.g. landings)	9
	Data from strategic environmental assessment / marine planning document	3
	Government-held open-source data (NMPi)	1
Primary data collection	Data collected by developer/neighbouring developers	23

In relation to the completeness of the fish and shellfish evidence base, all case studies obtained the maximum score of 3 except for the cable replacement case studies (Table 3-11). Even though the high scores indicate species-specific information was considered in the case studies,

a limitation of this indicator is highlighted by how [I03], [I14] both iterated the need to consider the impact of climate change on the whereabouts of fish stocks, which was not included as a factor in the framework.

Table 3-11 Score for indicator evaluating evidence base for the fish and shellfish receptor

Sector	Mean score across case studies (max = 3 points)
Wind	3
Tidal	3
Cable replacements	2
Transmission cables	3*

*One case study excluded from this metric (missing documentation)

To characterise the commercial fisheries receptor, as well as making use of existing data such as government-held statistics, Table 3-12 indicates developers also collected their own AIS and radar data using a temporary survey station, which is put in place at multiple times of the year to better understand marine traffic in the project area. This information from a primary source provides fine-scale detail in relation to spatiotemporal dynamics of vessels active in the area.

Table 3-12 Data sources used for characterising commercial fisheries across case studies

Category	Type of source	Number of citations
Government-held	Statistics per ICES square as well as finer-scale data collection projects (such as Scotmap)	46
	VMS data	46
	Aerial surveillance sightings	24
	Data collection projects (e.g. Scotmap)	16
	Fleet register*	4
	Data analysis outputs by government department	4
	Stock assessments	2
	Vessel and employment statistics	2
	Data from marine planning documents	2
	Government-held open-source data (NMPi)	2
Other national-level data sources	Seafish economic survey of the UK fishing fleet	2
	JNCC Coastal Directories Project	1
Regional studies and datasets	Orkney	8
	Clyde	2
	Shetland	2
Primary data collection	Marine traffic survey (AIS/radar)	24
	Surveys (benthic/acoustic/video)	2
	Consultation (Meetings, interviews, questionnaires, participatory mapping)	12

* Fleet register was used as a source in other cases as well, but not specifically referred to

Table 3-13 summarises the ways in which the evidence base for the fish and shellfish and commercial fisheries receptors were applied during project planning. The framework was not explicitly designed to capture the purpose of the inclusion of fish(eries) data in the documentation, but this information was gathered in Table 3-13 so that the context of the data inclusion could still be considered.

Table 3-13 Overview of how fish and shellfish data and commercial fisheries data were used during project planning

Document type		How was the data used, what function did it have at that step of the process
Initial routing/siting studies		Informs initial siting decisions
Scoping		Informs scoping in or out of potential effects on different segments of the fishing industry as well as different fish and shellfish species
Environmental Impact Assessment Process	**Fish and shellfish ecology technical report**	Provides information on fish and shellfish species present in the project area
	Commercial fisheries baseline	Provides information on fishing activity in the project area
	Navigational risk assessment	Assessment of safety risks associated with the project for fishing operators, including an assessment of marine traffic in the area
	Cable burial risk assessment	Gear type specific assessment of fishing activities to inform cable burial method
	Environmental statement	Fish and shellfish ecology technical report and (updated) commercial fisheries baseline informs expert judgement of the sensitivity of the potentially affected fish and shellfish species and commercial fisheries, and magnitude of the potential impact

3.3.2.1 Evidence base fleet composition

As well as the overall results for both receptors, Sections 3.3.2.1-3.3.2.3 report on the evidence base for three subcategories related to the commercial fisheries receptor: fleet composition, spatiotemporal footprint and socio-economics.

This indicator scored the availability of information on home ports of potentially affected vessels. Values reported for this study include N/A (information could not be found), 1.5 (when it was found for one section of a fleet and not for another), and 2 (home port specified). All but two (19/21) case studies scored the maximum of 2, for one case study this information could not be found (project was included in this study but not all documentation is available online yet) and for one case study information for vessels under 10m was missing (so it scored 1.5). These results indicate information on home ports was included in the majority of case studies, which can be used to link space use at sea with onshore activities.

Table 3-14 Score for the fleet composition category

Sector	Mean score across case studies per sector (max = 2)
Wind	2
Tidal	2
Cable replacements	1.9
Transmission cables	2*

* One case study excluded from this metric (missing documentation)

3.3.2.2 Evidence base spatiotemporal footprint

Spatially explicit information on fisheries activities identified in project documentation (n=384) was scored using the four spatiotemporal indicators. Spatiotemporal data was collected in various formats. Seven case studies incorporated outputs from participatory mapping during consultation events, including vessel details of the interviewed skippers. AIS data (12/21) as well as data from surveillance sightings (15/21) were included in fisheries baseline reports. Government-held data reported per ICES statistical square was included in all case studies. Across case studies, 169 maps represented vessels for which no vessel length was distinguished, 123 maps represented vessels longer than 12 m (19/21 case studies considered VMS data). Ninety-two maps represented vessels smaller than 12 m.

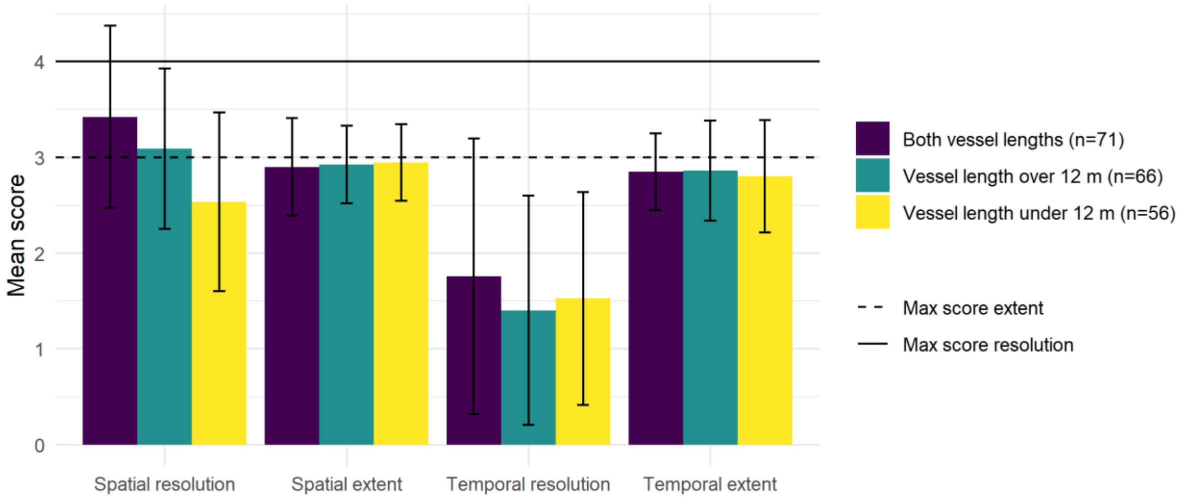

Figure 3-6 Bar chart showing the mean scores and standard deviations of spatiotemporal indicators per vessel length

Overall, temporal resolution was the spatiotemporal indicator that scored the lowest of all indicators (Figure 3-6). Spatial and temporal extent indicators scored consistently high. Spatial resolution did not score as low as temporal resolution, but also showed considerable variation, denoted by the error bars. The low results for resolution indicate fine-scale temporal and spatial differences may not be represented. The highest scores were found to represent vessels of both lengths in purple for the spatial resolution indicator, reflecting the spatial accuracy of the AIS and surveillance datasets used by the case studies. These types of data have a high spatial resolution, but are only snapshots of temporal space use, so they scored lower for temporal resolution. For the other indicators, differences in scoring between vessel lengths were less apparent.

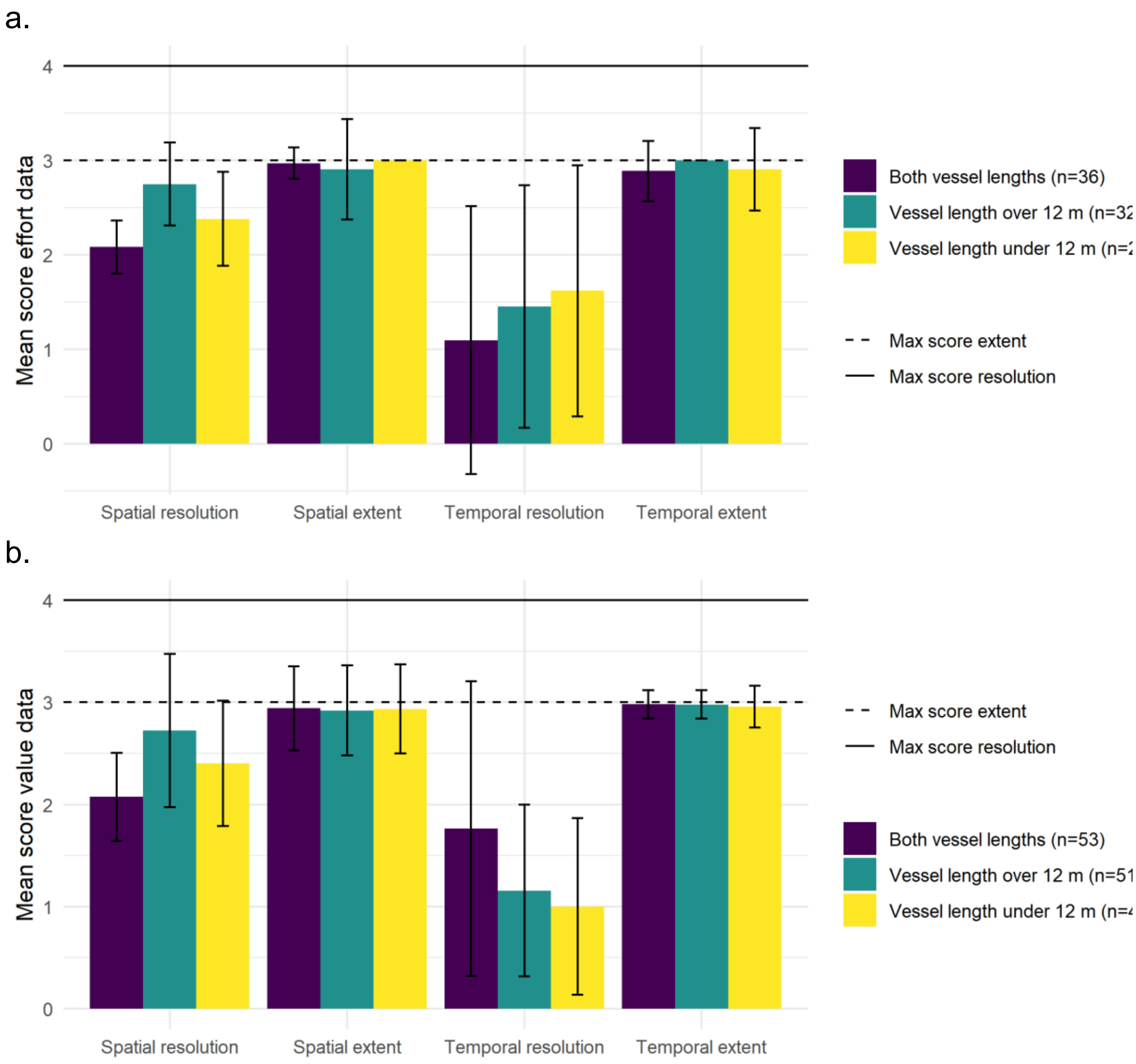

Figure 3-7 Scores for the spatiotemporal indicators for a. effort data and b. value (in GBP) data

Over two thirds of the data sources represented value (in GBP) and effort data, and the scores of these data source are shown in Figure 3-7 with part a. showing scores for effort datasets and part b. scores for value datasets. Compared to Figure 3-6 which includes all datasets, the spatial resolution indicator has lower scores for the effort and value datasets separately – it excludes high resolution datasets that do not contain any information on fisheries activities/landings (such as AIS or vessel surveillance data). The distinction between datasets using ICES square data ('Both vessel lengths' in purple) and datasets using VMS data linked with effort and landings data (vessel length over 12 m) is reflected in higher scoring of the data representing vessels over 12 m for the spatial resolution indicator. Figure 3-8 shows the differences in scoring between sectors, and as with Figure 3-6 and Figure 3-7, the lower scores of the temporal resolution indicator are also apparent here.

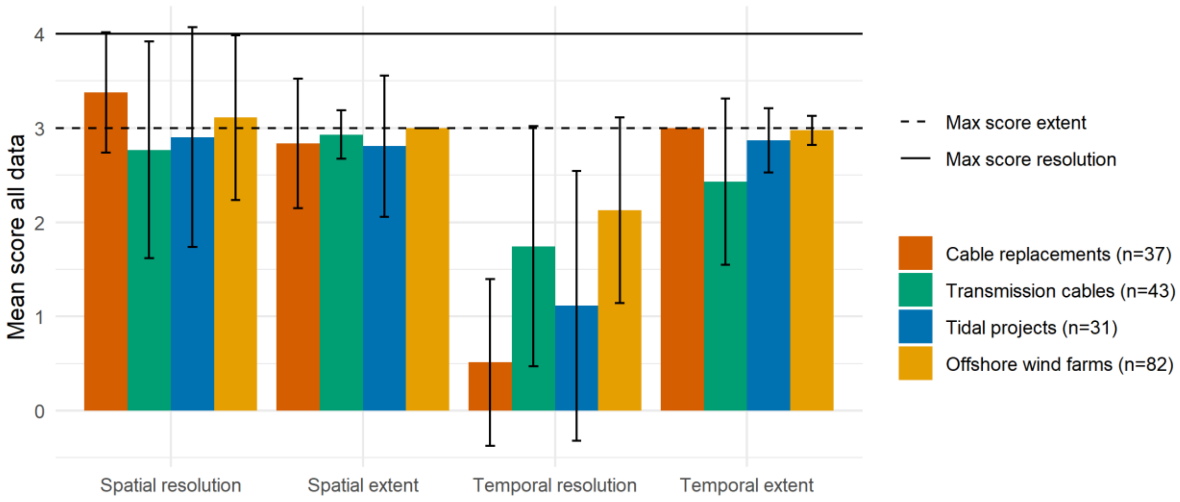

Figure 3-8 Scores for spatiotemporal indicators per sector

In terms of spatiotemporal footprint, all case studies distinguished fishing activities per gear type and per species (as was evaluated through indicators 1.3.5 and 1.3.6, App. 3.1). Yet interview results point out this distinction was not made at every spatial resolution – a fisheries representative expressed that it was not possible to evidence species-specific fisheries space use for one of the project areas, because government-held VMS data was not always species-specific due to confidentiality concerns [I14]. To overcome this, multiple participants suggested the use of plotter data owned and interpreted by fisheries bodies, where someone with expertise can identify specific fisheries based on spatial patterns in the plotter data, which can corroborate VMS data [I11], [I14]:

> *"so when people come to us we can sit down and say that happens there, that's important, this happens, and then they can match it up to the data that the government holds"* [I11]

An inshore fisheries representative highlighted the need for more data on inshore fishing activities to evidence space use [I10]. However, another inshore fisheries representative was doubtful of the value that mapping fisheries data brings:

> *"unfortunately maps quite often do us more damage than good… all it has done is secured in developers minds the idea that they can put a value on an area of land i.e. a field and say okay that's just a tiny field you've only got one cow on it. if you lose that one cow bad luck to you but it's nothing in the whole scheme of things… it doesn't capture the different mindset of* [I07]

how you use natural resources which is not segmenting it off into squares and property-owned areas."

These insights indicate a complexity that could not be captured with the evaluation framework designed for this study.

Applying the framework to the project documents revealed that the temporal resolution indicator scored lowest across all sectors and vessel sizes for both effort data and value data, indicating case studies do not fully consider seasonal patterns. The mean scores for the temporal resolution for all four plots (Figure 3-6-Figure 3-8) do not reach the score of two (except for the wind farm sector), indicating seasonality was not considered in a large proportion of the cases (the case studies were given a score of 2 if seasonality was considered, see App. 3.1). Data collected at the ICES rectangle resolution has monthly data available which can be used to identify seasonal fishing patterns, but finer-scale data such as VMS, AIS or aerial surveillance data are either snapshots in time or averages over multiple years.

There is also a large standard deviation range for the temporal resolution indicator, implying inconsistency between project documents of the various case studies. Throughout the project documents of the case studies, it was evident that consultation with the fishing industry provided information on seasonality of activities where this could not be derived from the data. This was also reflected in the interviews: an interviewed fisher that engaged in one of the consultations explained that the proposed site was used in winter by fishers as it provides more shelter than the grounds they would fish in during summer or during periods of calm weather [I06].

Related to temporal extent, applying the framework indicated that fishing activity was typically considered over the most recent five years of data available, reflected in the relatively high scores for temporal extent in Figure 3-6 to Figure 3-8. However, during interviews, fisheries representatives pointed out that longer time scales are also relevant [I10, I11, I14]:

"there has to be a kind of deeper understanding as well that habitats do change, and fisheries do change so say that somebody hasn't fished somewhere for 3 years… it might have been used for the last 70." [I10]

"there's a lot of stuff, there's a lot of things that don't happen now that happened 20 years ago, and we don't want to say to them, there's never any fishing there". [I11]

3.3.2.3 Evidence base socio-economics

Table 3-15 Results for socio-economic indicators per sector (FTE=Full Time Equivalent). Per indicator, the number of projects that include the information is listed in brackets, and for indicators where a score is assigned, this is reported on

	Cable replacements	Transmission cables	Tidal projects	Wind farms
Fishing income data	-	-	3/5	-
Number of crew	-	1/5	1/5	-
Number of FTE per vessel	-	1/5	1/5	-
Proportion of fisheries income disrupted	Max (5/5)	2 (1/5)	Max (1/5)	-
Number of fishers employed that will be affected	-	Max (1/5), 2 (1/5)	Max (1/5)	-
Number of jobs/businesses in the supply chain industry that will be affected	-	2 (1/5)	2 (2/5)	-
Processing sector costs and earnings	-	-	Included in scoping (1/5)	-

Table 3-15 summarises results for the socio-economic indicators. Across case studies, socio-economic data related to fishing activities are currently not an integral part of the baseline characterisation. This is contextualised by an interviewee from the cables/renewables industry:

"effects on the fish processing industry would only be relevant if it was permanent [the impact] *and maybe if there was no compensation for significant impacts"* [I03]

"*if we impact on the creels we impact on the creelers, we impact on socio-economics. So from a point of view of doing a route selection, I only have to worry about the creels. But I know at a later stage I'm going to do an assessment of the creelers and socio-economic impacts takes that into account*".

During the textual analysis, it was found that the onward processing of fish and shellfish landings was only mentioned in the scoping report of one of the case studies (Table 3-15), and through the interviews it was identified that fish processing does not always take place locally in the project area:

"We've had three shellfish processing factories on [Scottish Island]*, mostly paid for by HIE [Highlands and Islands Enterprise] money, and all shut. Because everything goes off the island unprocessed basically."* [I09]

An interviewed fisher did not anticipate the processing sector would receive less fish due to a change in fishing patterns because of a renewable energy or cable development, as the catch could just come from somewhere else instead [I06]. An alternate view was expressed by a fisheries representative based in another island community:

"*So if every site was consented it would probably have wiped out crab and lobster fisheries and with that the processing factory that we have in* [coastal town] *which at that time was a big employer. So economically these things are all inter-related you know it's – because it's critical mass of throughput, and a factory needs a quantity to make it viable, and if you're to keep employers on you have to have a certain amount of work for them to do every week and suddenly they have nothing for weeks"* [I07]

Two fisheries representatives also highlighted upstream business such as repair shops, blacksmiths and ship chandlers as having important ties to fishing activities [I07], [I10]. Also, when calculating monetary value earned by inshore fisheries from a specific sea area, interviewees indicated it would be lower than monetary value earned from a renewable energy development or another type of fishery such as pelagic fishing [I09], [I10]. However, an inshore fisheries representative emphasised the need to consider relative value of a sea area rather than the absolute value, and its value to the family and community it is supporting:

"of course it's not gonna be anywhere near that value. But it's supporting that family it's supporting that community it's supporting ... I think that's [I10]

when relative value becomes really important. Because if you look at it that way, these multinational renewable companies of course will make more revenue than our guys. So then do we just say they take all the space? So I don't think I don't think it's as easy just to compare it I think it needs kind of bespoke socio-economic work….particularly in the communities that we deal with because they are quite fragile I mean depopulation at this coast is running at a massive amount, island communities are the same…these factors I think are very easy to not consider in meeting rooms in Edinburgh or London… one person's being impacted is, it can be devastating. So I think there has to be more of an understanding of the local economy, the local socio-economics"

The importance of this understanding was also echoed by an interviewee from the cables/renewables industry:

"So let's make sure that we work with them [the fishers] *and that we understand what those impacts are … It's really important that you understand all those little impacts, whether it's on the one-man band, whether it's on the white fish boats that is going to affect a whole family, or the massive boats that have got 20-30 people on them. Or the plant that they come back in to and does the processing. It's really important that we understand. Are we going to impact on these people's livelihoods or not"* [I03]

Other interviewed fisheries representatives reported a lack of understanding:

"there's been a failure to understand, just about at every level, really how fishing works" [I07]

"When the difference in understanding became clear, we have had to put a lot of effort in to explain fishing for people that are primarily engineers, to try and work towards co-existence" [I11]

3.3.3 Data quality

For the data quality theme of the textual analysis, Figure 3-9 illustrates scores per sector and receptor using radar plots. As reflected in the varying shapes of the case studies plotted on the axes, the data quality scores differed between sectors. However, two common results can be derived across sectors and receptors from the plots: there is the most overlap between case studies (the most shading) at the axes representing the spatial dimensions (S) and timeliness (T) indicators, indicating case studies scored highest for these two data quality indicators. The least populated and thus lowest scoring axis is the 'Recognised uncertainty' (U) indicator, which had a median score of 1/3 across all case studies and receptors.

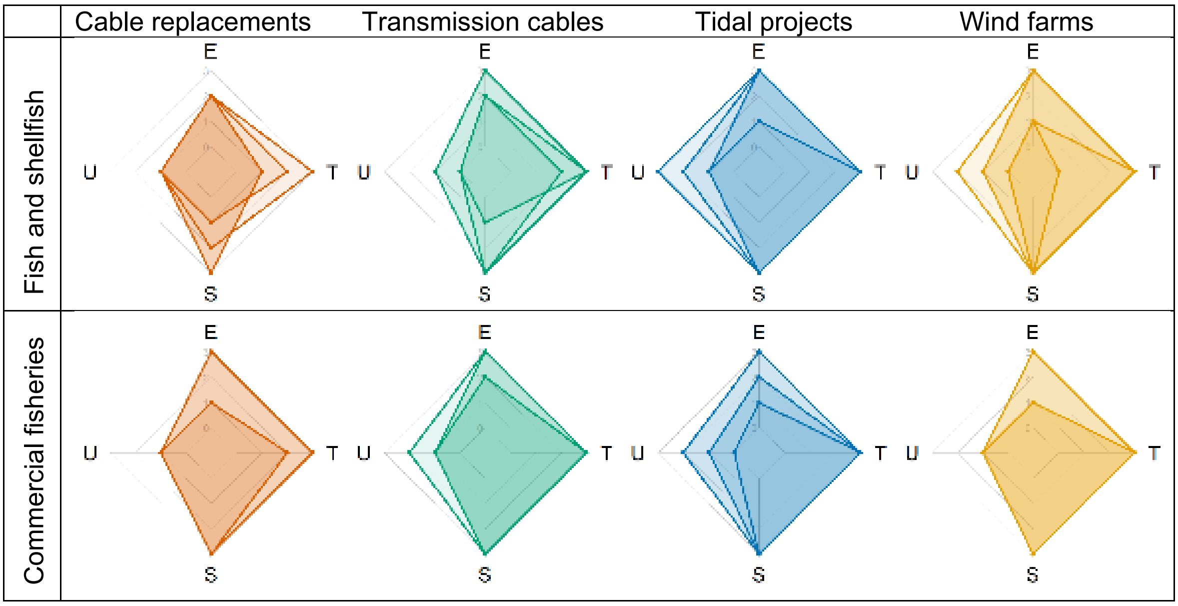

Figure 3-9 Radar plots for data quality indicators per sector (E: Evidence, T: Timeliness, S: Spatial dimensions and U: Recognised uncertainty)

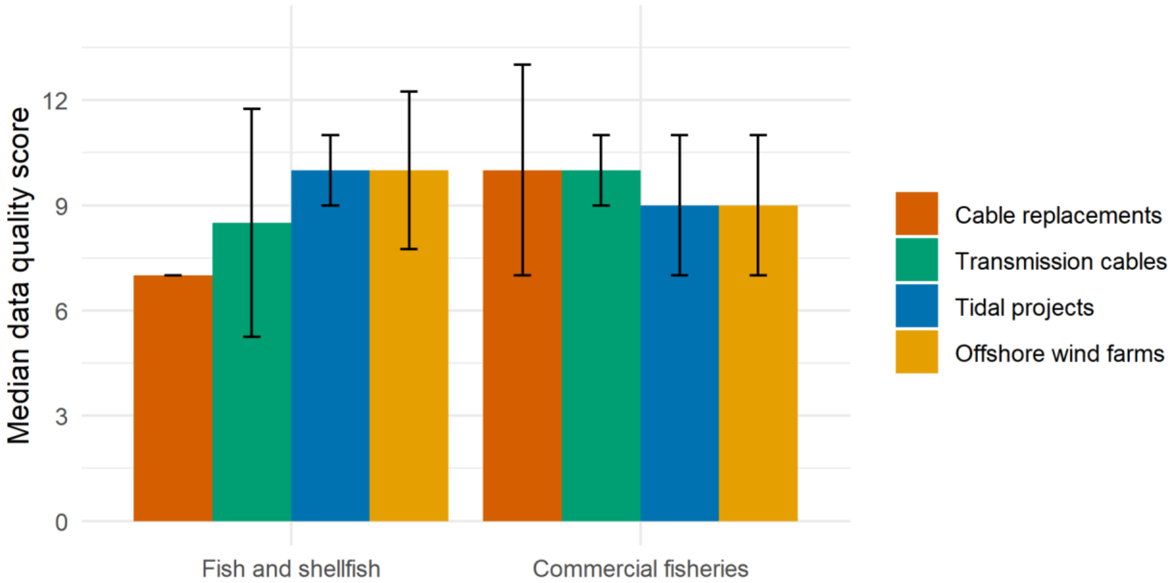

Figure 3-10 Median data quality score and IQR per receptor and per sector

Figure 3-10 allows a comparison of data quality between the two receptor groups: fish and shellfish data and commercial fisheries data. The tidal projects and offshore wind farms score better for the fish and shellfish category than for the commercial fisheries category, whilst the cable replacements and transmission cables score better for the commercial fisheries category than the fish and shellfish category. However, there is a large inter-quartile range, indicating a large variation between case studies within sectors.

3.3.3.1 Evidence indicator

For both the fish and shellfish and commercial fisheries data, all case studies mentioned the data sources (no case studies had a score of 0). For the fish and shellfish species data, except for three case studies, a minimum score of two was given for the evidence indicator, where data not only came from an authoritative source but was also verified with local representatives or local data sources. For the commercial fisheries data, 11/21 case studies achieved the highest score of using measured, verified data.

3.3.3.2 Recognised uncertainty

Table 3-16 Scores for 'Recognised uncertainty' indicator for all datasets included

	Scores for recognised uncertainty indicator			
	0	**1**	**2-3**	**Sum all scores**
All	155	157	10	322
%	48%	49%	3%	100%
Cable replacements	14	33	0	47
%	30%	70%	0%	100%
Transmission cables	66	25	1	92
%	72%	27%	1%	100%
Tidal projects	23	29	8	60
%	38%	48%	13%	100%
Wind farms	52	70	1	123
%	42%	57%	1%	100%

Table 3-16 shows the total number of data sources per score option: 0, 1, or between 2-3. As can be seen on the pedigree charts, as well as in Table 3-16, only 3% of the case studies quantified data limitations or uncertainties or acknowledged the compounding error. For 48%, uncertainty was not acknowledged and for 49%, uncertainty was acknowledged (but not compounding error).

Results for the 'Recognised Uncertainty' indicator per receptor:

- **Fish and shellfish –** Only 1/20 case studies scored the maximal value of 3, while 2/20 case studies scored a value of 2. Data limitations and uncertainties (score of 1) were acknowledged by 13/20 case studies, while 4/20 case studies did not include any mention of uncertainty in project documents. For one of the case studies, documentation on how fish and shellfish species were considered was not publicly available and was therefore excluded from analysis (hence 20 rather than 21 case studies)

- **Commercial fisheries –** No case studies scored the maximal score of 3 for the commercial fisheries data, 3 case studies scored 2, 17/21 scored 1, while 1 case study did not include acknowledgement of data limitations and uncertainties in any of the project documents (so scored 0).

To sum this up, uncertainty is considered to varying degrees in the case studies.

3.3.3.3 Spatial dimensions and timeliness

Table 3-17 Overview of the results per receptor for the spatial dimensions and timeliness quality indicators

	Spatial dimensions	Timeliness
Fish and shellfish species	17/20 case studies scored the maximum of 3 where both location and extent were accurately identified	14/20 case studies scored the maximum score of using data within the last two years, whilst only one case study relied on a source older than 10 years.
Commercial fisheries	All case studies scored the maximum of 3 for commercial fisheries data	Apart from two case studies, maximal scores of 3 were assigned for the timeliness indicator, indicating datasets that data from within the last two years were used.

As described in Table 3-17, data sources used to characterise the fish and shellfish species were timely, but recent datasets were combined with references to older publications, such as Coull et al., 1998 (Table 3-18). This indicates that a publication older than 20 years is still deemed relevant, albeit in combination with updates.

Table 3-18 Overview references to spawning and nursery ground publications UK

Data source spawning and nursery grounds	Year	# Case studies that refer to this source
Coull et al.	1998	18/20
Ellis et al.	2010	3/18
Ellis et al.	2012	15/18
Aires et al.	2014	6/11
González-Irusta & Wright	2016-2017	1/11

For the commercial fisheries receptor, for projects with documents published 2014 onwards which overlapped with the study area of the Scotmap project (Kafas et al., 2017), 10/12 case studies included Scotmap data in their fisheries baseline assessment.

3.3.4 Impact assessment

For assessing impacts, the proportional area technique (proposed area/total ICES statistical rectangle area*total ICES statistical rectangle landings) was found to be adopted by only one case study. Cable replacement case studies were not scored with this indicator as no impacts were assessed for those projects, and for one project the relevant documentation was not publicly available. All but three (12/15) case studies considered differences in effort per ICES rectangle, and one case study corroborated effort data with available information on average annual income per vessel (£). All but one (14/15) case studies also reported consulting with potentially affected members of the fishing industry before assessing impacts. Even though the cable replacement projects did not formally asses impacts as part of their project planning, impacts on the fishing industry including safety risks were incorporated into a cost-benefit analysis decision support tool used to inform choice of cable installation technique (SHEPD, 2019).

3.4 Discussion

Results from applying the framework provided valuable insights, but also show the framework was limited in the extent to which it could capture the complexity of the planning process. Also, discrepancies between framework results and interview results were apparent, highlighting the importance of context. Section 3.4 will discuss results pertaining to how data gaps were dealt with, how data was adopted in decision-making and how interested parties perceived the effectiveness of data use during siting and impact assessment. This is followed with a brief reflection on the data collection approach taken for this study.

3.4.1 Ensemble analysis fills information gaps on temporal dynamics of the fisheries

To capture the spatiotemporal dynamics of the fishing industry, the textual analysis results in Section 3.3.2.2 indicate spatial patterns are well represented but changes over time and seasonality are underrepresented compared to spatial location in the case studies. Even though VMS has led to improvements in spatial resolution of available data, publicly available spatial information derived from VMS is not available at a high temporal resolution, even if the raw data is collected every two hours, due to confidentiality concerns. To overcome this, primary data collected through consultation as well as using AIS and radar equipment at the project area allowed more detailed fishing patterns to be considered at a finer temporal scale, indicating a triangulation of data sources is required to understand fisheries space use.

Ensemble analysis combines multiple sources of fisheries data for a better spatial representation of fishing effort (Stelzenmüller et al., 2022; Thoya et al., 2021), and this study identified this approach is applied in a project planning context as well. To capture the added value of combining multiple datasets, the evaluation framework can be adjusted for future research so that it assesses the combination of multiple sources to contribute to reaching an understanding of the fishing patterns, rather than scoring individual data sources, as was done for this study. Such an analysis could capture how different datasets complement each other and how the limitations of each dataset are considered.

3.4.2 Temporal extent and the condition of the commercial fishing industry

While in this study a maximal score for temporal extent was given when multiple years of data were considered, changes on a decadal scale were also deemed relevant by interviewees. The need for consideration of a larger time scale for nomadic fleets such as scallop dredgers is reflected in a recently published guidance commissioned by Marine Scotland. For considering interactions specifically between offshore wind farms and the scallop dredging fleet, data of at least the last 7 years is recommended, and ideally 10-15 years of data. For other fishing methods, a shorter 5-year period is recommended (Marine Scotland &

Xodus, 2022b). However, interviews allude to changes in fishing patterns beyond that, spanning over the last 20-70 years. Data on such a large temporal scale may be relevant to assess the condition of specific fisheries, similar to how the condition of a receptor species is assessed (e.g. if it is threatened or not).

Current spatiotemporal patterns of certain fleets may be the result of restrictions that have been in place for multiple decades, such as the Common Fisheries Policy, marine protected areas or other changes (Lloret et al., 2018). Understanding changes in fisheries space use across multiple decades could also better reflect the time scales at which the proposed development is expected to have an effect, e.g. subsea cables are expected to be in place for 30 years or more. A better understanding of the condition of different fleet segments could inform their sensitivity to loss of fishing grounds, and the need for an understanding of this was highlighted in a recent publication by the National Federation of Fisherman's Organisations (NFFO, 2021). It could also be used to understand the capacity of a fleet segment to adapt to changes, which has been identified as one of the components that should be taken into account when characterising fisheries (Trouillet et al., 2019).

However, as Table 3-1 indicates, prior to 2005 there is a lack of spatial data on fisheries space use. In another EIA review study focusing on cumulative impacts, there was also a lack of consideration of the condition of ecological receptors for which impacts were assessed, unless it was a receptor of conservation interest (Willsteed et al., 2018). The authors of the NFFO publication and the EIA review both caution against a 'shifting baseline' syndrome, where the current condition is implied to be the natural baseline condition of the receptors (NFFO, 2021; Pauly, 1995; Willsteed et al., 2018). For ecological receptors, Willsteed suggests baselines could be agreed on at a regional level, so that a common reference point can be taken for different projects (Willsteed et al., 2018). A similar approach could be adopted for the different segments of the fishing industry.

3.4.3 Lack of access to government-held data and the potential role of fisheries representatives as data managers

Despite the spatial resolution indicator scoring relatively high for the case studies in the textual analysis, an interviewee indicated there is still a lack of data to evidence space use of a proposed project area at the level of species-specific fisheries, such as the *Nephrops* fleet. This was attributed to a combination of limitations in the spatial resolution of species-specific statistics reported at the ICES square level, and barriers to access to VMS data held by the government, even for fisheries representatives. One approach that was suggested that could overcome this limitation is the use of plotter data when it is owned and managed by fisheries representative bodies. This approach is not currently being used at a project level but has been adopted for strategic decision-making, as part of the sectoral marine planning process for offshore wind (Marine Scotland, 2019).

Having ownership over data and how it is used ensures fisheries representatives are invited to the decision-making process and can enhance procedural justice of the process (Haggett et al., 2020), as demonstrated by a fisheries data collection project in France (Trouillet et al., 2019). Another example of data ownership is the Shetland Shellfish Management Organisation (SSMO, identified as a community based management initiative by Goodlad, 2000), which collects and manages data on the fishing activities carried out by its members (over 100 vessels are listed members (SSMO, 2021)), using grid cells that are more detailed than ICES rectangles (Figure 3-11). Fishing federations taking up the role of data managers was also suggested in Rodwell et al., 2013, based on the results of a workshop that brought together members from the fishing and from the renewable energy industries.

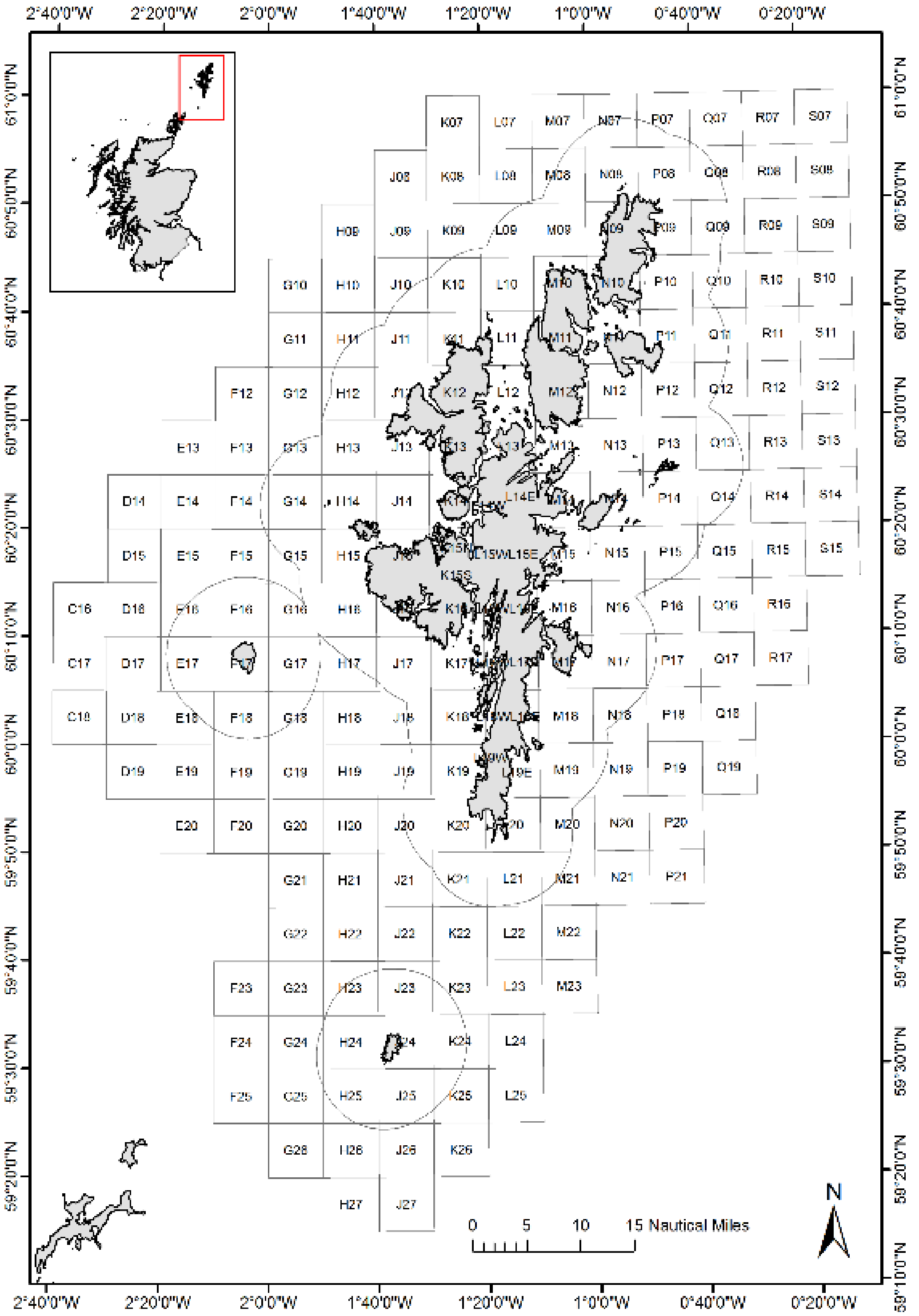

Figure 3-11 SSMO squares used to log landings by its members (source: UHI Shetland)

3.4.4 Distinction between data availability and an understanding of the fishing industry

Fisheries representative bodies taking up the role of data managers would also overcome the potential misinterpretation of freely available data such as Scotmap, which was disregarded by an interviewee. A study on Orkney fisheries also highlighted fishers' concerns around the dataset, indicating a snapshot in time was being used to represent a dynamic industry, and could lead to 'unmappable' factors such as weather conditions being overlooked (Bakker et al., 2019; Smith and Brennan, 2012). This indicates that there are unstated assumptions tied to static maps which are not represented in the process. Also, one-off data collection efforts through interviews have limited spatiotemporal coverage (Trouillet et al., 2019), and do not easily lend themselves to regular updates (Breen et al., 2015). Research priorities related to this have been identified by a recent report by Brown and May Marine, and include the need to understand how existing qualitative data can be integrated with quantitative data, and how the combination of these two types of data can be regularly updated (Marine Scotland & Brown and May Marine, 2022). Qualitative data cannot be disregarded as it fills in important data gaps for smaller fleets (Marine Scotland & Xodus, 2022b).

Both the fishing and energy industry make use of natural resources in the marine environment, but during the interviews a fisheries representative highlighted that fisheries use of natural resources does not have the same notions of property ownership as is seen in energy projects, which make use of distinct areas of seabed for which they get a spatially distinct licence, a distinction in marine space use which is also highlighted in (Weir and Kerr, 2019). For the fishing industry, their use of space is dynamic, and they are freer to roam, but this 'common' space to use is being encroached upon by other uses of the marine environment (Bakker et al., 2019; Stelzenmüller et al., 2022; Weir and Kerr, 2019). Interviews indicated that fisheries representatives perceive that this difference in space use is not always understood by developers. This resonates with findings by Weir & Kerr, that ownership of the marine space in Scotland is not easily understood, and they link this to a lack of awareness (Weir and Kerr, 2019).

Statements by participants I07, I10 and I11 (who are fisheries representatives) in Section 3.3.2.3 reflect a perceived lack of understanding by the energy industry of how the fishing industry works. Mobilising local knowledge is a key mechanism for inclusion to facilitate procedural justice in energy decision making (Jenkins et al., 2016), and this cannot be facilitated when communities depending on the ecosystem for their livelihood are misunderstood. As well as the statements presented here Schupp et al., 2021 identified a limited understanding by developers of fishing, including its variability between seasons.

This demonstrates an important distinction between an availability of data and an understanding of the activity represented by the data. Fisheries data sources used to inform siting and impact assessment may not always be designed to be used for that purpose, and a lack of data or a lack of understanding of the data may lead to misinformed mitigation strategies and errors in decision-making (Green, 2016; Rodwell et al., 2012). A report commissioned by DG MARE that aimed to identify data and knowledge gaps that are hindering the implementation of marine spatial plans across member states emphasised the difference between missing data and the ability to understand data, to be able to contextualise it and turn it into information needed to make a decision, especially for socio-economic data (Cahill et al., 2016).

Therefore, a better understanding of the differences in space use by different marine users could already improve relationships between sectors, and this could be achieved by initiatives that improve mutual understanding. Other studies have demonstrated that setting up a community of practice (Steins et al., 2021) can create a positive learning environment, or bringing different actors together in a 'serious game' setting (Mayer et al., 2013), but both require time and resources which need to be available.

3.4.5 Bio-economic data better represented in documentation than social data

The textual analysis revealed that over two thirds of the data sources evaluated in this study represented either value (in GBP) or fishing effort, also known as bio-economic data (Said and Trouillet, 2020). At present, Said & Trouillet argue there is an overemphasis on bio-economic variables such as fishing effort, revenue and catches, but a lack of understanding on the effects on local fishing communities (Said and Trouillet, 2020; Stelzenmüller et al., 2022). Bio-economic data does not allow the value of a sea space to specific communities to be evaluated, which can lead to a risk of overlooking the human dimension of impact assessment (St. Martin and Hall-Arber, 2008; St. Martin and Olson, 2017). It obscures the possibility that smaller-scale fisheries may employ a larger number of people than larger-scale fisheries, despite large-scale fisheries representing a higher monetary value (e.g. when comparing the pelagic fishery to inshore fisheries) (Carvalho et al., 2011).

The textual analysis indicated bio-economic variables were widely used to characterise fisheries, but information on social and cultural values was largely missing. The omission of this type of data can have repercussions for distributive justice as it may lead to unanticipated impacts – such as knock-on effects on downstream processing sectors located inland (Billing et al., 2018). The need for socio-economic data to inform the planning of upcoming developments has been highlighted in relation to offshore wind farms (Rydin et al., 2018b), wave and tidal developments (Copping et al., 2018; Freeman, 2020), as well as for the integration of fisheries into marine spatial planning (Janßen et al., 2018). Guidance commissioned by Marine Scotland is under way to aid developers in evaluating 'what is local' to an offshore area (Cleary, 2020), and an understanding of upstream and downstream sectors of the fishing industry would be relevant to this. Such type of research is already available for specific regions, such as the cultural and economic value of Orkney's fishing industry (Fennell, 2019a, 2019b).

Missing information on socio-economic impacts in environmental impact assessment has been identified by the Scottish Government as a knowledge gap (MS-LOT, 2018; ScotMER, 2018), and this finding is underpinned by the results presented here. Several other studies show that this lack of information has led to failures/objections in siting energy developments or MPAs (de Groot et al., 2014; MS-LOT, 2018; Scholz et al., 2011; St. Martin and Hall-Arber, 2008). The lack of consideration of the connectivity of the fishing industry to other sectors as well as social values has implications for the success of mitigation measures, as it may be difficult to know whether the mitigation measures benefit the impacted community (Blyth-Skyrme, 2010).

A challenge to socio-economic data is that marine data may be hard to disentangle from terrestrial data (Cahill et al., 2016; Morrissey, 2017). Moreover, Seafish Seafood Processing Statistics are only available in a combined format for both the inshore and offshore sector, so statistics cannot be distinguished between the inshore and offshore fleet (Billing et al., 2018). The interview results demonstrated mixed views on the need to consider the processing sector. This seemed to be of higher importance in remote communities where the viability of a fish processing sector is more fragile. On the west coast of Scotland, onshore jobs rely on the success of the fishing industry (K. A. Alexander et al., 2013).

Comprehensive guidance has been published on what a socio-economic assessment specifically for fisheries can entail (Bennett et al., 2021b). Furthermore, recommendations have been made on what data should to be collected a strategic level and what data at a project level for marine renewable energy devices (Freeman, 2020). The availability of social and economic data that could inform the baseline characterisation of fisheries space use when scoping in or out potential impacts of a proposed project could make it easier to understand the sensitivity of a fleet segment, and upstream and downstream sectors dependent upon it. Currently the scoping is primarily informed by spatial data as well as bioeconomic data, which might underrepresent other types of fisheries value such as cultural aspects, as addressed in Bakker et al., 2019 and Fennell, 2019a.

3.4.6 Limitations in how uncertainty of datasets is considered

For the textual analysis, the ‘Recognised Uncertainty’ indicator scored lower compared to the other indicators, indicating a lack of consideration or communication of uncertainty. Uncertainty and limitations of the included datasets was commonly mentioned in the beginning of commercial fisheries chapters, but it was not clear in the documentation how this uncertainty was considered when the data was used to inform decisions in siting and impact assessment of projects. It is currently not obligatory for the scoping, assessment or technical documents to communicate the awareness of data/knowledge gaps and uncertainty, and even though it is not explicitly documented, it will presumably have been considered during the expert judgement of predicted potential impacts. Other studies have also identified limitations of communication of uncertainty in impact assessment and call for the need for a more explicit reporting of assumptions and uncertainty by practitioners (Leung et al., 2015). An EIA review performed by Willsteed et al, also found a weak average score for the consideration of uncertainty during the consideration of ecological receptors, across 9 large scale offshore wind farms in the UK (Willsteed et al., 2018). Further research could be used to further assess how uncertainty is considered, as a follow-up of whether uncertainty was considered or not.

3.4.7 Fisheries data informs expert judgement of predicted impacts

The indicator used to score the impact assessment methods used by the case studies was developed based on a guidance document referenced by over half of the case studies (Seafish and UKFEN, 2012). Even though the guidance suggests the use of quantitative methods, the case studies used expert judgements rather than a quantitative calculation to determine impact significance. This finding resonates with findings from an EIA review focused on ecological receptors (Willsteed et al., 2018). Expert judgement allows a consideration of qualitative elements of the fisheries characterisation, the requirement of which is highlighted in a recently published guidance document (Marine Scotland & Xodus, 2022b), but it made it challenging to compare significance determinations between case studies.

The discrepancy between the approach taken by the case studies and the guidance referred to could be because the guidance document was aimed at an impact assessment of marine protected areas rather than proposed energy developments (Seafish and UKFEN, 2012). Marine protected areas (MPAs) may be larger in scale compared to the case studies, so a quantitative calculation of impact using logbook data at the ICES square resolution may be more accurate for assessing MPAs than for smaller-scale energy projects. Another EIA review identified that the use of quantitative impact assessment tools varied per type of impact, where for example noise impacts were modelled quantitatively but the percentage of habitat loss was not regularly quantified (Willsteed et al., 2018). As well as the difficulty in comparing qualitative impact assessments, it also makes it difficult to understand cumulative impacts of multiple projects when assessments are done qualitatively, which will become more important as the number of proposed projects in the marine space increases.

3.4.8 Reflection on data collection approach

As with a similar study conducted using public documents (Willsteed et al., 2018), the information needed for scoring the case studies using the evaluation framework was retrieved from multiple chapters which referenced different appendices, and some case studies applied for a licence multiple times. This led to an extensive number of pages being screened to allow a scoring of the case studies. As well as that, not all documentation that was referred to in environmental statements could be found. It took some time before the author could navigate the landscape of these documents and their function in the project planning process. This was eased by the opportunity to reflect on the process with the interviewed participants, who have experience with writing or reviewing these documents. For future studies on the documentation of the environmental impact process, finding a contact person per project, who is willing to aid the researcher with the collation of the documents, would make the data collection stage more efficient.

3.5 Limitations of study

Even though a representative sample of individuals was interviewed for the three broad interest groups, fisheries, government and the energy industry, when observing the eight subdivisions in Figure 3-5 (the interest group map), the representation per subdivision varied between 1-5 interviewees. This indicates that not every subdivision was equally represented, which has an influence on the results collected during this study. For future research, this imbalance can be overcome by explicitly seeking out a minimum number of interviewees per subdivision.

3.6 Conclusion

A compilation of cable and renewable energy projects in Scottish waters was analysed to identify the presence or absence of data deemed necessary to characterise the fishing industry (and the species it depends upon). The review identified spatial patterns are better represented than temporal patterns of fisheries activities, and developers rely on consultation to understand seasonal patterns as well as shifting baselines. Rather than the absence of data, challenges around an understanding of the data and its underlying uncertainties were identified, as well as issues around accessibility. Further research is merited to understand how these challenges could be overcome, for example through facilitating fisheries representative bodies to function as data managers, who could provide data that complements government-held datasets.

Socio-economic data is currently not being systematically used, even though linkages between onshore communities and the space at sea could inform the relative sensitivity of different fleet segments to changes introduced by a proposed development. As the interactions between the fishing industry and the energy sector are expected to increase, results from this study highlight the need for a better understanding of socio-economic links between the fishing area and the value of that area for onshore communities.

4 Just energy transition? How current practice is considering fisheries during the emergence of renewable energy production

Chapter 3 demonstrated how the use of data during project planning influences procedural justice for the fishing industry. In continuation, Chapter 4 considers how both engagement and the inclusion of data in the licensing process relates to distributional, procedural and recognitional justice. The purpose of this analysis is to understand how the siting and impact assessment of energy developments consider energy justice for the commercial fishing industry.

4.1 Introduction

This section starts with a description of the licensing process for Scotland's marine cable and energy generating projects, following on from the brief introduction of this process in Chapter 1. Subsequently, interactions between energy projects and the fishing industry are outlined. This chapter focuses on two of these interactions: loss of access to fishing grounds and snagging risk. A theoretical framework is then introduced, which will be used for the analysis of the results. Finally, an overview is given of existing research on interactions between fisheries and the renewable energy sector, which provides context for the aims and research questions in Section 4.2.

To decarbonise Scotland's electricity sector, renewable electricity generation and transport is currently taking place in various forms in Scottish waters, and several projects are in development (see Section 1.3.2). Before projects can commence construction and installation, they must obtain a licence and, in some cases, also a consent (see Section 1.3.6). Licences and consents can be obtained through a single authority in Scotland, the Marine Scotland Licensing Operations Team (MS-LOT). This one-stop shop approach is intended to streamline the process, making it more effective and attractive for investment (Ramos et al., 2021; Scottish Government, 2018; Wright, 2014b). Statutory measures are in place to ensure the developer considers the needs of other marine users before they can obtain a licence or consent, including Scotland's National Marine Plan (Scottish Government, 2015a) and the sectoral marine plans (Scottish Government, 2021b, 2020b). Non-statutory guidance by the Fishing Liaison with Offshore Wind and Wet Renewables group (FLOWW, 2014) advises developers on best practice. These guidance and measures reduce the risk of the new developments causing injustices to existing users, including the fishing industry, which has been highlighted as a concern in relation to blue growth aspirations (Bennett et al., 2021a).

The commercial fishing industry is one of the most ubiquitous existing marine users (Wood and Dragicevic, 2007). In 2019, the Scottish fishing fleet consisted of 2098 active Scottish registered vessels, of which 74% were under ten metres in length, employing 4886 fishers on both a regular (81%) and irregular (19%) basis (Scottish Government, 2020d). Around half of these vessels are represented in national federations through fisher associations[7]. Along with existing regulations such as marine protected areas and quotas, fishers are increasingly having to share marine space with new developments such as subsea cables and offshore wind projects (Gray et al., 2005; Jentoft and Knol, 2014; Kafas et al., 2018; Yates et al., 2015). There are three main ways in which marine space use by cable and renewable energy developers can affect the fishing industry:

1) Direct spatial overlap between the project and areas used for fishing
2) Direct and indirect effects on commercial fish species
3) Disruption of steaming routes (by renewable energy structures) (Slijkerman and Tamis, 2015; Soerensen and Hansen, 2001; Taormina et al., 2018)

[7] This estimation is based on available member information on the websites of Scottish fishing bodies (consulted December 2020)

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This study focuses on the first category, and two resulting types of impacts: 1a) the temporary and/or permanent loss of access to fishing grounds (Figure 4-1) and 1b) snagging risk (Figure 4-2), which occurs when a vessel engaged in fishing catches its gear in a cable. This can put the vessel at risk of capsizing and/or result in loss of fishing gear (Carter et al., 2009; Kingfisher Information Service, 2021; Vize et al., 2008). These two interactions are the focus of this study because they are applicable to both the cables and renewables industry. In contrast, subsea cables will not normally affect steaming routes, and commercial fish species will be affected differently by different types of development (offshore wind farms, tidal projects, or cables).

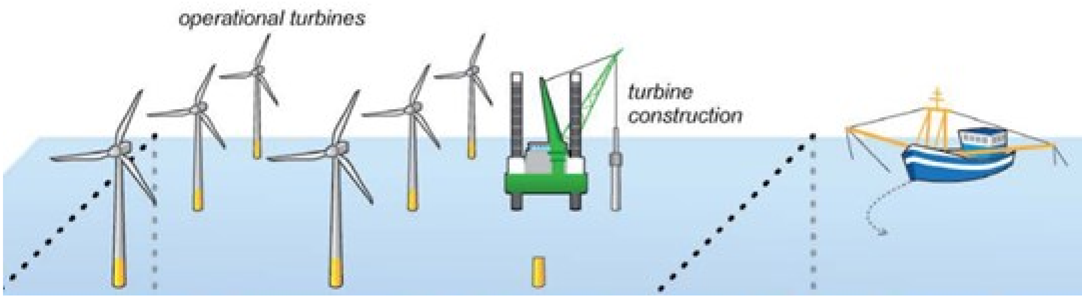


Figure 4-1 Diagram to illustrate loss of access to sea areas, adapted from Gill et al., 2020 to only include the top part which is relevant to this study

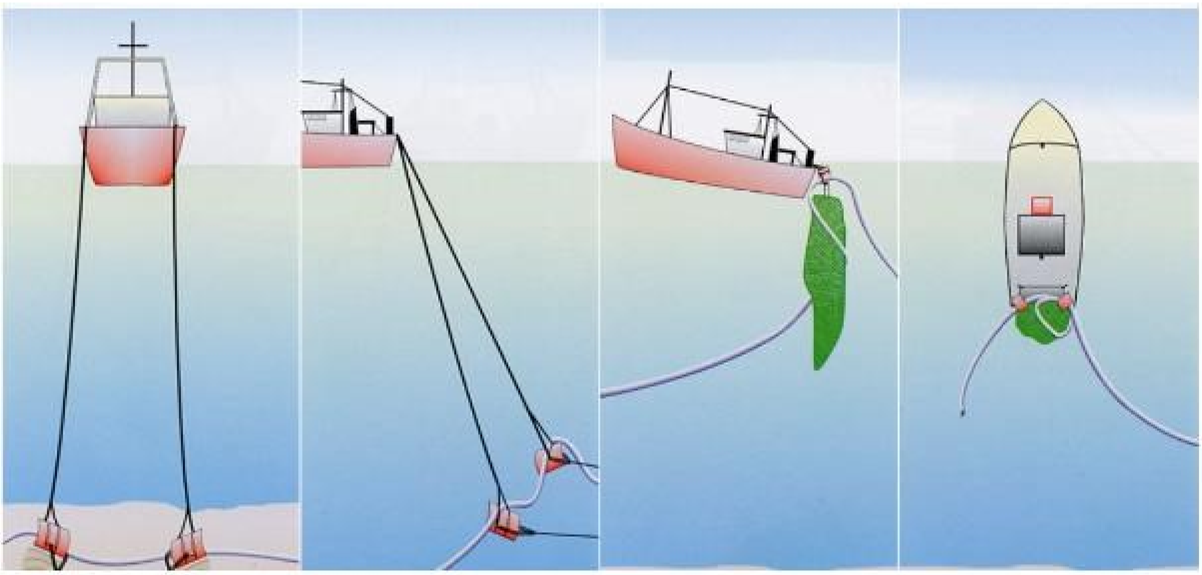


Figure 4-2 Diagram that illustrates a snagging incident (Source: Seafish UK)

Access to a reliable supply of electricity is enabled by subsea cables and is critical to transport energy from the points of generation to end users (Subsea Cables UK, 2014). Subsea cables are important for energy security which have implications for social well-being (Elliott and Al-tabbaar, 2016; Hattam et al., 2017). To secure the continuity of electricity supply and safe operations, for both renewable energy projects and cables there is legislation in place that controls access for fishers. Access by all ships is prohibited within safety zones, which may be put in place on a temporary or permanent basis up to 500 metres around infrastructure at sea (Article 60, UNCLOS).

Internationally, the 1884 Convention for the Protection of Submarine Telegraph Cables and the 1982 United Nations Convention on the Law of the Sea (UNCLOS) consider “breaking or injury of a submarine cable” a “punishable offence”. In the UK these conventions are implemented via the 1884 UK Telegraph Act, the UK 1964 Continental Shelf Act and the 1984 UK Telecommunications Act. Based on a global database of 2162 cable faults spanning from 1959 – 2006, 44.4% of cable faults were caused by the fishing industry (Carter et al., 2009, Tyco Telecommunications (US) Inc.). This highlights that snagging risk, which includes safety considerations, risk of loss of gear as well as liability for cable damage, presents serious implications for the accessibility of areas of seabed where cables are installed for bottom-contacting fisheries.

While renewable energy projects may result in reduced access to fishing grounds, it has been argued they may provide benefits for the fishing community. Offshore wind farms can potentially act as artificial reefs and sanctuaries devoid of fishing pressure, which could benefit the productivity of stocks and consequently, the fishers dependent on them (K. A. Alexander et al., 2013; Barbut et al., 2019; Degraer et al., 2020; Langhamer, 2012; Petersen and Malm, 2006). As this study does not consider potential negative effects on commercial fish stocks, it will not explicitly consider potential improvements in fish stocks as a potential benefit either. Instead, it will evaluate the access to economic benefits of the projects, such as alternative sources of revenue.

Emerging industries such as offshore renewable energy can provide an alternative source of revenue and diversify local economies, providing employment opportunities such as guarding duties and survey assistance (K. A. Alexander et al., 2013; Blyth-Skyrme, 2010; Bocci et al., 2019; Kerr et al., 2014; Rodwell et al., 2013; Schultz-Zehden et al., 2018). Experience on inshore fishing vessels prepares young professionals for a career in the offshore renewables sector (Jones et al., 2014). To understand how the fishing industry's access to benefits and exposure to potential impacts has implications for energy justice, the siting process for renewable energy and cable developments in Scottish waters will be analysed in relation to how it fosters or prevents distributional, procedural and recognitional justice for fisheries (as introduced in Section 1.3.4).

Research into justice is complex and this study does not aim to evaluate whether the energy transition is just, but rather how current practice accommodates energy justice, specifically for the fishing industry. This study does not explicitly consider energy justice for bill payers, which is also an important aspect of a just energy transition (Just Transition Commission, 2021). The reason to focus specifically on fisheries is that the footprint of renewable energy and cable infrastructure will cause changes to how fishers operate, which must be distinguished to costs and benefits for bill payers in general, many of whom will not be affected by the direct footprint of the developments. Explicit consideration of justice implications for fisheries can improve the siting and impact assessment of proposed projects, and foster positive relationships between two users of the same marine space (Haggett et al., 2020).

Figure 4-3 illustrates how the three dimensions of energy justice can be related to fisheries. Distributional justice is considered as the direct benefits and impacts for fishers of the energy transition. The way in which the fishing industry is considered throughout project planning will be evaluated in the context of procedural justice. Finally, recognitional justice will be used to evaluate justice within the fishing sector, and whether different fishing segments are equally represented. While recognitional justice could also be relevant here in terms of the underrepresentation of the fishing industry compared to other marine users in spatial decision-making (e.g. Janßen et al., 2018), this aspect is not considered explicitly as a justice dimension within this study.

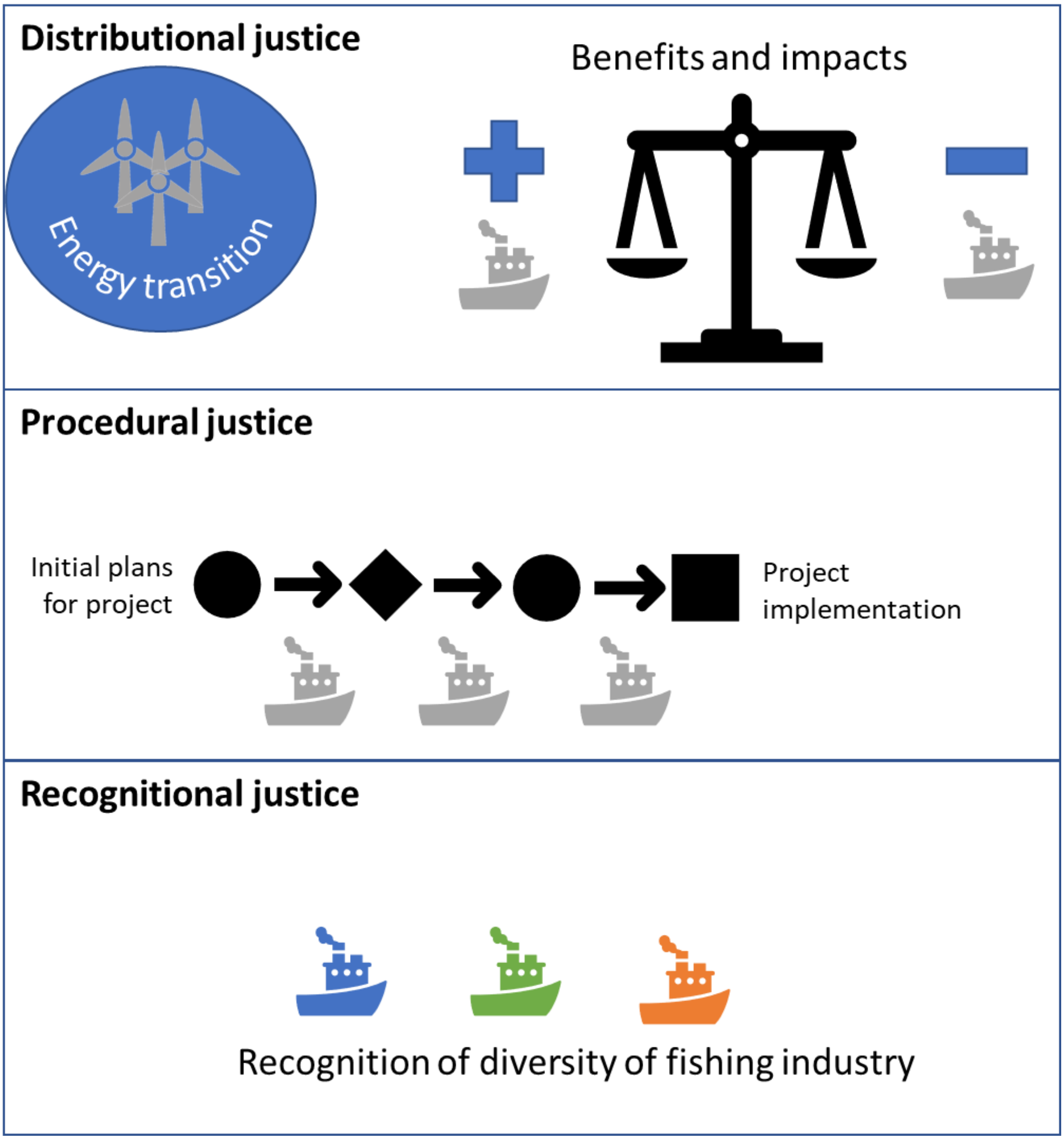


Figure 4-3 Illustration of the three types of justice considered in this study

Energy justice for fisheries will depend on the relative opportunities and impacts energy projects bring to the fishing industry, as well as which mitigation measures are implemented to reduce impacts. To advocate the use of mitigation measures to avoid/reduce impacts, the mitigation hierarchy is an approach applied in impact assessments (Glasson et al., 1999; Mitchell, 1997; Tinker et al., 2005). It consists of three different levels, where 1) priority is given to avoid impacts as a form of primary mitigation, 2) remaining impacts are minimised with secondary mitigation measures, and in some instances 3) residual impacts are compensated for as a final resort (Figure 4-4).

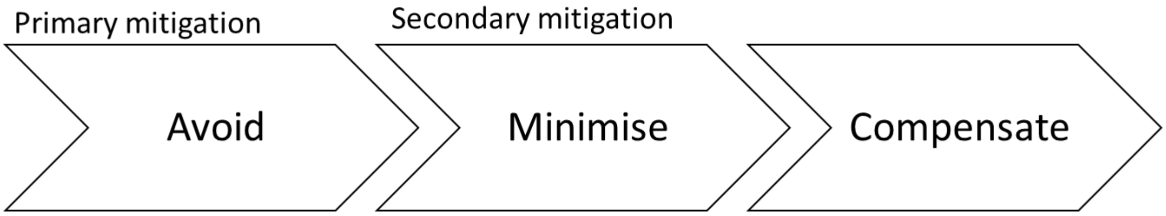


Figure 4-4 Three levels of the mitigation hierarchy: avoid, minimise and compensate (adapted from Mitchell, 1997)

Primary mitigation includes changes in the location or design of the project, during the strategic planning (e.g. sectoral plans) or pre-application stage, before the developer applies for a licence (IEMA, 2016). Secondary mitigation measures require specific action by the developer to reduce the significance or likelihood of impacts, and may be imposed as licence/consent conditions by the licensing authority (IEMA, 2016), such as timely communication with marine users prior to installation works (FLOWW, 2014). Here it is relevant to categorise mitigation measures in terms of which aspect of justice they address. For example, timely communication with marine users prior to installation works is a procedural mitigation measure but will not directly influence distributional justice. Moreover, it is necessary to keep in mind that even though licence conditions for different projects are worded the same, they may be underpinned by different legislation, for example electricity generating projects are considered differently from cable projects in the Marine (Scotland) Act 2010.

Compensation is considered the last resort in the mitigation hierarchy and can involve financial means to offset residual impacts (Glasson et al., 1999), however there is no obligation on developers to compensate impacted marine users such as fishing and shipping. Where compensation measures are implemented it can take the form of either a disruption settlement (monetary payment to specific vessels) or a fisheries community fund, which is defined by the FLOWW group to be “a fund established by an OREI [offshore renewable energy installation] developer which is to be used for the general betterment of the members of a fisheries community” (FLOWW, 2015).

One limitation to the mitigation hierarchy is that it only considers the elimination/reduction of negative impacts, whilst changes induced by the development of a project may also result in positive impacts as described above, which should be maximised to facilitate energy justice. Therefore, the mitigation hierarchy was used to create a more comprehensive flow chart that encompasses positive impacts, the three levels of the mitigation hierarchy as well as residual impacts (Figure 4-5). Residual impacts are defined as predicted negative impacts of the proposed project on the fishing industry (such as potential effects stated earlier), after a project already implemented primary and secondary mitigation measures. This flow chart will be used as a framework to consider potential positive and negative impacts of renewable and cable projects on the fishing industry. 'Compensate' is represented as a process with dashed lines to indicate this is not an obligatory step in the process for assessing impacts on marine users.

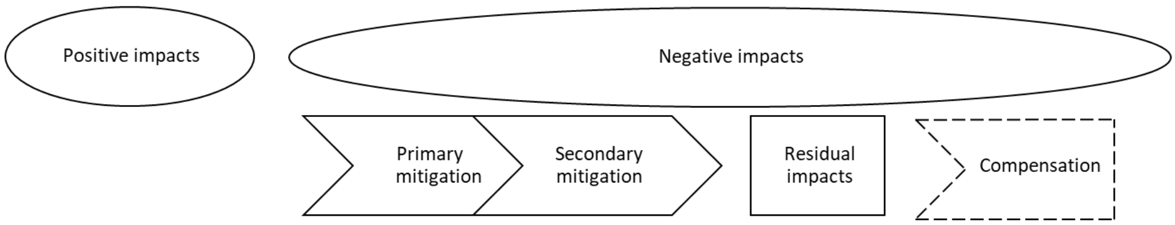


Figure 4-5 Flow chart to show the different processes and predicted impacts that will influence distributional justice for the fishing industry of energy projects

4.1.1 Existing research

A review of existing research on interactions between the energy and fisheries industry highlights the need for inclusive forms of engagement that allow relationships to be built between both sectors, facilitating a better mutual understanding (Haggett et al., 2020). Specifically in the context of the UK and Ireland, Table 4-1 lists the relevant studies that have explored the relationship between fisheries and emerging renewable energy projects. Three studies focused on collecting information on perceptions and attitudes of fisheries in relation to renewable energy developments, where the most recent study explored perceptions on coexistence. Seven studies incorporated the perspectives of multiple interest groups, where fisheries representatives, developers and regulators were interviewed, asked to complete a survey, or participated in workshops. Progress in the renewable energy field allowed a comparison between earlier studies focusing on perceptions before renewable developments were in place, with later studies that report on experiences with existing projects. To the author’s knowledge, at present no study has investigated how the cables industry engage with fisheries.

Table 4-1 Existing studies on interactions between the renewables and fisheries industry in the UK and Ireland

Year of data collection	Source	Sector	Region	Method	Interest groups included	Focus
2003	T. S. Gray et al., 2005	Offshore wind	UK	Interviews	Fisheries, developers and regulators	Characterisation of interest groups
2005-2006	Mackinson et al., 2006	Offshore wind	UK	Interviews, workshop	Fisheries	Perceptions of the fishing industry on potential impacts of offshore wind farms
2010	O'Keeffe & Haggett, 2012	Offshore wind	East Coast, Scotland	Interviews	Fisheries, developers and regulators	Explore barriers to offshore wind development
2010-2011	Alexander, Potts, et al., 2013; Alexander, Wilding, et al., 2013	Wave, Tidal	West Coast, Scotland	Survey and Interviews	Fisheries	Attitudes fishers towards renewables
2012-2013	de Groot et al., 2014	Wave, Tidal	UK	Survey and workshops	Fisheries, developers, regulators and academia	Identify mitigation agenda
2013	Hooper et al., 2015	Offshore wind	England, Wales	Interviews	Fisheries	Experiences and opinions of fishers and developers of co-location
<2016	M. Gray et al., 2016	Offshore wind	UK	Survey and interviews	Fisheries and developers	Experiences of changes in fishing practices
2013	Reilly et al., 2015	Offshore wind, wave and tidal	Island of Ireland	Surveys	Fisheries and developers	

Table 4-1 (continued)

Year of data collection	Source	Sector	Region	Method	Interest groups included	Focus
2013-2014	Reilly et al., 2016a, 2016b	Offshore wind, Wave and Tidal	Island of Ireland	Survey and interviews	Fishers and company fisheries liaison officers	Experiences with proposed projects
2017	CH6 PhD Andronikos Kafas, 2018	Offshore wind	East Coast, Scotland	Document analysis (EIA documentation)	Developers	EIA review of proposed projects
2017	Schupp et al., 2021	Offshore wind	East Coast, Scotland	Document analysis (policy context) and interviews	Fishers, developers, regulators and academia	Perspectives on multi-use
2019-2020	Kamidelivand et al., 2020	Offshore wind	Ireland	Interviews	Fishers	Perspectives on coexistence
2020	*This study*	*Offshore wind, tidal and cable projects*	*Scotland*	*Document analysis (project documents, documents licensing authority, consultation responses) and interviews*	*Fishers, developers, regulators*	*Mechanisms and barriers to distributive, procedural and recognitional justice*

In their study, de Groot et al., 2014 propose a research agenda needed for mitigating fisheries displacement, including the need for a better understanding of the effectiveness of implemented mitigation measures. This knowledge gap is addressed with this study, through an assessment of existing practice. To date, this has not yet been done in a comprehensive way at a Scottish level. As the renewables and cables industry has grown, it is now timely to link existing projects with perceptions of interested parties via case study analysis. This will also allow a temporal comparison of factors that influence the justness of the energy transition for the fishing industry.

4.2 Aim and research questions

To understand what mechanisms are currently in place to facilitate a just energy transition for the fishing industry and evaluate their effectiveness, this study assesses a range of projects across the energy generating and energy transporting sector. The study aims to answer the following questions:

How does the siting and impact assessment of offshore renewable energy and cable developments consider energy justice for the commercial fishing industry?

- Distributive justice
    - Do the projects provide benefits for the fishing industry and are these temporary or long-term?
    - Have developers adapted the siting and design of their project to avoid/reduce impacts on the fishing industry and how?
    - How are residual impacts mitigated?
        - Are compensation mechanisms in place?
- Procedural justice
    - How is the fishing industry represented in the project life cycle?
        - At what stage are they represented by data and at what stage are they physically present to contribute to decision-making?
- Recognitional justice
    - How are different segments of the fishing industry represented?

- Are there mechanisms in place to avoid underrepresentation of certain segments?

To answer these questions within the framework of the same overarching legislation, the choice was made to focus on Scottish projects, which must conform to the Marine Scotland Act (for projects within 12 nm) and the UK Coastal Access Act (for projects out with 12 nm). Considering both cable projects and renewable energy projects within the same study provides a more comprehensive picture of the interactions experienced by fisheries. The reason inter-isle cable replacements were also included as projects in this study was to allow a comparison between projects that have been in place for over 50 years (the inter-isle cables), with newer sectors that may be perceived as having the burden of setting a precedent for future projects.

Analysing current practice using ‘real world research’ in the form of a case study analysis allows an exploration of the relationship between the energy industry and the fishing industry in its context (Robson and McCartan, 2016). In Scottish waters, a wide range of energy projects have already been licenced/undergoing planning, which offer valuable case studies for analysis. This study will evaluate the effectiveness of current practice in facilitating a just transition for the fishing industry during project planning using a selection of case studies dating between 2011-2020, so temporal changes in practice can also be considered.

4.3 Methods

A selection of case studies was analysed using a mixed methods approach (a combination of qualitative document analysis and semi-structured interviews). Both methods are qualitative but use different information sources, allowing a triangulation of perspectives (Robson and McCartan, 2016). The case studies and documents used were the same as in Chapter 3 (see Section 3.2.2). For this chapter, two case studies were added to the selection as they were specifically alluded to in the interviews (tr01 & tr07), so 23 case studies in total were analysed (Figure 4-6). When the information was collected for the chosen case studies, they were in different stages in the project life cycle, which allowed a comparison of fisheries engagement at the various stages. The project phases considered in the study are 1) the planning phase 2) the construction and installation phase and 3) the operational phase.

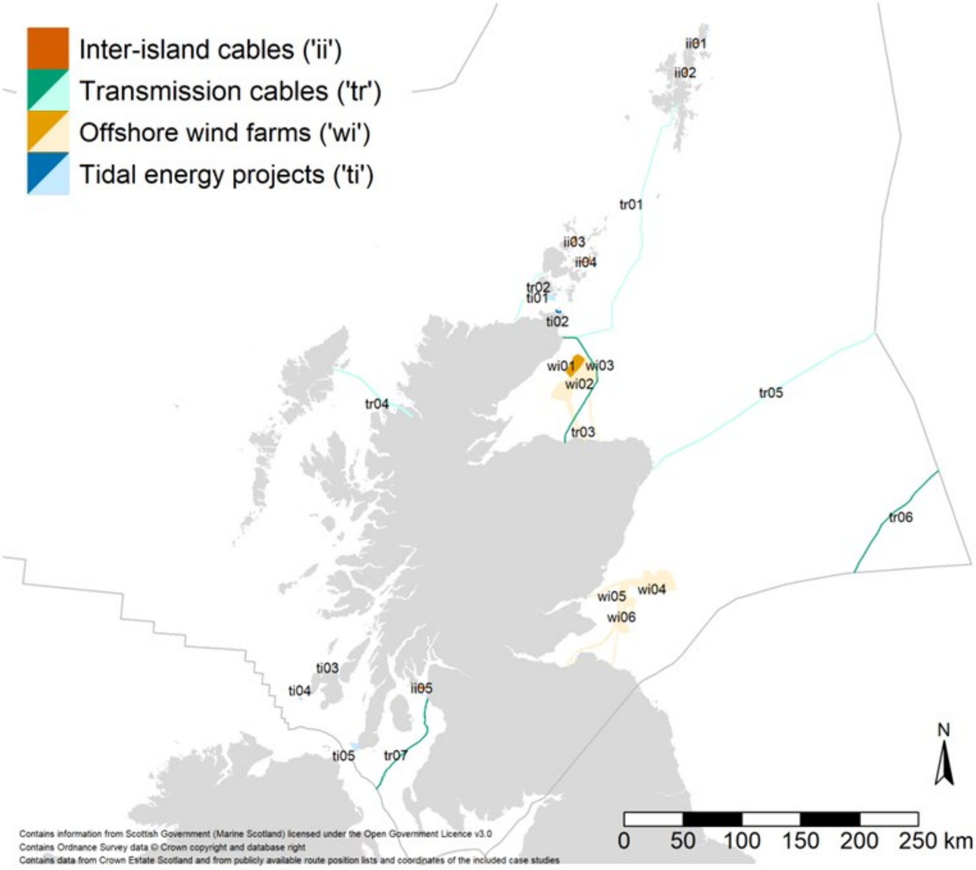


Figure 4-6 Included case studies, with incomplete projects in a lighter shade (as of October 2021). Inter-island cable, transmission cable, offshore wind farm and tidal energy projects were given codes which are indicated at the locations of the projects

4.3.1 Semi-structured interviews

The same individuals were interviewed as in Chapter 3 (see Section 3.2.3). The interview guides varied in wording according to interest group but aligned with the same overarching themes (see version per interest group in App. 4.1). The questions are summarised across interest groups in Table 4-2. The study received ethical approval from the University of the Highlands and Islands ethics committee, and the documents that were submitted for the ethics application can be found in App. 3.3.

Table 4-2 Interview guide across interest groups

Fisheries engagement Timing/Continuity *1)* At what stage in a project are fisheries representatives usually consulted? *2)* Do you think impacts can be avoided through early engagement? If yes/no, why? *3)* At what stage in a project are members of the fishing industry consulted? *4)* How do you choose when to start engaging with potentially affected parties? *5)* Are you happy with the communication with fisheries representatives from the onset of a project through to the post-consent construction and operational phase? *6)* How do consent conditions including the setup of a commercial fisheries working group play a role in this? Outreach *7)* Is it easy to find the relevant fisheries representatives to consult? *8)* What is the role of (umbrella) fishing associations for reaching out to members of the fishing industry? *9)* What is the role of consultation events for reaching out to members of the fishing industry? *10)* Has it been possible to take all fisheries representatives' views into consideration? **Assessment of impacts and benefits and proposed mitigation measures** *11)* Do you think there could be any improvements in the mitigation measures proposed that consider fishing communities dependent on fishing? *12)* Are you happy with the proposed mitigation measures? *13)* Is there an opportunity for employing fishers for guard work/FLOs as a form of mitigation? *14)* What is (potentially) the role of fishing associations for coordinating this? **General questions** *15)* Do you think there might be better ways for the fishing industry and the renewables industry to engage? *16)* Do you have any examples of fisheries interactions with offshore energy developments that went particularly well or were particularly unsuccessful?

4.3.2 Document analysis method

Table 4-3 shows the relative representation of the interest groups in the interviews, and which types of public documents represent each interest group. These documents could then be triangulated with perceptions from the interviewees.

Table 4-3 Interviews and documentation representing the three interest groups

Interest group	No. interviewed	Documentation
Fisheries	8	• Formal consultation responses • Pre-application consultation reports from developers which may include meeting minutes with fisheries bodies
Government	6	• Scoping opinion (or equivalent) • Marine licences issued and attached conditions • Formal consultation responses by government advisory body • Planning and policy level documents
Developers	6	Submitted documents required for a marine licence including but not limited to: o Scoping report (or equivalent) o Pre-application consultation report o Environmental statement (or equivalent)

Differences in cable installation methods between case studies were visualised using the 'ggplot2' package in R (R Core Team, 2021; Wickham, 2016).

4.3.3 Processing and analysis of documents and interviews

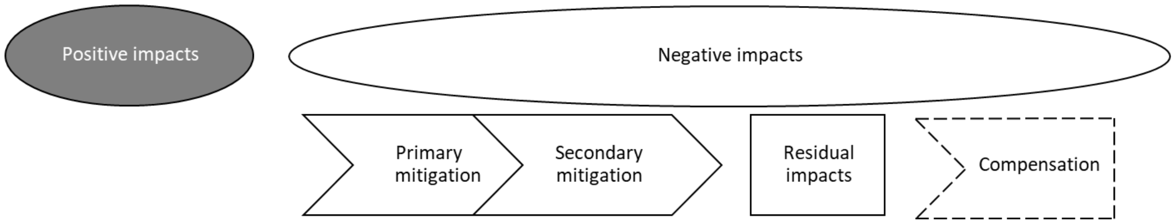
All interviews were transcribed from audio recordings by the interviewer (IW). Transcripts were initially coded according to prescribed themes, using NVivo software. These prescribed themes were defined based on the analytical framework: the five aspects in the flow chart in Figure 4-5 combined with the three dimensions of justice. This analysis was combined with a grounded theory approach, which allows for the discovery of emerging patterns in the data that were not anticipated before the data collection (Willig, 2013). The prescribed themes as well as the emerging themes can be found in App. 4.2. Case study documents were also imported into NVivo and coded with the themes, to compare and analyse results from both the interviews and the document analysis. Conclusions made based on the interviews were verified with the interviewees to avoid misunderstandings. Follow up meetings with the interviewees to ensure everything had been interpreted according to their wishes led to new information and insights that were also included, which captured the rapidly evolving nature of the renewables and cable industries.

Because this study considered different sources of information, triangulation was used. Triangulation is where multiple sources of information (obtained through multiple methods) are used to reach an understanding of a phenomenon, so that a finding based on one source can be confirmed with a finding through a second source (Denzin, 2017). In this case the methods included interviewing and public document analysis. The documentation from case studies can give context to data collected during interviews, and provide detail on events that happened a number of years ago, about which interviewees may have forgotten the details (Bowen, 2009). Whilst conducting the study, it became apparent that the spatial location of each case study as well as the time period when it was being licenced/consented affected the approach to engagement with fisheries, so this was considered throughout the analysis by taking care when making generalisations across space and time.

4.4 Results

Results are organised according to the five different steps of the flowchart (which are represented graphically at the beginning of each subsection). For each stage, specific findings are first reported on, and then summarised according to the three dimensions of justice.

Across the 23 case studies of energy projects in Scottish waters, around 616 documents were gathered, and 20 individuals were interviewed. The most relevant documents were coded with themes also used for the interview transcripts using NVivo software (see App. 4.3). The documents from the case study selection date between 2006-2020. Query searches were used to triangulate results from the interviews with text in the gathered documents. Throughout this section, “[X]” as a source refers to the public documents (sources listed in App. 4.2), and “[IX]” refers to one of the interviews.



4.4.1 Positive impacts

Across all 23 case studies, both onshore and offshore opportunities were identified in the project documentation, including improvements in infrastructure, local employment opportunities and access to cost-effective electricity ([1]– [3] [4], [5] [6] [7]). One of the wind farm projects estimated that £500,000 was spent commissioning fishing vessels for survey and guard work, and individuals for fisheries liaison work [8]. For the fishing industry, offshore guard work by fishing vessels was identified by both fisheries and developers as an employment opportunity for when vessels cannot go out fishing e.g. due to quota restrictions or seasonality of fishing patterns [I03], [I05]:

"because of the fishing quotas these days then fishing boats aren't necessarily used all the time. So there are opportunities for fishermen to make extra living out of being guard vessels"	[I03]

Yet, barriers to this opportunity were also highlighted by a fisheries representative in that construction is likely to happen during calm sea conditions which is when it might be more profitable for fishers to be out at sea rather than undertaking guard vessel work [I07]. Another challenge identified is that local employment such as the use of local boats as guard vessels cannot be guaranteed because developers would be violating procurement laws if they influenced the selection of guard vessels [9]. However, project documentation also points out that developers can encourage their contractors to use the local supply chain e.g. by organising meet the buyer days [7]. Furthermore, locally procured vessels for guard work were perceived to be cheaper as they are already positioned in the area of work [I03].

"it makes sense to use local boats because in theory they should be cheaper because they're local and incur lower mobilisation cost."	[I03]

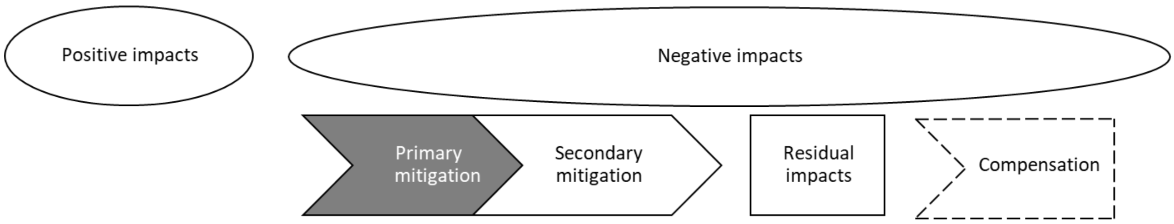
Meeting minutes in a pre-application consultation report stated that if the company tendering for guard vessel services represents a nation-wide fleet, they can choose to assign the work to locally affected vessels within their fleet [9]. However, access to these employment opportunities also depends on whether local vessels meet the required safety measures and vessel specifications, including vessel length and appropriate equipment on board (e.g. satellite tracking might be mandatory) [I07, I09,10]. Moreover, another interviewee perceived fishing vessels taking up guard vessel work to be unfair competition to merchant vessels, as well as to former fishing vessels that invested in converting their vessel into merchant vessels to be more eligible for guard vessel work [I08].

Several interviewees highlighted that fishing liaison or guard vessel work organised via fishing associations can result in a conflict of interest as they then must represent both the developer and the fishing industry [I06], [I10], [I13]. Additionally, two fisheries representatives commented that temporary employment during the installation phase of a project represents an opportunity for fishers, but that this only represents a short-term benefit for a few vessels [I10], [I11]. Whilst potential onshore opportunities were included as positive impacts in the socio-economics chapter of the environmental assessments of the projects for which this was available, two fisheries interviewees did not believe the proposed energy projects would bring the suggested employment opportunities that were alluded to [I05], [I11]. One interviewee argued that this disbelief could also be related to the messenger – that local benefits should be communicated by local representatives as opposed to an external project representative that *"jets in and jets out again"* [I09].

Also related to perceptions of benefits, two participants expressed concerns that there is a disparity between national benefits of utility-scale renewable energy and local access to these benefits for remote or island communities [I07], [I09]. Barriers to local access of economic benefits that were identified during interviews include factors that make the local facilities unsuitable for utility-scale infrastructure, including port capacity, port accessibility for larger vessels during low tide and housing [I09], [I12]. The Scottish Crown Estate's strategic management plan stipulates that the seabed should be "managed for the benefit of Scotland and communities" [11], but as pointed out by an interviewee, their guidance for developers applying for a lease does not specify this [I09],[12]. Table 4-4 links the findings related to positive impacts with each of the justice dimensions. Mechanisms and barriers to distributional justice were identified, as well as barriers to recognitional justice.

Table 4-4 Findings for positive impacts linked to justice dimensions

Justice type	Mechanisms/barriers identified for positive impacts
Distributional	*Mechanisms* Access to employment opportunities (survey work, fishing industry representatives, fisheries liaison officers and guard work) [3, 8, 9, I03, I05] *Barriers* • No guarantee guard vessel work is allocated to affected vessels [9] • Employment opportunities short-term in nature compared to permanent presence energy project in seascape [I10, I11]
Procedural	N/A
Recognitional	*Barriers* • Vessels need to meet required specifications to be eligible for employment opportunity [I07, I09,10] • Disconnect between national economic benefits and perceived local access to them for remote or island communities [I07, I09]



4.4.2 Primary mitigation

Findings related to primary mitigation are reported on in four sub-sections: 1) spatial mitigation, 2) design mitigation, 3) minimising duration of impact and 4) pre-application engagement.

4.4.2.1 Spatial mitigation

Two siting steps are relevant to spatial mitigation: a) the spatial decisions made at a strategic level by government, followed by b) project level decisions regarding routing or site selection made by developers.

a) Strategic spatial guidance

Strategic spatial guidance and leasing rounds for the wind farm and tidal projects are listed in Table 4-5. No strategic spatial guidance or leasing rounds were present for the inter-isle and transmission cable projects.

Table 4-5 Availability of strategic spatial guidance for the wind farm and tidal case studies. The relevant documentation is referred to with footnotes

	Lease awarded independent of leasing round	**Leasing round without prior spatial analysis**	**Leasing round guided by prior spatial analysis**
Time frame	-	2011	2009-2014
Number of wind farm case studies	0	3[h]	3[i]
Number of tidal project case studies	1	2[j]	2[k,l]

As can be seen in Table 4-5, half of the tidal case studies were part of leasing rounds informed by prior spatial analysis, namely for the 2014 “Further Scottish Leasing Round” under the Saltire Prize programme, where suitability of the proposed sites was informed by around 60 datasets, including fisheries which was represented with VMS data from vessels larger than 15 m [13]– [15]. Half of the wind farm case studies are found in zones identified by the Crown Estate for the 2009 ‘Round 3’ leasing round. The selection of these zones was informed by strategic spatial guidance, but the list of datasets used did not include fisheries data [16].

[h] Scottish Government, “BLUE SEAS-GREEN ENERGY PART A: A Sectoral Marine Plan for Offshore Wind Energy in Scottish Territorial Waters (The Plan),” Edinburgh, 2011
[i] The Crown Estate, “Round 3 Offshore Wind Site Selection at National and Project Levels,” 2013
[j] The Crown Estate, “Pentland Firth and Orkney Waters Round 1 Development Sites,” 2011
[k] M. Harrald, C. Aires, and I. M. Davies, “Further Scottish Leasing Round (Saltire Prize projects) Regional Locational Guidance,” Scottish Mar. Freshw. Sci., vol. 1, no. 18, 2010.
[l] Marine Scotland, “The Saltire Prize Programme - Regional Locational Guidance,” Top. Sheet, vol. 84 v3, 2014.

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More recently, multiple interviewees stated that the 2020 sectoral marine plan that has informed the more recent ScotWind leasing round for offshore wind energy has considered fisheries data (VMS, Scotmap, plotter data) and consulted with fisheries representatives at an early stage, which led to refinements in the plan options made available for lease [I11], [I14], [I12]. A fisheries representative body has recently collated a database of plotter data which they can now use when engaging with planners and developers during the site selection process of projects, to evidence their suggestions [I11].

The active engagement by the fishing industry is also reflected in the sectoral marine plan documents [17], and according to interviewees a better engagement process for the fishing industry than before [I07], [I11], [I12]. The devolvement of the Crown Estate into Crown Estate Scotland was also considered by interviewees as an influential factor in this improvement [I09], [I11], [I14]. A fisheries representative also stated that the implementation of the national marine plan can benefit the fishing industry, as they can now make the argument in consultation responses that a proposed project plan *“does not conform to … policy”* when they perceive that this is the case [I11].

b) Project level spatial decisions

Table 4-6 Summary of the ways in which impacts are avoided on fisheries

How the cable footprint is minimised	How spatial overlap with fisheries is minimised
Minimise cable length [I03] Minimise cable crossings [I03, 21, 41] Maximise burial [I03, 9, 41]	Avoiding nearshore areas (wind) [25] Site boundary relocation (wind) [26] Adjustment to location HDD bore (cable) [6] Adjustment landfall location (cable) [I02]

As summarised in Table 4-6, two main approaches to minimising impacts on fisheries were identified throughout the projects: minimising the cable footprint and minimising spatial overlap with fisheries. Firstly, minimising the footprint of the cable in the marine environment was identified as the primary way of avoiding impacts on the fishing industry by one of the developers:

“Your ideal is to try and get your cable to go through sandy areas that you can get the cable to go in where you want it to go, to the depth you can [I03]

get it to, with the least hassle, which is to the benefit of the fishermen as well, because then you've got no rock dumping and you can do it as quickly as possible"

For example, data on the seabed substrate can help developers identify soft sediment areas where the cable can be buried. As well as data that can be used to minimise the footprint of the cable, data that represented fisheries activities or important areas for target species were also considered in the siting process, in some cases collected together with members of the fishing industry (Table 4-6, e.g. [2], [18]–[21]). For example, data on current fishing activities were included as a constraint layer in initial desk-based routing/site selection for at least two of the case studies [20]– [22]. Participants from both the fishing and cables/renewables industry reported limitations to fisheries data however, as it only considers current fishing activities which may change location during the lifetime of the cable, which can be up to 50 years, especially considering potential climate change effects on fish stocks [I03, I07, I14]:

"it's a moving feast, which is very difficult for developments which are not going to get constructed immediately." [I03]

Experiences by interviewees on how spatial decisions were accounting for fisheries interests varied considerably. First, positive experiences are reported on, followed by examples of missing engagement. Cable route options that were preferred by the fishing industry were prioritised where possible [23, I08]. Moreover, there have been cases where the point where the cable emerges from the HDD bore into the marine environment was modified to avoid fisheries [6], as well as changes to the cable landfall location [I02]. For the wind farm case studies, it was found nearshore areas were avoided, and in one case site boundaries were relocated in relation to safeguarding fisheries interests [25] [26].

However, inclusive decision-making regarding the cable route does not seem to be common practice yet. In response to a scoping report, a fisheries representative body advocated for a rerouting of the export corridor. The existing route did not consider fishing activities, and the local fishing industry was not consulted with [24]. Additionally, for one of the transmission cable case studies, a fisheries representative felt that their knowledge on how to minimise the number of tows a cable would disturb was not considered during the cable route selection [I10]. A general limitation to avoiding fisheries impacts through optimising siting was identified by two fisheries representatives, that certain fisheries as well as the energy industry both prefer soft flat seabed to hard rocky seabed to operate in [I01], [I07].

4.4.2.2 Design mitigation

Section 4.4.2.2 examines how the design of the projects considered the fishing industry, including the chosen installation method. Results for this section are split up into a) renewable energy devices and b) cables, and findings are summarised in Table 4-7 at the end of this section.

a) Renewable energy devices

As well as contributing to siting decisions, fisheries interests may also be considered during project design. Alterations were made to turbine foundation design due to snagging risk [27]. Fishers raised concerns that designs which failed to consider the natural features of the seabed utilised by fishers in tows, for instance in gridded designs, increased impacts on fishing [I07]. However, gridded turbine layouts were still preferred to curved designs which were perceived to lead to safety risks [27].

> *A wind turbine layout design option of arranging the wind turbines in curved rows was considered in the early design stages. Through consultation with shipping and sailing stakeholders, and the local fishing fleet, this design concept was dismissed on the basis of navigational risk and therefore also safety. Straight rows of wind turbines are considered much safer and more straightforward to navigate through or around and straight rows therefore form a key design element of the Wind Farm layout.* [27]

To minimise loss of access to fishing grounds, a minimum spacing of 1 km between wind turbines was recommended by the licensing authority for two case studies [28], [29], and 4/6 offshore wind farm cases included this specification in their project design. However, modifications which reduce impact for one fishery type may not reduce impacts on all fishery types. A consultation response by a fisheries representative claimed that mobile gear remained incompatible with the project site, despite an increase in turbine spacing compared to a previous design

[30]. The associated inter-array cabling was identified as a snagging risk, especially in relation to the scallop fleet [31]. This indicates the footprint of the renewable energy device should not be regarded in isolation of the footprint of the required cabling, which is the focus of the next section.

b) Cables

Three aspects of the cable installation were identified in the case studies that can accommodate “overtrawlability”: installation method, burial depth and rock placement. “Overtrawlability” is a term that was used in project documents repeatedly, to refer to the ability of trawl fishing gear to pass over the cable safely.

Installation method

Figure 1-9 in Chapter 1 illustrates the three main ways in which cables are found in the marine environment: surface-laid, buried or protected with rocks. Since the implementation of the national marine plan in 2015, cable project documentation includes explicit commitment to maximise burial of cables, to comply to marine planning policy and minimise impacts [32]. Maximal cable burial is also in the interest of the developer, to protect their assets [I03], [I13], but is also more costly [I02]. For the inter-isle case studies a cost benefit analysis model was used to identify the installation method with the lowest societal cost, depending on various indicators including snagging risk (which was quantified in collaboration with fisheries representatives), as well as costs to the bill payer [33], [34], [I02].

The results from this cost-benefit analysis model and preferences by fisheries operating in the area informed project design. For example, for two inter-isle case studies where burial was not possible, cables were surface laid rather than protected with rocks, in response to the preference of fishers for a surface—laid cable rather than one involving rock protection [33], [35]. Previous negative experience with rock dumping were highlighted by two fishers in relation to separate projects [I01] [36]. A third fisheries representative also confirmed this view on rock protection, specifically in scalloping grounds, as the rock protection worsened snagging risk [33].

At the pre-application stage, developers will estimate the percentage of the cable that will be buried and communicate this with fisheries representatives (e.g. [33], [35]– [38]). However, for the two transmission cable case studies that have progressed to the operational phase since the time of writing, fisheries representatives have identified that the percentage of rock protected cable as opposed to buried cable was an underestimation, as subsequent surveying has revealed more rock placement would be necessary than anticipated [I10, I14]. Unanticipated extra rock placement means the developer must apply for a new licence, which extends the installation time of the project but also means that previous estimates of project impacts will have been underestimated.

For the tidal project case studies, a lack of sediment in high energy tidal environments was highlighted as a barrier to cable burial, indicating the cables needed to be surface laid [39]. Mitigation measures identified to minimise snagging risk for surface-laid cables include the use of natural crevices to protect the cable, weighting it to reduce mobility of the cable and cable bundling [39], [40].

Burial method and depth

For cable burial, fisheries representatives as well as developers have expressed a preference for jet trenching over ploughing, as jet trenching does not leave spoil heaps which can cause nets to fill with mud [41],[9]: *"jet trenching was the [fisheries representative's] preferred method of burial, as the berms which result from ploughs can be problematic for certain fisheries"* [9]. Burial depth was determined in the cable burial risk assessment, which considers fishing gear methods deployed in the project area as well as sediment stability and shipping. Project documentation as well as interviews reflect that cable burial can reduce snagging risk if cables are buried deep enough, for which gear penetration depth for different gear types is taken into consideration [42]– [44], [I03], [I13].

> *"Once the cable's installed and buried, then there shouldn't be any interactions with the fisheries because they can fish over the top of it"* [I03]

Rock placement

For areas where cable burial to the required depth could not be guaranteed, project documents indicated rock placement was then required. Rock berms can be designed to allow rock hoppers (a type of fishing vessel) to still trawl over the protected cable [45]– [47], and for transmission cables, inter-isle cables and cables for offshore wind projects, fisheries representatives have been consulted on their preferred rock berm gradient. According to a transmission cable environmental statement, the grade of stone also has an influence on the overtrawlability of rock berm gradients, and "*rock berm and mattresses will be designed to have a smooth over trawlable profile, utilising appropriate rock grades*" [44]. Table 4-7 summarises the design measures that have been identified in the case studies which can avoid/ reduce loss of access and snagging risk for the fishing industry.

Table 4-7 Design measures identified that can avoid impacts on fisheries

Renewable energy devices	Cables
Turbine foundation: avoid guyed monopiles and floating structures [27] *Turbine layout:* Fisheries expressed a preference for a gridded over a curved design [27] *Turbine spacing*: Minimum distance of 1 km advised by licensing authority [28,29]	*Burial:* maximise proportion of cable that is buried, bury deep enough and remove residual spoil heaps and trenches after cable burial [32] *Surface-laid:* use of natural crevices for protection, weighting and bundling of cables [39,40] *Rock protection:* optimise rock berm gradient and grade of stone [44] *Installation:* preference of jet trenching over ploughing [41,9]

4.4.2.3 Minimising duration of impact

All developers collected information, including via fisheries representatives or interviews with local fishers, on seasonality and intensity of fishing activities along the cable corridor or in the project area. This was used to inform the timing of the construction works, to minimise disruption (e.g. [41], [48]– [50]). However, one interviewed fisheries representative emphasised that not all developers accommodate fishers' views on when was suitable, referring to an instance where construction occurred during *"prime fishing time"* [I10]. In another project's environmental statement, the justification for the chosen timing of works was weather conditions [49]. Two mitigation measures were identified to shorten the installation time which also lessens temporary impacts on the fishing industry: 1) minimising the length of the cable and 2) consulting with local fishers on the best way to operate in the area [I03], [49]. For the inter-isle cable replacements, minimisation of installation time was factored into the cost-benefit analysis model as a way of minimising disruption.

4.4.2.4 Pre-application engagement with fisheries

In general, improvements in engagement and consideration of fisheries over the preceding ten years (2010 to 2020) was acknowledged by different interest groups ([I10], [I12]). Two key roles facilitate engagement (Figure 4-7). The fisheries liaison officer is employed by the developer and should represent the developer on fishing issues, often with the support of a fishing industry representative (FIR). A FIR serves as a trusted contact point onshore with the fishing community at a local level and relays information between the FLO and the fishing industry (Figure 4-7).

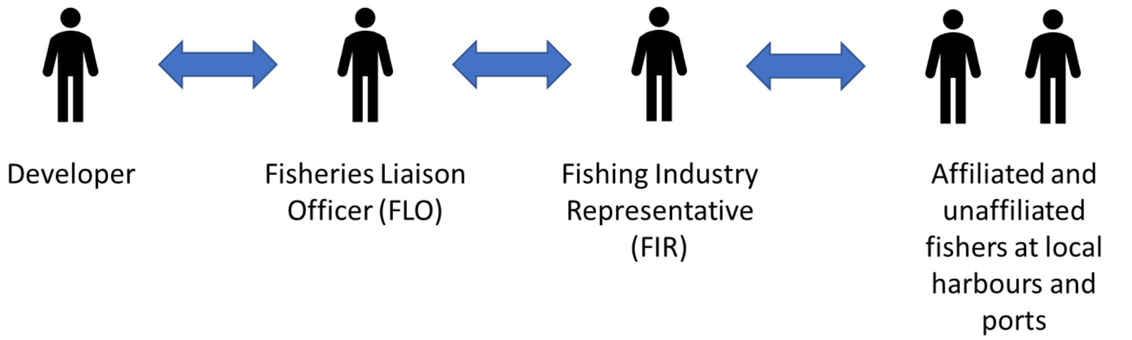

Figure 4-7 Illustrating the roles of FLOs and FIRs to facilitate liaison between developers of energy projects and the fishing community. The left-right arrows reflect continuous back and forth communication throughout the process.

Developers identified that the purpose of engaging with fisheries at a pre-application stage, as well as receiving first-hand information on fisheries activities, is to get feedback on primary mitigation measures such as rock berm gradient and installation method to minimise snagging risk, and this was identified by a developer to be critical for developing mitigation strategies [51]. Section 4.4.2 detailed the various inputs by fisheries representatives that informed the siting and design of a project (primary mitigation). These inputs were given by different types of fisheries representatives in different settings. Table 4-8 summarises which methods have been adopted across the case studies, and subsequently, reflections on these approaches by the interviewees will be elaborated on, as well as the role of fisheries liaison officers and fishing industry representatives.

Table 4-8 Engagement approaches for informing primary mitigation measures

	Steering group strategic siting	Project-specific public consultation event organised by developer	Project-specific official consultation responses requested by licensing authority[m]	Project-specific meetings
Unaffiliated fishers		X		X
Regional inshore fisheries groups[n]	X	X	X	X
Local/regional associations		X	X	X
National associations/(umbrella) federations	X	X	X	X

All case studies considered fisheries interests at both a national level and in more detail at a regional and/or local level. For all case studies this included contacting fishing associations and regional inshore fisheries groups if there were any active in the project area. All the wind farm and cable replacement projects explicitly included in their documentation that non-affiliated fishers were also contacted, amounting to 15/23 case studies. In the remaining 8 transmission cable and tidal projects it is unclear if no non-affiliated fishers were present, or if they were contacted but this contact was not documented.

Each of the next five sections (a)-e)) describe a prominent theme that came up during the interviews and document analysis in more detail.

a) Resources

As summarised in Table 4-8, specific fisheries bodies are invited to respond to official consultations by the licensing authority, to which they may or may not respond. A consultation response for one of the case studies points out that the formulation of a response requires the consultee to process and understand a

[m] This only includes responses from consultees contacted by the licensing authority (responses from the general public were not analysed)
[n] Regional inshore fisheries group network: http://ifgs.org.uk/

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large amount of information for which they would need sufficient resources [52]. An interviewee suggested this might be a barrier for smaller boats or smaller associations that also need the resources to respond to other proposals e.g. aquaculture sites or marine protected areas [I10].

A lack of resources was also identified as a barrier to attending meetings:

> *"*[inshore fishers] *shouldn't be marginalised because we can't be everywhere at the same time."* [I10]

Another fisheries representative reported fisheries attendees stopped attending meetings because the outcomes of the previously attended meetings did not meet their expectations [I11]. Some fishers also voiced a perception that fisheries attendees are outnumbered by representatives for the proposed development during meetings [I10]. Some developers have opted to attend meetings organised by the fishing industry instead, so that project plans can be included as agenda items as part of an already planned meeting, as opposed to expecting members of the fishing industry to attend one of their meetings [53].

b) Fisheries associations and umbrella organisations

From the interviews as well as project documentation it was found that fisheries bodies such as national or regional associations/federations can help a project developer to find suitable fishing industry representatives, but an unaffiliated fisher pointed out that these representative bodies might be biased towards specific types of fisheries [I06]. An alternative method of recruitment was identified for one of the other case studies, through a local community development group [I09].

As can be seen in Table 4-8, umbrella organisations such as national-level federations are involved in public consultation events, respond to official consultations and attend meetings with project developers. An interviewee pointed out that umbrella organisations can facilitate sharing of good and bad practice experiences. However, there is a difference in the capacity of the different umbrella organisations that are active, which depends on their membership which might be dominated by specific types of fisheries [I10]. Interviewees as well as a consultation response reflected that the regional inshore fisheries groups (RIFGs), which were set up by the government to improve the management of the 0-6 nautical mile zone, are a potential vehicle to reach many members of the fishing industry, including unaffiliated fishers [I12], [54], [I04], [I14], [I15]. However, despite RIFGs being in place since April 2016 (5 years at the time of writing), one unaffiliated fisher reported a lack of awareness of the existence of RIFGs [I06].

c) Fisheries liaison officers (FLOs)

[I03] and [I13] expressed the importance of fisheries liaison officers in facilitating communication between the fishing and electricity industry. However, three interviewees from both the fishing and renewables industry have expressed a difficulty in finding appropriate fishing industry representatives for the project areas [I07], [I11], [I13]. Five interviewees highlighted this post is frequently taken by retired fishermen [I11], [I07], [I02], [I13], [I03], as this role cannot be performed when out at sea [I11].

d) Public consultation events

An interviewee from the cables/renewables industry perceived the role of consultation events to be to inform the fishing industry as well as a chance for the fishing industry to have a voice and stated that in the past inputs from consultation events have led to changes in the project [I08]. However, another participant from the energy industry stated fishers should already be contacted at an earlier stage before consultation events via the fisheries liaison officer (FLO) [I13], and that consultation events are a subsequent mechanism to capture the views of people who may not have been reached out to via other channels yet [I02]. A fisheries representative also felt public consultation events were important but should be combined with separate meetings specifically for discussions between the two industries as marine users [I10].

Two fishers believed their inputs during consultation events did not get considered in the planning of a project [I05, I06]. One fisher felt that sometimes there was a new consultation event without any new information, yet he was still willing to cooperate with the developer to ensure he got properly compensated [I06]. Timing and location of consultation events were identified as a barrier for individual fishers to attending as they may not be compatible with fishing activity [I05]. Additionally, a fisheries representative noted that there was an instance where fishers were not aware of consultation events taking place [I10].

e) Fisheries knowledge

Sections 4.4.2.1 and 4.4.2.2 demonstrated how fisheries inputs informed the siting and design of projects, as well as mitigation strategies [51]. However, three fisheries representatives from different organisations expressed a concern that fishers familiar with the project area did not have the chance to share their knowledge on the seabed composition that could help inform the best cable route for maximising burial [I10], [I11], [I14]. Although not directly linked to avoiding impacts on the fishing industry, an interviewed independent fisherman expressed similar frustration over the initial disregard of local fishermen's concerns regarding the feasibility of a tidal development when subsequent surveying by the developer backed up their concerns [I06]. A similar comment was made by another fisheries representative that extensive knowledge by the fishing industry of tidal behaviour was not taken on board in project development [I07].

f) Timing of engagement within the process

Multiple interviewees expressed a preference for early and continuous engagement between the energy industry and the fishing industry [I14], [I15], [I11]. For strategic siting, multiple interviewees also stated the more recent sectoral marine plan for offshore wind [17] engaged the fishing community very early on in its development [I11], [I12]. One of the national federations as well as the inshore fisheries group network are part of a steering group for the strategic planning process ([55], Table 4-8). Fisheries representatives reported that some developers that applied for a lease as part of the ScotWind leasing round (informed by the latest sectoral marine plan) contacted the fishing industry prior to their application for a lease (from 2020 to July 2021). This early contact was preferred by interviewed fisheries representatives to a situation where they only get contacted at a later stage by the licensing authorities for a scoping opinion, when developers have already obtained a lease and are applying for a licence [I11], [I14].

Conversely, interviewed representatives from both the cables and fishing industry expressed that on a project level, early dialogue does not necessarily lead to a more meaningful engagement because in the very early stages of the project, cable routes can change significantly due to factors independent of the fishing industry, which can lead to confusion, frustration and engagement fatigue [I01], [I03], [I06].

"I would say speaking to the right people at the right time. And I don't think early dialogue is necessarily what you need."	[I03]

This was brought up as a reason why at the earliest, most uncertain phases of the project, fishers are primarily represented with the available fisheries data before efforts are made by the developer to get in touch [I03]. Another barrier to engagement highlighted by an interviewee is the large time scales between the start of a project and the time at which construction starts [I11].

g) Renewables/cables as a growing industry

Five interviewees representing fisheries interests ([I05], [I07], [I10], [I11], [I14]) highlighted that the expansive trend of renewable energy and cable projects makes the fishing industry feel they are not on an equal footing to the developers:

"the more and more of these projects that are looming the more and more fishing grounds are being lost"	[I05]

This poses as a barrier for the fishing industry to make compromises [I10].

"There's no way to win. There's no way to keep what you're doing right now. And I think if you felt like you were walking into a room on an equal footing with an understanding that you both have to coexist in the area then that would be fine. But I think that the legislation being as it is, it's gonna happen anyway".	[I10]

Linked with this, three fisheries representatives ([I01], [I07], [I11]) believed they had limited influence on the site selection of a development due to the nature of energy infrastructure being of "national importance". Two fisheries interviewees specifically referred to fisheries being at the bottom of the *"pecking order"* [I05], [I07].

"they'll consult with us, and they'll try to avoid rock dumping, where they can. However, this is where it's going"	[I01]

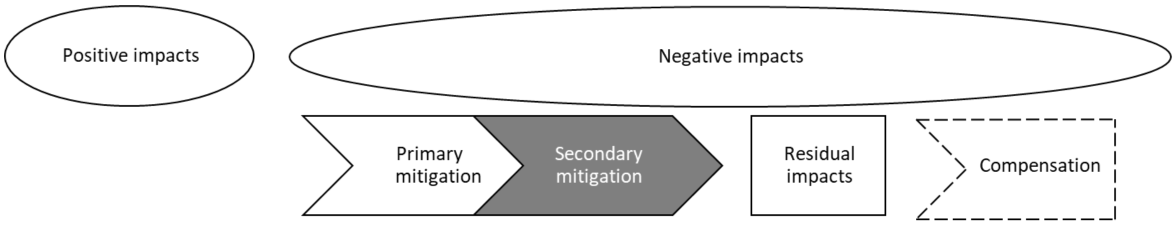
Table 4-10 summarises the findings related to engagement aspects for the primary mitigation phase (procedural and recognitional justice). Table 4-10 summarises the findings for the primary mitigation stage for strategic level and project level mechanisms and barriers to distributional justice. Some findings may be relevant to both levels, but they were reported at the level at which the finding was found.

Table 4-9 Summary table engagement aspects at the primary mitigation stage

Theme	Findings
a) Resources	*Recognitional:* • Smaller boats or smaller associations have less resources to respond to consultation requests, or attend meetings [52, I10] • Developers have attended meetings organised by the fishing industry instead [53]
b) Fishing associations and umbrella organisations	*Procedural:* • Fisheries associations/federations engaged with the proposed projects (Table 4-8) • Plotter database managed by fisheries representatives was used to evidence space use during sectoral marine planning [I11] *Recognitional:* • Unaffiliated fishers reached through regional inshore fisheries groups [I12, 54, I04, I14, I15] • Fishing associations/federations perceived to be biased towards specific types of fisheries [I10]
c) Fisheries liaison officers (FLOs)	*Procedural:* Important mechanism for facilitating communication [I03, I13], but difficult to recruit [I07, I11, I13]
d) Public consultation events	*Procedural:* Fisheries-specific meetings identified as a necessary addition to broader public consultation events [I10, I13]
e) Fisheries knowledge	*Procedural:* • Fisheries preferences and information informed project design and siting decisions (Table 4-6, Table 4-7) • Perceived disregard of local fisheries knowledge [I06, I07, I10, I11, I14]
f) Timing of engagement	*Procedural:* • Continuous as well as early engagement recommended [I11, I14, I15] • Sectoral marine planning included fisheries at an early stage through steering groups and umbrella organisations, which led to adjustments of the lease sites [I11, I14, I12, 55] • Early engagement impeded by project uncertainty [I01, I03, I06]. • Continuous engagement impeded by long time scales [I11]
g) Growing renewables/cables industry	*Distributional:* Uncertainty around number of future energy projects the fishing industry will also have to share the marine space with barrier to making compromises [I10] *Procedural:* Perceived power imbalance between the energy industry and the fishing industry due to renewable energy targets [I01, I05, I07, I11]

Table 4-10 Distributional justice findings, not directly linked to engagement, for the primary mitigation stage

Strategic level	Project level
• Interests of the fishing industry represented in planning policies at an early stage [17, 55, I11, I12] • Strategic spatial guidance avoided high value fishing areas	• Projects minimised cable footprint and spatial overlap with fisheries • Project location and design adapted to reduce impacts on fisheries • Installation time minimised
Barriers: Certain fisheries prefer the same seabed composition as the energy industry: soft, flat seabed	*Barriers:* • Underestimation of necessary rock dumping at planning phase • Limitations to the extent to which changes in dynamic fishing patterns during lifetime of project (up to 50 years) can be considered in advance at the planning stage



4.4.3 Secondary mitigation

Results related to secondary mitigation measures are subdivided into four sections according to themes identified during the analysis.

4.4.3.1 Role of licence/consent conditions

Whereas primary mitigation measures are embedded in the project siting and design phase, secondary mitigation measures may be imposed as licence conditions. Primary mitigation measures aim to avoid the presence of impacts while secondary mitigation measures aim to minimise/reduce the effects of anticipated impacts, and may be imposed as licence conditions. For all wind farm and transmission cable case studies, proposed secondary mitigation measures relevant to this study are listed in Table 4-11. Each of these measures will be explained in more detail in the text. Even though renewable energy generating projects require a consent as well as a licence, from this point forward both documents will be referred to as a licence, to enable comparison with the cable projects. For two of the case studies, fishing representatives lifted their objections to the project once they agreed with the way mitigation measures were included in the licence conditions [56], [57]. Interviews confirmed that the licensing authority may take issues raised by the fishing industry into consideration and include them in future licence conditions if deemed necessary [I14], [I15].

Table 4-11 Secondary mitigation measures included as licence conditions relevant to fisheries engagement

Wind farm projects	Transmission cable projects
Fisheries liaison officer (FLO) [76,77,78]	Fisheries liaison officer (FLO) [59, 62, 63]
Fisheries Management and Mitigation Strategy (FMMS) [76,77,78]	Fisheries Liaison and Mitigation Action Plan (FLMAP) [59, 62, 63, 75]
Commercial Fisheries Working Group (CFWG) [76,77,78]	Communication strategy [59, 62, 63]

The tidal case studies also proposed the secondary mitigation measures listed in Table 4-11 in their environmental statements/environmental appraisals, but the measures were not included as licence conditions. For the cable replacement projects included in this study, no marine licences were available online even though they were granted, but two marine licences of similar projects were examined and in one of them a condition specifies "*the licensee must ensure that all activities are carried out in accordance with the approved Fisheries Liaison and Mitigation Action Plan"* (FLMAP), indicating a consideration of fisheries in the licence conditions [58].

As stated by an interviewee, the Fisheries Management and Mitigation Strategy (FMMS) *"contains a statement by the developers to promote coexistence between the two sectors"* and *"lays out the strategy for fisheries mitigation"* [I15]. In the licence for one of the case studies, it is stated the FMMS should also be implemented by subcontractors of the developers [57]. Similarly, a licence condition that was recurringly issued for transmission cable projects is the requirement to submit a Fisheries Liaison and Mitigation Action Plan (FLMAP), similar to the Fisheries Management and Mitigation Strategy (FMMS) required for offshore wind farms [57], [59]. While the environmental appraisal/environmental statement provides a commitment to mitigation, the CFMS/FMMS specifies how these mitigation measures will be implemented [60], [I15]. According to the two FLMAP documents that were publicly available for two of the transmission cable case studies, the aim of the FLMAP is to address potential effects (that could not be overcome by primary mitigation) by stipulating secondary mitigation measures to minimise and mitigate them, and to lay out the strategy for fisheries liaison [10], [60]. The FLMAP was reported to be informed by preceding meetings with the fishing industry [10], [60].

For the installation phase, impacts are minimised by ensuring marine users are made aware of the works. A licence condition included in five transmission cable projects complementary to the FLMAP is the communication strategy, which details how different marine users will be informed of installation works and as laid positions of the proposed developments [61]. The licence condition requiring a communications strategy, states that *"the licensee must document clearly defined procedures for the distribution of information relating to all cable installation, protection and survey activities to the fishing industry and other legitimate users of the sea"* [62]. For example, in two case studies a clear diagram is included of how the developer intends to engage with each type of fisheries representative [10], [60]. Channels of communication for the installation works were found to be adapted to different recipients, where a distinction was made between inshore fisheries and national organisations and direct (WhatsApp, face to face meetings) compared to indirect (notice to mariners, website) communication [61]. The importance of the distinction between who is to be contacted directly and indirectly was highlighted by a fisheries representative who expressed discontent that a 'Notice to Mariners' update was used in one instance as a form of indirect communication to notify fishers in the area about an emergency rock placement in an area that is busily fished. The interviewee would have preferred a direct method of communication via the fisheries liaison officer or fishing industry representative for this situation [I10] [64]. As with the engagement during the primary mitigation phase, an important channel of communication is the fisheries liaison officer and fishing industry representatives for communication during installation and operation [40].

The communication of the geographical positions of the energy structures once operational was included as a mitigation measure and licence condition for all the case studies for which their licence was available online. For the two most recent transmission cable licences issued, this condition specified the inclusion of the position of cable protection “including berm heights” with this [59], [63].

4.4.3.2 Commercial Fisheries Working Groups (CFWGs)

As identified in Table 4-11, a licence condition that was included for offshore wind projects is a formal commitment by the developer to engage in a ‘Commercial Fisheries Working Group’ [15]. These working groups are set up on a regional basis, with one currently active for the Moray Firth region and one for the Forth and Tay region [I13]. As stipulated in a licence condition for one of the case studies, a Commercial Fisheries Working Group “*will facilitate ongoing dialogue throughout the pre-construction, construction and operational phases of the Wind Farm”* [65]. Interviewees specified CFWGs are only a requirement for projects that have already obtained a licence and for which this licence condition is specified [I10], [I15].

As described by interviewees, *“these groups bring together developers and the relevant fishing interests”* [I15] for *“a formal exchange of ideas at least every six months”* [I13]. An interviewee stated that draft versions of documents such as the fisheries mitigation and management strategy (FMMS) are brought to these groups and discussed with both the fishing industry and the project developers [I15]. The arrangement of a commercial fisheries working group for discussing items such as the fisheries mitigation strategy was perceived positively: *“it’s good that we have people around that table now”* [I10].

The terms of reference as well as the role of government in chairing these sessions were highlighted by both fisheries and renewable energy representatives as helpful to avoid a potential imbalance in representation of the two industries [I10], [I13]. Formally specifying who is to attend these meetings and what they should expect to get out of it was an initiative a fisheries representative believed helped ensure the time and travel costs sacrificed by attendees will lead to effective engagement [I10]. An interviewee from the renewables industry iterated that more informal smaller-scale meetings with the fishing industry on a regular basis are an essential complement to these commercial fisheries working group meetings to maintain positive relationships, as binding actions could be decided on at formal meetings but discussed beforehand at informal meetings [I13].

4.4.3.3 Differences in communication throughout phases

An interviewee reported that communication between the fishing industry and the project developers during installation can be complicated by the subcontracting of various operations to different companies. Representatives from both the energy and fishing industries believed this prevents the trust established at the beginning of a project to be carried through to subsequent phases [I10], [I13]. Additionally, three fisheries representatives pointed to a perceived change in power relations once the developer had obtained a licence, as well as a reduced level of engagement with the fishing industry [I10], [I11], [I14]. Three interviewees attributed this change to the structure of the companies of the proposed projects. Separate teams within the same company may be responsible for obtaining project consent, construction and post-construction (operations and maintenance) [I11], [I13], [I15]. Maintaining engagement with the fishing industry while handing over a project from one team to another was identified as challenging, and an interviewed energy industry representative is investigating how a *"less siloed approach"* can be adapted throughout a project's lifetime in the future [I13]. This challenge was also said to be compounded by high staff turnover for the company positions that facilitate engagement [I11], [I13]. Between the time interviews were conducted and the submission of this PhD thesis (18 months), a third of the interviewees had changed jobs, and half of the interviewees who changed jobs were in fisheries representation positions.

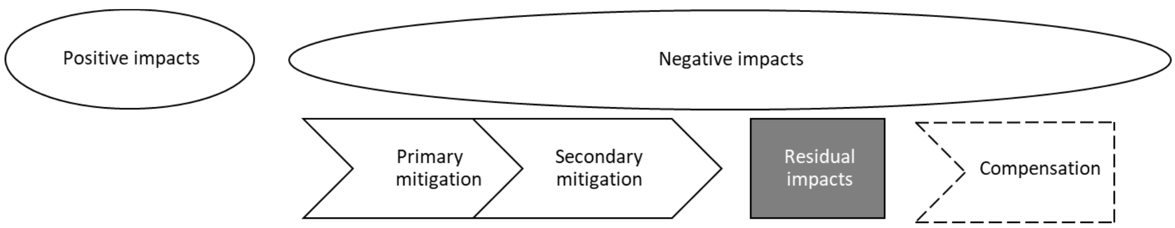
4.4.3.4 Post construction overtrawlability surveys

For offshore wind farms, overtrawlability surveys have been included as a licence condition to assure fishers the installed inter-array cables in offshore wind farms are overtrawlable [65]. However, fisheries and developers reported that a barrier to conducting such a survey is that if the developer says the cable is safe to fish over, they could be held liable if an accident still occurs [I14], [I13]. Such a licence condition has not been included for any other type of development (such as transmission cables).

Table 4-12 Summary findings per type of justice for the secondary mitigation stage

	Mechanisms/barriers
Distributional	*Mechanisms* Agreement on the wording of binding licence conditions led to a fisheries body lifting their objections [56,57]
Procedural	*Mechanisms* • Mitigation measures that facilitate engagement included as binding licence conditions (Table 4-11) • Mitigation strategies formulated in collaboration with the fishing industry [I15] • Commercial fisheries working groups combined with more regular informal meetings allow binding actions to be discussed beforehand [I13] • Communication strategy as a binding licence condition ensures communication of works to marine operators [61] *Barriers* Perceived change in power relations once the developer obtained a licence, including a perceived reduction in the level of engagement with the fishing industry [I10, I11, I14]
Recognitional	*Mechanisms* • Communications strategy specifies how different types of fisheries representatives need to be contacted differently [61] • Clear terms of reference for commercial fisheries working group attendance [I10, I13]

Table 4-12 shows mechanisms identified for distributional, procedural and recognitional justice, as well as barriers to procedural justice for secondary mitigation measures.



4.4.4 Residual negative impacts

As can be seen on Table 4-13, only three case studies report predicted significant residual effects on access to fishing grounds. Table 4-14 indicates which fishery and project phase significant effects were reported for (n=3). The most recurrent significant residual effects were temporary impacts on demersal gear fisheries during installation of the export cable (Table 4-14).

Table 4-13 Predicted significant residual effects for the case studies

Case study group	Predicted significant residual effects
Inter-isle cables	0/5
Transmission cables	0/6
Tidal projects	0/5
Offshore wind farms	3/6

Table 4-14 Composition of predicted significant residual effects related to loss of access for three wind farm case studies (a, b and c)

	Construction and installation		**Operations and maintenance**	
	Wind farm area	Export cable	Wind farm area	Export cable
Static gear	a,b	b,c	a,b	-
Demersal gear (incl. *Nephrops* and squid fisheries)	b	a,b,c	b	-
Scallop gear	b	b,c	b	-

For one of the wind farm case studies that did not predict significant residual effects on access to fishing grounds, it was stated "*existing legislation does not prohibit fishing activity from resuming within operational wind farm sites*" [66]. However, during the interviews some barriers were highlighted that are preventing fishers from returning, including safety concerns. Fishing in these regions is perceived to be risky because it may not be covered by the insurance or result in more expensive insurance premiums [I12]. When a fishing vessel is in need, helicopters may have difficulties entering the wind farm area for search and rescue operations [I14]. Hazards related to snagging risk and liability for cable damage were also reported as barriers [I14].

A fisheries representative noted that the impact of loss of access to traditional fishing grounds is not considered adequately, especially not for passive or smaller mobile gear day boats (<12 m) [I10]. In comparison to larger boats operating further offshore, the interviewee argued that small boats are more exposed to existing nearshore pressures such as upcoming aquaculture sites and newly designated marine protected areas [I10]. In contrast to the wind farm environmental statement that assumes fishing will resume within wind farm sites, the environmental appraisal for a proposed transmission cable explicitly states the developer *"cannot condone demersal trawling over the proposed cable"* [45].

Even though it was not included as a residual significant effect for any of the case studies, sections of exposed or rock protected cables were perceived by several interviewed fisheries representatives as a snagging risk [I01], [I10], [I14]. Related to this, an interviewee referred to an incident where an exposed cable was not charted accurately after an unreported snagging incident had moved it [I01]. A developer suggested that regular inspection surveys should detect such incidents and update UKHO charts [I02]. Figure 4-8 illustrates the estimated proportion per cable installation method for the 12 case studies for which this information was publicly available. Surface-laying the cable was the preferred method of installation for inter-isle cable replacements located in high-energy tidal environments. For the transmission cables and the export cables of the offshore wind farm projects for which information was available, the proportion of the cable that required rock protection varied between 10-45%.

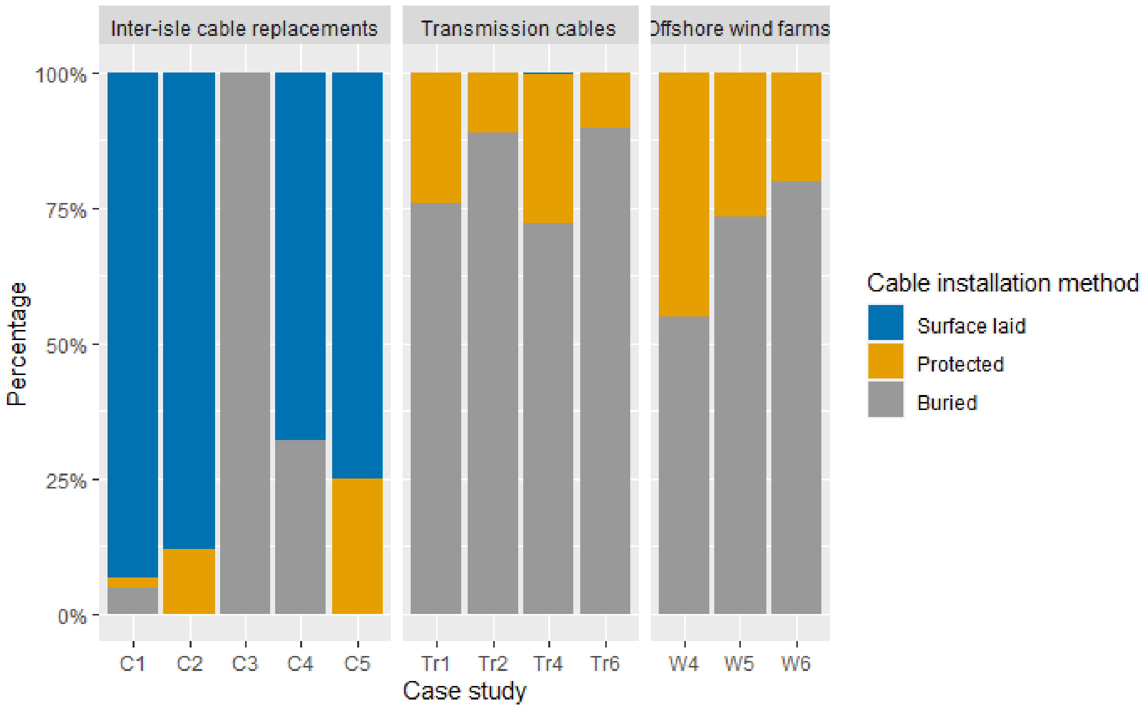


Figure 4-8 Cable installation method estimations found in project documentation (please note these proportions are subject to change as the project progresses)

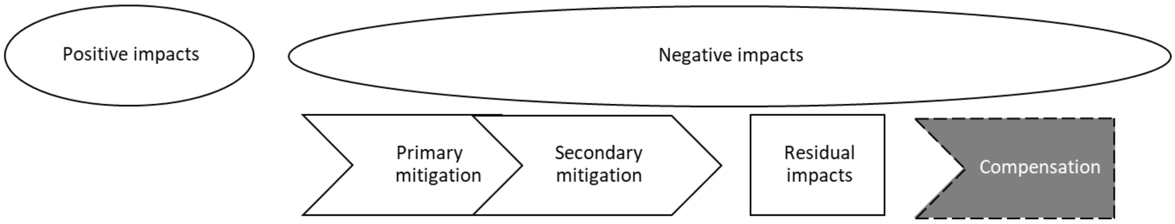
However, as projects progress and more information becomes available, these proportions may change. For two case studies the percentage of cable requiring rock protection had been an underestimation [I10, I14]. Cable sections that needed rock protection were identified as a risk particularly for scallop dredge vessels. It was identified that cable protection measures can damage the gear as the rocks used for protection may resemble the dimensions of the target species [66], [I01]. These rocks an get caught in the gear, making the vessel unstable and putting the crew at risk [I01]. For buried cables, there are no anticipated interactions if the cable remains buried at an appropriate depth throughout its lifetime, which can be guaranteed via cable monitoring post-lay, a mitigation measure included in wind farm and transmission cable case studies [45], [67].

For the tidal case studies, project documents from all case studies indicated cables would not be buried in the seabed. The lack of sediment in high energy tidal environments means the seabed is composed of hard rock, which prevents burial [4], [40]. Out of the five tidal case studies included in the analysis, only one has been constructed (at the time of writing). For this site, the subsea cables are laid on the seabed and protected with rock bags [40]. For the inter-isle cable replacements, some degree of habituation by the fishermen was reported on by both industries, *"if it hadn't interacted with us in the last 50 years, we shouldn't really complain"* [I11], [I02].

Mechanisms to facilitate energy justice for minimising residual impacts are covered in Sections 4.4.2 and 4.4.3 on primary and secondary mitigation. Table 4-15 list the barriers to justice related to residual impacts after mitigation measures have been implemented. Four findings related to distributional justice were identified and one related to recognitional justice.

Table 4-15 Barriers to the dimensions of justice for residual impacts

	Barriers
Distributional	• Difference in reported significant impacts in environmental statements and perceived impacts by the fishing industry [66, I12, I14] • Barriers to returning to wind farms (e.g. safety concerns, liability cable damage) [I12, I14] • Different projects took different views on the level of access of the project areas to fisheries once operational [45, 66] • Unanticipated rock protection increased the proportion of the cable that potentially interacts with fishing activities [I10, I14]
Procedural	N/A
Recognitional	Inshore fisheries also affected by other changes at sea such as an increase in aquaculture sites and marine protected areas [I10]



4.4.5 Compensation

Findings related to the compensation stage of the flowchart are split up into 1) disruption payments and 2) fisheries community funds, and are summarised in Table 4-17.

4.4.5.1 Disruption payments

For temporary impacts, financial compensation was arranged for inshore fishermen who were requested to move their static gear during surveys or cable installation [10],[9] [15]. Affected fishers were either compensated through a fisheries association/federation, or through fisheries liaison officers contacting individual fishers directly, and there was a disagreement between responses from different fisheries interviewees in terms of which approach was preferred. One interviewed fisheries representative argued that compensating the individual vessels making use of the proposed site does not mitigate the impact completely, as a change in fishing patterns affects the fishing community as a whole [I07]. However, it was highlighted that fishing communities on islands are easier to identify as a unit, *“you can identify discrete boundaries as an island… But I know* *that it's a much more complicated thing once you go to the mainland of Scotland"* [I07]. This issue was also reported by another interviewee [I09]. For one of the case studies there was a disagreement between a regional fishing association and local independent fishers as to how fishers in the area should be compensated [I06, I09]:

> *"It was not possible to find an agreement to which the fishing association and independent fishers could subscribe."* [I09]

4.4.5.2 Fisheries community funds

No fisheries-specific community funds were deployed in the cable case studies, as no significant impacts were anticipated. Table 4-16 summarises the compensation initiatives identified for the wind farm and tidal case studies. Their effectiveness cannot be evaluated because the projects that suggested the listed measures have not yet progressed to the operational phase. Funding fisheries research as a form of compensation was something that one of the interviewed fisheries representatives supported. In contrast, the interviewee felt that offering training opportunities for alternative employment as compensation to fishers fails to acknowledge *"the importance of isles-based sea skills and prosecuting your raw resources around your isles"* [I07]. The interviewee was therefore more supportive of forms of compensation that can facilitate a move towards a more efficient fishing industry [I07]. Three fisheries representatives were in favour of fleet-wide initiatives rather than financial compensation of individual vessels [I07], [I10], [I11].

Table 4-16 Suggested measures to the benefit of fisheries communities found in the case studies (but not yet implemented as of the writing of this study)

	Tidal projects	**Wind farm projects**
Enhancement affected fisheries	Enhancement of local scallop and lobster stocks [79]	Stock assessment and enhancement [3]
	V notch scheme to preserve breeding female lobsters [51]	Scallop re-seeding scheme within wind farm site [3]
	PhD research on enhancement lobster stocks [51]	Research on stocks, gear trials, interactions between marine renewables and fisheries [3]
		Support efforts towards accreditation of fisheries and seafood products [3]
Enhancement infrastructure	Improvements in port infrastructure (e.g. storage, fuel) [79]	Ice plants, fuel storage facilities, safety equipment [3]
Enhancement alternative opportunities	Development of mussel/oyster aquaculture possibilities [79]	
	Provision of training for local fishermen to enhance employability for opportunities such as guard vessel work [79]	

One fisheries representative highlighted there is no equivalent of onshore community benefits for offshore projects: *“whoever wrote the rules forgot that there’s a community that makes it’s living out there”* [I11]. Four interviewees across the different interest groups identified the West of Morecambe Fisheries Ltd. as an example of how funding provided by offshore wind farm developers can be managed to support the fishing industry [I11], [I13], [I14], [I15]. This not-for-profit UK company managed funding provided by offshore wind farm owners, which was used to set up projects that benefited fisheries that were operational in the same area as the wind farms [72]. Projects include the restocking of fish boxes, crustacean stock research, purchase of a refrigerated van and harbour improvements [73]. The company has since ceased operations, but their website remains live to serve as a good practice example of co-existence between the energy and fishing industry [74]. Table 4-17 indicates that compensation and community benefit funds can enhance distributional justice, but barriers have been identified for all three justice dimensions.

Table 4-17 Barriers and mechanisms related to compensation measures/fisher community benefit proposals

Justice type	Mechanisms/barriers to justice dimension
Distributional	*Mechanisms* • Financial compensation for the temporal removal of static gear [9,10, 15] • Community benefit funds suggested for enhancement affected fisheries, infrastructure and alternative opportunities (Table 4-16)
Procedural	*Barriers* Disagreement between different fishing segments as to what entails suitable compensation [I06, I09]
Recognitional	*Barriers* Difficulties in defining the fishing community that use the affected area [I07]

4.5 Discussion

Before discussing the results, a brief overview, diagram and summary table is presented here.

Overview results
Results across steps of the flowchart are summarised in Figure 4-9, mapped along different stages of the project life cycle. Potential for facilitating distributive justice is highest at the strategic planning stage by avoiding high value fishing areas. Once a project has obtained a spatially explicit licence there is less room to adjust location. Short-term positive impacts (employment opportunities) and compensation (for temporary removal of static gear) contrast with long-term perceived negative impacts. Potential discontinuities in communication identified in this study are marked in yellow and indicate barriers to procedural justice. The mechanisms in place to overcome discontinuities and facilitate continuous engagement to foster procedural justice are shown as green arrows: the use of fisheries liaison officers and fishing industry representatives as well as commercial fisheries working groups at the post-consent phase (once the developer has obtained a licence). These also facilitate recognitional justice if they also reach out to fishing segments that are underrepresented by fishing associations or federations in place to protect fishing interests. Table 4-18 summarises the findings per flowchart step and per justice dimension.

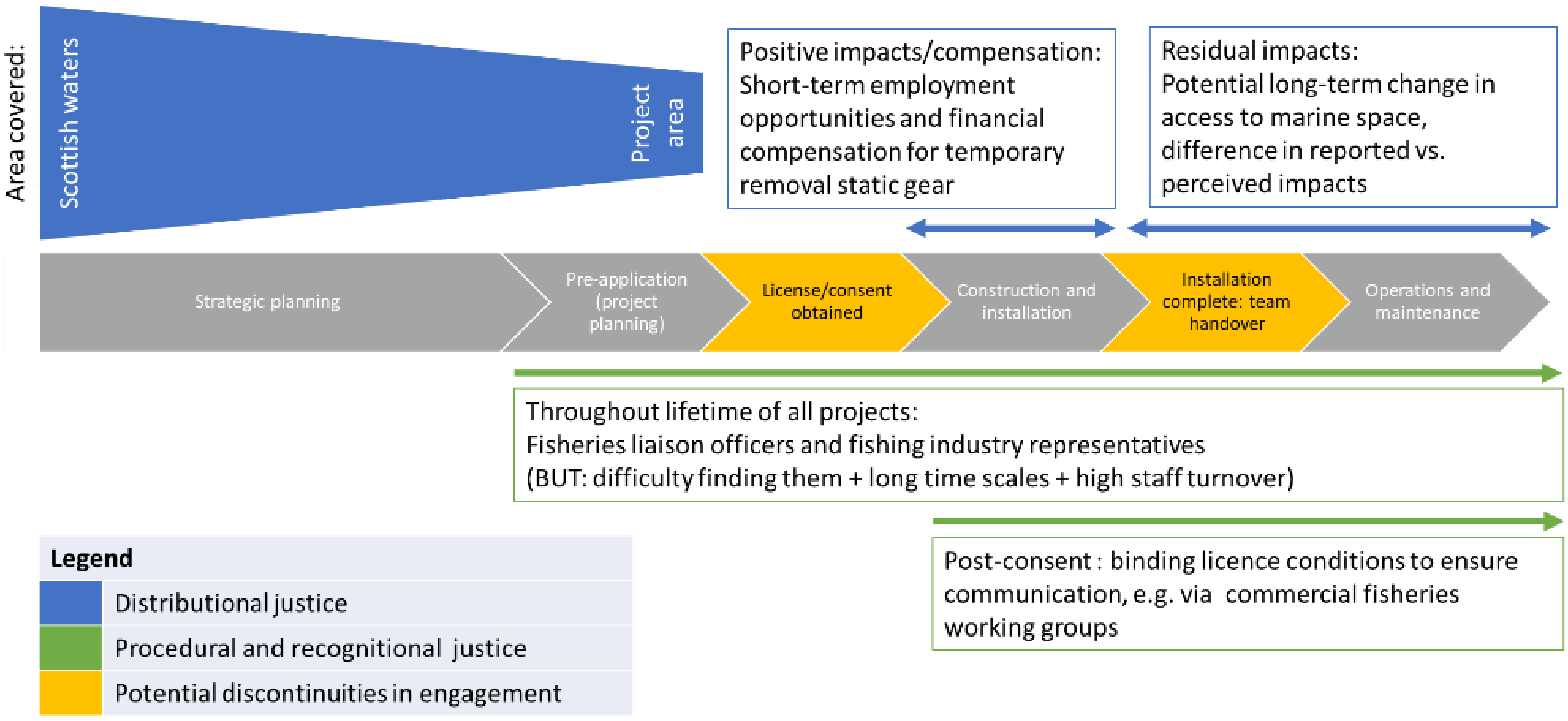
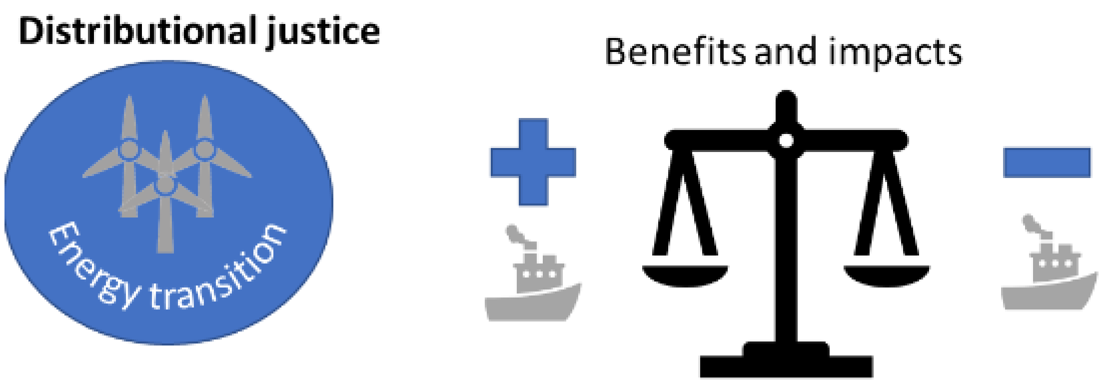


Figure 4-9 Simplified version of a project lifecycle. Marked in blue are mechanisms identified that affect distributional justice. Marked in yellow are project milestones that influence engagement with the fishing industry as highlighted by interviewees. Green arrows depict mechanisms currently in place to facilitate procedural and recognitional justice.

Table 4-18 Overview of findings per mitigation level and per justice dimension

	Distributive	Procedural	Recognitional
Positive impacts	Employment opportunities (but short-term)	-	• Not all vessels eligible • Perceived barriers to access to benefits for remote or island communities
Primary mitigation	Strategic siting most effective, but hampered by uncertainty as to extent of marine space that will be needed for the energy transition	Fisheries inputs have led to changes in the location and design of projects, but fishers feel they are on unequal footing with developers due to national energy targets, and there is a perceived disregard of local fisheries knowledge	Not all members of the fishing industry have enough resources to adequately engage with energy industry
Secondary mitigation	Binding licence conditions attached to an issued licence that protect fishing interests led to fisheries bodies lifting their objections	Licence conditions obligate the developer to set in place timely communication channels with fishing industry during installation works, as well as employ a fisheries liaison and take part in working groups	Communications strategy as a licence condition ensures appropriate communication channels for each type of marine user to ensure no fishers are being overlooked
Residual impacts	Differences between reported significant impacts in environmental statements and perceived impacts by the fishing industry (e.g. barriers to returning to wind farms)	-	Inshore fisheries also affected by other changes at sea such as an increase in aquaculture sites and marine protected areas
Compensation	Financial compensation for the temporal removal of static gear, no examples yet of implemented community benefit funds	Disagreement between different fishing segments as to what entails suitable compensation	Difficulties in defining the fishing community that use the affected area

Section 4.4 indicates mechanisms are in place which can facilitate a just energy transition for the fishing industry, but barriers to achieving energy justice also exist. By explicitly considering multiple dimensions of justice, findings demonstrate how a just transition is multifaceted. This could not have been elicited using conventional techniques such as cost-benefit analysis, which would only capture distributional justice concerns. Each stage of mitigation poses different challenges and opportunities to facilitate a just transition and have different implications for different fisheries segments. These results combine findings from different sectors and can hopefully guide future collaborations between the fishing and energy industry, as well as strategic planning of upcoming projects. In Sections 4.5.1 and 4.5.2, findings are discussed in more detail for 1) distributional, and 2) procedural and recognitional justice.



4.5.1 Distributional justice

The ability of developers to maximise distributional justice for the fishing industry, for example through siting decisions, depends on higher level decision-making, such as planning policies in place and strategic siting guidance (Scottish Government, 2020b, 2015a). For example, areas identified for offshore wind farm development were adjusted to avoid high value fishing areas. However, national policy can also hinder distributional justice. For example, national targets for renewable energy generation make the fishing industry feel they are not on equal footing with the renewables sector, as an equivalent quantitative target does not exist for the fisheries sector. Renewable energy installations and cables may take priority over other marine uses as they can be classified as critical national infrastructure (Scottish Government, 2020e). Energy transitions, such as the current transition from fossil fuels to renewable energy sources, create winners and losers (Carley and Konisky, 2020).

Loss of access to fishing grounds has been identified as one of the social struggles fishers are increasingly confronted with, in combination with other stressors (Bavinck et al., 2018). Addressing this requires action at a strategic level. Governments across the world have started to consider the justness of the energy transition, for example the creation of the Just Transition Commission in Scotland which was set up to identify practical steps to achieve a just transition (Just Transition Commission, 2021). However, this does not currently include potential impacts on displaced sectors such as fisheries, pointing to a gap in the perception of a just transition taken up by government.

Even though only 2/6 wind farm projects identified significant residual effects on the fishing industry once the wind farm is operational, several barriers were identified which prevent fishers returning after construction. This includes safety concerns and liability for cable damage during a snagging incident, issues that have also been identified in previous UK studies (Gray et al., 2016; Hooper et al., 2015). There appeared to be a disconnect between perceived impacts by the fishing industry and reported impacts by the projects. The way affected people perceive and judge an intervention has been termed ‘sense of justice’ in other work (Svarstad et al., 2011). This aspect of justice cannot be overlooked, and perceived injustices, as well as material deprivation, contribute to social struggle as defined by Bavinck et al., 2018. To date, no long-term fisheries compensation measures were implemented for any of the case studies, so their effectiveness of mitigating the residual impacts could not be evaluated. However, a best practice case from England was highlighted by government, the energy industry and the fishing industry which could guide the implementation of future initiatives.

There were also differing perceptions on the level of acceptance towards demersal trawling over cables. Section 4.1 lists the acts and conventions in place that make it illegal for a fishing vessel to damage a cable, and the European Subsea Cables Association (ESCA) recommends “vessels should avoid any such activity [including fishing] at a minimum distance of 0.25 nautical mile” from the subsea cable (ESCA, 2021). This position statement is echoed in the environmental appraisal of one of the transmission cable projects as reported in Section 4.4.4. On the other hand, within wind farms, project developers are carrying out overtrawlability trials to encourage fishers to resume their fishing activities within the wind farm site. Perspectives on access to fishing vessels to areas where subsea cables are installed are inconsistent. If this ambiguity is not addressed, there is a risk that the EIA process will misidentify impacts and that fishing vessels will be excluded from wind farm sites due to insurance and liability concerns regarding cable damage, therefore the current legal framework needs to be revised (Marine Scotland & Brown and May Marine, 2022).

Specifically for subsea cables, a memorandum of understanding has been reached between NFFO (the National Federation of Fishermen's Organisations) and Subsea UK, calling for the need for "strong communication links" for a successful coexistence (NFFO, 2012). And specifically for renewable energy projects, a revised guidance document by the FLOWW group that is currently being drafted has compiled the positions of ESCA, the NFFO and the Scottish Fishermen's Federation, to improve communication on this issue (The Crown Estate, 2020). Different approaches are taken by different sectors operating cables. Issues around loss of access will need to be treated differently for different types of cable projects, offshore wind farms and tidal energy sites, and will also depend on the type of fishing that takes place.

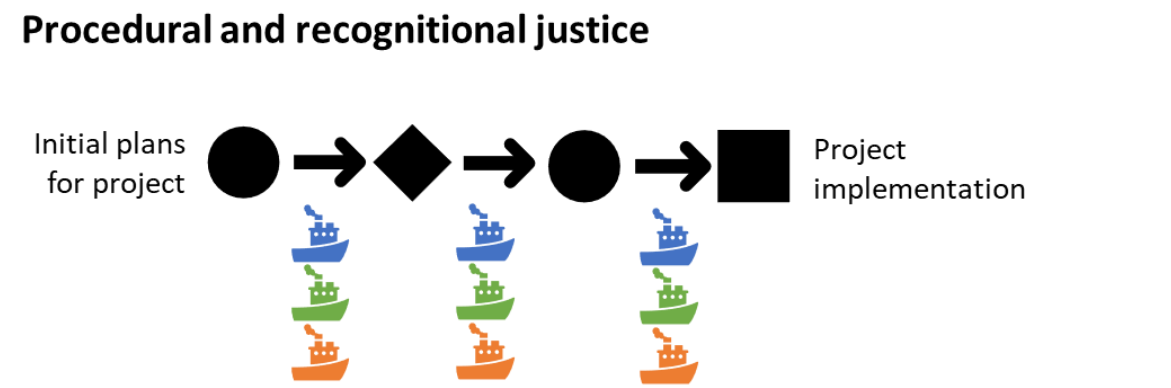
After strategic-level guidance and prior to applying for a licence and consent, this study has identified specific examples where developers have made adaptations to the siting and design of a project (primary mitigation) to maximise distributional justice for the fishing industry. At the pre-application stage, important contributions were made by the fishing industry with regards to the layout and installation method of projects, in addition to influencing siting decisions. This included the preferred method of protecting cables with rock berms, or method of burial. The specific examples of how cable installation techniques considered fisheries contribute to an understanding of how co-existence can occur, the need for which was highlighted in a recent report (Marine Scotland & Brown and May Marine, 2022). These examples demonstrate how meaningful participation in the process by the fishing industry, indicating procedural justice, have led to improvements in distributional justice (avoidance of impacts).

Explicitly comparing positive impacts with residual negative impacts highlighted a potential mismatch in timing, hindering the possibility of the negative impacts being offset by the positive impacts. Employment opportunities were mostly available in the construction phase of a project, whilst permanent changes to access due to a project were more long-term in nature. A potential mismatch was identified in terms of who would receive positive impacts and who would be potentially affected by negative impacts.

Long-term positive impacts were not explicitly identified in this study, whilst perceived long-term negative impacts were identified in the case studies and the interviews. However, this comparison does not consider indirect positive impacts such as improvements in infrastructure and reduction in the reliance on fossil fuels for electricity production. Also, research is currently being conducted on the effects of offshore wind farms on fish stocks (Gill et al., 2020). For example, increases in catch rate of plaice around the edges of wind farms in the Belgian part of the North Sea have been reported, demonstrating that new habitats formed by wind farms can be beneficial for target species and result in novel fishing opportunities for vessels (De Backer et al., 2019). Therefore, positive impacts could benefit certain fisheries, but there is still greater uncertainty around the prediction of these benefits compared to the prediction of negative impacts.

Currently, no direct fisheries-specific benefits of renewable energy and cable developments for fisheries in terms of energy supply were identified, and this could be related how the industry is currently still predominantly fossil fuel-based (Scottish Government, 2022). In future, if fishing vessels transition towards being powered by electricity (e.g. Corvus Energy, 2015), direct energy benefits could become more relevant. This would allow marine users to take up the role of active energy citizens and engage with a proposed renewable energy project as an opportunity for cheap charging points for vessels, for example. In a terrestrial context, it has been demonstrated that it is possible to foster energy citizenship through material objects, such as smart energy meters or photovoltaic panels (Ryghaug et al., 2018), which could become a relevant approach for introducing marine energy citizenship once relevant technologies for marine users are more readily available.

At the post consent stage, measures imposed by the licensing authorities help to facilitate a just transition for the fishing industry. An instrument that was found to be important for guaranteeing the implementation of proposed mitigation measures and overcoming objections to the case studies, was agreed-upon licensing conditions. However, the mitigation measures that have been identified in this study mostly concern procedural justice. Indirectly, this can also improve distributional justice, but the mitigations embedded in licence conditions did not specify any measures that could directly improve distributional justice. A review of existing practices by the Seaplan project report similar findings: 29 tools were identified that could aid mitigation of impacts, and only 11 tools to aid avoidance of impacts (Moura et al., 2015). This indicates that the capacity to maximise distributional justice for the fishing industry is greatest at the earlier strategic and project planning phases before a licence is obtained, as reported in Kafas, 2017; NFFO, 2021.



4.5.2 Procedural and recognitional justice

Four main themes are used to structure the findings related to procedural and recognitional justice, related to 1) employment opportunities, 2) consideration of fisheries during project siting and design, 3) how different channels of communication were used and 4) commercial fisheries working groups.

4.5.2.1 Unequal access to employment opportunities

As presented in the results, expenditure by a project developer on services provided by the fishing industry such as fisheries liaison and guard work can be a contribution to a fisher’s income. However, several barriers to accessing these opportunities were identified. The specific crew and vessels requirements needed can exclude segments of the fleet, indicating a barrier to recognitional justice. Barriers to access due to the required specifications were also identified by other studies in Scotland and Ireland (K. A. Alexander et al., 2013; Reilly et al., 2016a), and this study adds a temporal dimension to this in that the need for fishing vessels for guard vessel work might coincide with optimal fishing conditions. Improvements to access could be facilitated by government-funded projects, such as the performance review of work boats based in Orkney to support marine renewable operations (EMEC and Aquatera, 2017).

Employment opportunities may not necessarily be allocated to vessels that will be affected by the project works. To align affected vessels with employment opportunities and facilitate distributive justice, a study in Ireland suggested programmes that link affected vessels with employment opportunities (Reilly et al., 2016a). Procurement law prevents the developer from influencing candidate selection, and unfair competition was also identified as a barrier in this study. However, national-level fisheries organisations that organise guard vessel work can coordinate guard vessel work allocation within their membership. Notably, this could result in a difference in access to guard work opportunities between members and non-members, indicating recognitional justice concerns.

4.5.2.2 Consideration of fisheries during the siting and design of projects

Even though preferences by the fishing industry were taken into consideration for the design and siting for a number of the case studies, a frustration that was repeatedly voiced by fisheries representatives is the lack of regard by developers of fisheries knowledge of an area. The integration of local knowledge into decision-making was identified as a key component for procedural justice in the energy transition (Jenkins et al., 2016). However, difficulties in collecting local fisheries knowledge have been previously identified (K. A. Alexander et al., 2013). For a wind farm project on the East Coast of the U.S., the compilation and translation of local fisheries knowledge by a local community development organisation increased accessibility and credibility of the information for developers (Klain et al., 2017). If considered at an early phase before expensive surveys are carried out for a project, it could also be cost effective for the developer. For a recent floating wind project, fishers recommended a route for the export cable that also avoided steep drops in the seabed (Moore, 2019). These two examples illustrate there are instances where fisheries knowledge has been integrated into project planning, in combination with empirical data collected by the developer, but it is not yet common practice.

As the existing literature supports (de Groot et al., 2014; Haggett et al., 2020; O'Keeffe and Haggett, 2012), interviewees emphasised that engagement with the fishing industry at the earliest possible stage is more effective, and the findings of this study suggest that effective early engagement is becoming more common, compared to earlier practice. However, uncertainty at early stages of planning at the project level, such as changes in the cable route or an overestimation of the proportion of the cable that can be buried, were identified as barriers to meaningful early engagement. This uncertainty could be another reason why integrating fisheries knowledge of the seabed at an early stage is not common practice yet, as it could lead to disappointments if the route advised by fishers is not taken on board, and siting decisions also depend on fisheries-independent factors. For wind farm projects, uncertainty around the location of projects is reduced through strategic siting initiatives, but this is not in place for cable projects. Therefore, at the early stages of a cable project when the route is still subject to changes, it was deemed more appropriate to rely on fisheries data for planning the route rather than consultation, to avoid project uncertainty leading to confusion and frustration for the consulted fisheries representatives. This emphasises the need for high quality fisheries data endorsed by the fishing industry as well as timely communication, to effectively foster procedural justice.

Previous studies highlight the importance of early engagement, but this study identified continuous engagement as being equally important, which is hampered by the long time spans of project planning. The time between the inception of a project and its commissioning took between 5-11 years for the analysed case studies. Delays of project timelines can be attributed to unexpected circumstances such as additional rock placements, as identified in Section 0. Such considerable time spans can complicate engagement, especially when there is high staff turnover in the fishing industry representative bodies, the energy company or its subcontractors, as indicated by the number of interviewees that have changed jobs in the timespan of under two years. This poses as a barrier to the need for consistent points of contact from both the fisheries and energy industry which was highlighted by a previous study (Rodwell et al., 2013). Relationships between the industries sharing the marine space constantly need to be rebuilt, to enable ongoing consideration of procedural justice.

4.5.2.3 Different channels of communication are used to reach out to fishers

An important mechanism to maintain consistent points of contact between developers and the fishing industry are fisheries liaison officers (FLOs) and fishing industry representatives (FIRs). A locally-based liaison can function as a bridge between developers and members of the community, fostering effective communication and trust (Klain et al., 2017; Rodwell et al., 2013; Rydin et al., 2018b), which can enhance procedural justice in the planning process. However, difficulties in recruiting locally for these roles were highlighted by interviewees, which can pose a challenge in the future with more upcoming projects in more areas. Interview results indicate recruitment of a local fisheries liaison can be facilitated via local fishing associations, but also through third party community-owned organisations, which could be regarded as an example of a bounding or bridging organisation that can help run community engagement (Klain et al., 2017), also known as “unbiased intermediaries” (Dwyer and Bidwell, 2019).

Additionally, “unbiased” local representation of projects in remote or island communities was pointed out as essential to a project in terms of influencing local understandings of impacts and benefits, highlighting the role of the messenger in translating information between actors, a result that complements a finding of a similar study in the United States (Klain et al., 2017). Local representation of projects in remote or island communities can improve the planning process as well as access to information, which can improve procedural justice, as well as ensuring remote/island communities are not underrepresented (recognitional justice). Involvement of third parties was also recommended as a mechanism to reduce the potential of conflict between the fisheries and renewables/cables industries by Stelzenmüller et al., 2020.

Recognitional justice concerns included the lack of resources for smaller boats or smaller associations to respond to consultation requests or attend meetings. An interviewed unaffiliated fisher also stressed that fishing associations sometimes embody a specific segment of the fishing industry which may be a different one of unaffiliated fishers operating in the same area. Mechanisms identified that can overcome this recognitional injustice is offering potentially affected members of the fishing industry multiple ways to engage as specified in the communications strategy for some of the case studies, as well as the initiative of energy industry representatives attending as a guest to fisheries meetings. This was also suggested as a strategy by a fisheries representative during an international workshop on fisheries interactions with offshore wind energy developments (RODA, 2020).

As well as fisheries liaison officers and fishing industry representatives, umbrella organisations representing multiple associations functioned as a point of contact between developers and local fishers operating in the areas of interest and could help to facilitate both procedural and recognitional justice concerns. Umbrella organisations can reduce the pressure on individual associations or fishers to make time and resources available to engage with developers. Specific umbrella organisations have resources to employ people to be involved in various stages of the decision-making of different projects, as well as on a strategic planning level. However, different umbrella organisations have different levels of resources available for this, and they do not include the needs of unaffiliated fishers. This highlights the potential role of regional inshore fisheries groups, who also represent unaffiliated fishers, to overcome this recognitional justice issue.

The regional inshore fisheries groups network was set up in 2016 by Marine Scotland, and aims to give commercial inshore fishermen a stronger voice in marine planning initiatives (Marine Scotland, 2020), which can include offshore energy projects. Chairs of the regional inshore fisheries groups are employed by Marine Scotland and organise meetings where both non-affiliated and affiliated fishers and their representatives convene to address fisheries related matters (RIFG, 2016). However, this network runs on a limited budget, and only represents fishers between 0-6 nautical miles (nm) off the coast (Shucksmith et al., 2020).

This can hamper their capacity to engage with developers on project plans, or their remit if the project is outside 6 nm.

Broadly speaking, two engagement tools influenced project level decisions: 1) contacting individual fishers via fisheries liaison and 2) engagement through umbrella organisations. Therefore, an alignment between the needs of individual fishers and the objectives of umbrella organisations (commercial or government-funded) can enhance procedural and recognitional justice consistently from initial siting ideas until project implementation.

4.5.2.4 Post consent commercial fisheries working groups improve procedural and recognitional justice

Attendance at commercial fisheries working groups was imposed as a licence condition for all analysed wind farm projects. This study highlighted that this commitment has the potential to facilitate both procedural and recognitional justice aspects of the energy transition, as an agreed upon terms of reference could ensure recognitional justice by stipulating who is to be included in these meetings. However, the obtainment by a developer of a licence can change power relations, which was also a finding of a study focusing on interactions between fisheries and offshore wind farms in Scotland and Germany: there is the perception that post consent, the developer has the upper hand (Schupp et al., 2021). This puts the two industries on an unequal footing. Schupp et al suggest an earlier implementation of the commercial fisheries mitigation and management strategy before the licence is obtained (Schupp et al., 2021). An earlier formal agreement on necessary mitigation measures, before a licence is obtained, could take the form of a “statement of common ground” between developers and the potentially impacted fishers (e.g. Royal HaskoningDHV, 2019), which can help to overcome power imbalances (Kafas, 2017).

4.5.3 Further research

To the author’s knowledge, this study is a first attempt to link the consideration of fisheries in project planning explicitly to how it affects energy justice, using a framework developed for that purpose. Analysing results by combining dimensions of energy justice with the flowchart steps allowed better comparison between different results, as the framework helped to contextualise results. The framework allowed the integration of different perspectives on the same issue, an outcome that was challenging to achieve for what can be perceived as a contentious debate. The use of a framework is a recommended approach to navigate methodological challenges in 'real world research' (Brennan, 2021). Further research could examine ways to develop quantitative and qualitative indicators that could measure energy justice in relation to fisheries, so that in the future different energy scenarios can be compared. This approach has already been developed for evaluating justice implications of marine protected areas for small-scale fisheries in the Mediterranean Sea (Bennett et al., 2020).

4.6 Limitations of study

Out of the 23 projects that were analysed for this study,14 have not yet been completed and 4 took between 5-11 years to progress to the operational phase. Results are based on findings through the interviews and project documentation available online, but the amount of publicly available information varied between case studies. Therefore, findings that have been drawn from this analysis may have overlooked events that played a role in the consideration of energy justice that were not identifiable in the interviews or in the consulted documents. This can have repercussions for the generalisability of the results. This limitation can be mitigated for in future studies by systematically mapping out the information sources available per case study, so that it becomes clearer how each case study is represented with different sources of information. Nevertheless, the presentation of the results of this analysis using the framework can be a step towards identifying possible omissions, to improve an understanding of how a just energy transition can be achieved.

4.7 Conclusions

This study presents novel results on mechanisms and barriers for a just energy transition for the fishing industry in the context of electricity generating and transporting projects in Scottish waters including wind farms, tidal projects and subsea cables. Combining document analysis with interviews allowed an understanding of how proposed mitigation measures work in practice and identified the current challenges. Energy justice is presented as a multifaceted concept that can be progressed in a multitude of ways at multiple scales. Decomposing energy justice into different dimensions allows each facet to be explored in more detail.

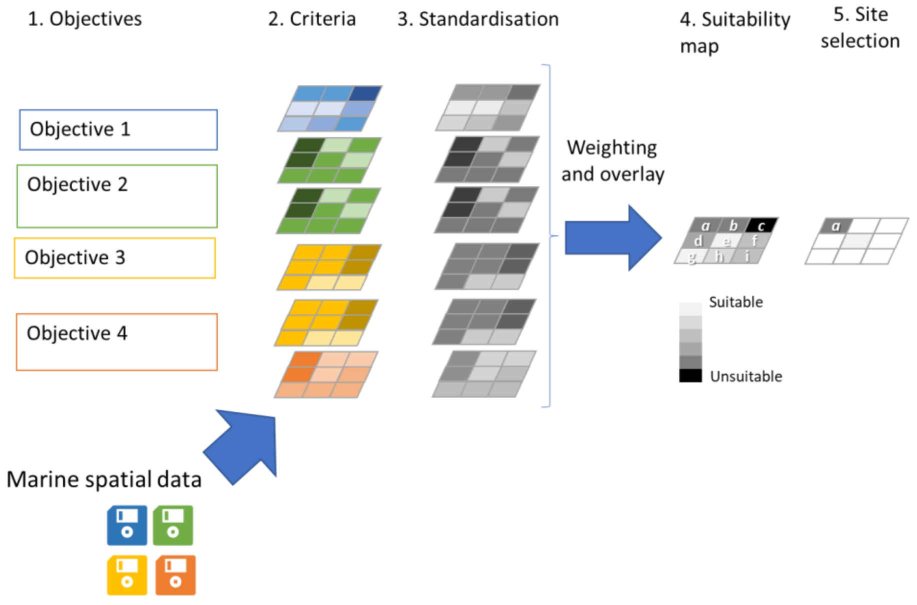
Mechanisms to facilitate distributive, procedural and recognitional justice for the fishing industry are in place. This study indicates that procedural justice has improved over time - fishers are getting increased representation. A remaining barrier to procedural justice is the perceived lack of consideration of fisher knowledge of the local area. While procedural justice has improved over time, challenges still exist related to recognitional justice, with concerns that different types of fishers are not equally represented in the process. This highlights the complexity of the fishing sector, with fisheries representative bodies unable to represent all types of fishing in all locations. Different approaches are necessary for different areas around Scotland that may differ in their degree of remoteness, the composition of fishers operating in the area and how fisheries are organised.

In terms of distributional justice, a mismatch was identified between how impacts are reported on in the environmental impact documentation and perceived impacts by the fishing industry, pointing to a difference in perceptions of justice. As well as that, facilitating distributive justice is hampered by the uncertainty related to the extent to which the energy industry will expand into the marine space also used by fishers. It remains unclear how many more projects will ask fishers to share the marine space with them, making it hard to find compromises. Questions remain as to how this barrier to distributional justice for the fishing industry should be considered within the wider energy justice debate and the transition towards renewable energy, and requires further study, especially as Scotland has clear ambitions to support the sustainable growth of its blue economy through its Blue Economy Action Plan (Scottish Government, 2020f).

This chapter and Chapter 3 provide insights into how energy justice is represented in practice, drawing on a set of ‘real world’ case studies to improve an understanding of a) which measures currently facilitate energy justice for the fishing industry and b) where the consideration of energy justice can be further improved.

5 Exploring fuzzy and spatially explicit standardisation techniques in spatial decision support for marine planning

In this thesis, Chapter 2 set out a procedural framework with three steps that can be used to contextualise existing decision support tools or design novel tools. The first step consists of defining the objectives for the decision problem. In the second step, criteria are selected to represent the defined objectives, and can be derived from marine spatial data. Chapter 3 focused on this second step of how data is used during spatial decision-making, specifically to characterise the fishing industry, and Chapter 4 focuses on the engagement during this process. The final step of the framework laid out in Chapter 2 is the standardisation step, where the criteria values are translated into suitability values using value functions. Chapter 5 focuses on this step, and how different standardisation techniques can lead to different decision outcomes. The focus lies on criteria layers that represent socio-economic activities, therefore their representation in decision-making has implications for procedural justice. When comparing this chapter to the focus of Chapter 4, the technique presented here is relevant to the primary mitigation stage of project planning, when siting decisions are yet to be made.



(Figure 2-2, included here for ease of reference)

5.1 Introduction

Socio-economic activities at sea include fishing, shipping, recreational use and tourism. These activities might be affected by emerging industries such as the renewable energy industry when they overlap spatially (Freeman, 2020). To consider their spatial needs when finding a suitable site for renewable energy developments, socio-economic activities may be included as a suitability layer, in combination with layers depicting other interests such as environmental considerations (e.g. BVG Associates, 2017; Davies et al., 2014; Tweddle et al., 2014). For spatial representation, socio-economic activities at sea are typically represented with heat maps, also called intensity maps (Falco et al., 2019; Johnson et al., 2020; Kafas et al., 2017; LUC, 2016; Tweddle et al., 2014). Computational techniques such as kernel density estimation convert discrete points, lines and polygons into a continuous measure of intensity (DeBoer, 2015). For example, shipping tracks may be used to create a layer depicting shipping density.

Units for heat maps may be measures of density that also indicate a temporal component to represent intensity of use, such as hours/km^2/month or mean number of fishing hours. To incorporate heat maps into suitability mapping, they need to be translated into suitability levels using value functions, as explained in Section 2.3.1.3. These composite indicators of socio-economic space use may be more challenging to translate into suitability values using a value function compared to other criteria, as they represent an activity that depends on many different factors (e.g. fisheries space use depends on weather conditions, time of year, market prices). Therefore, there will be a degree of uncertainty as to how a location with a socio-economic value will be affected by a new development. This uncertainty can be interpreted as decision rule uncertainty, which is defined as uncertainty related to the relationship between the criteria and how it informs the objective of the decision support tool, i.e. how socio-economic value of an area translates into a constraint level for new developments. As in Chapter 2, ‘constraint’ is used as the opposite of suitability.

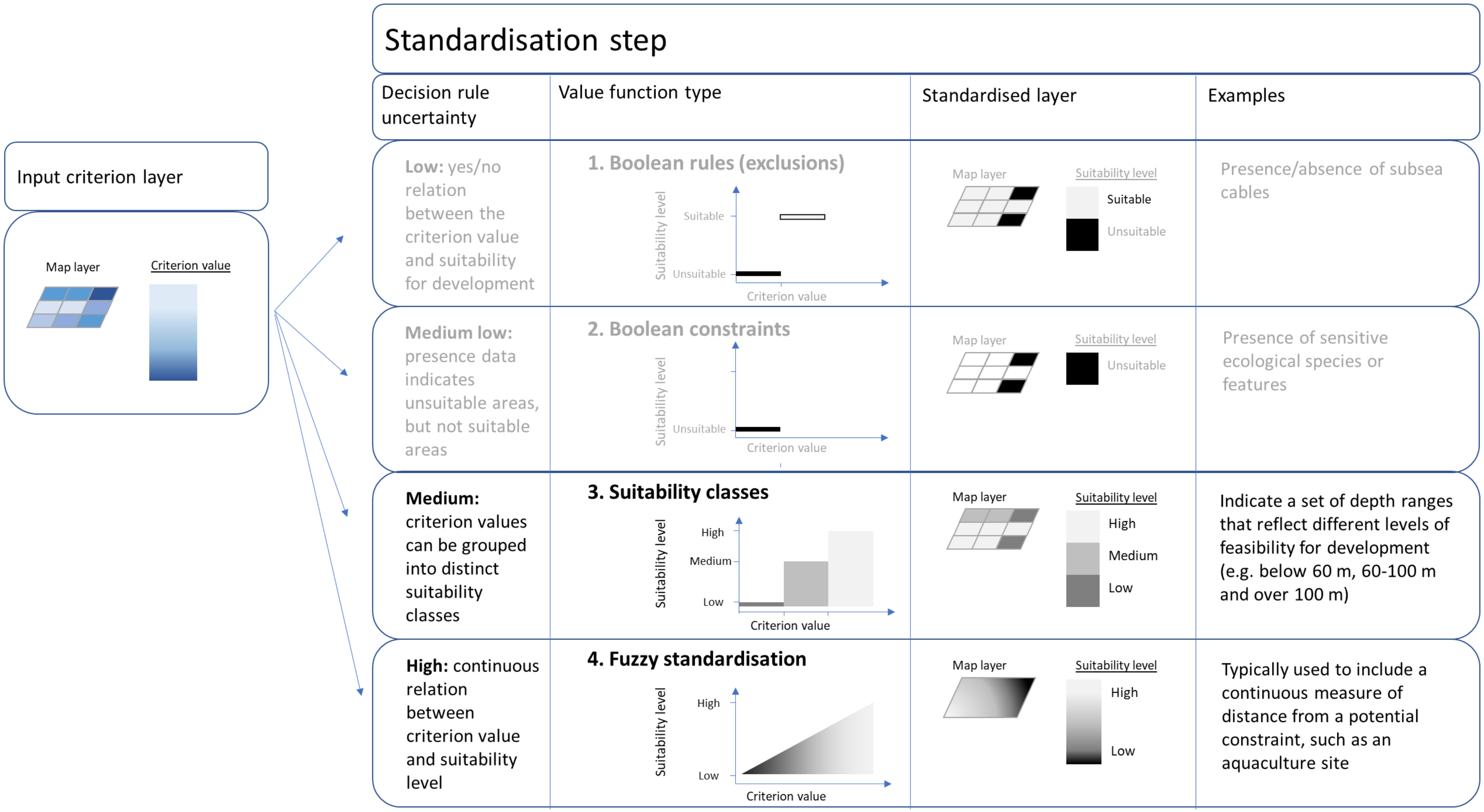


Figure 5-1 Standardisation techniques 3 and 4 are the focus of this chapter (figure adapted from Figure 2-8)

As introduced in Chapter 2, standardisation techniques can be used to account for decision rule uncertainty. The framework identified three main ways of standardising input data into levels of suitability or constraint: Boolean rules, suitability classes or fuzzy standardisation. Boolean rules will indicate there is low uncertainty while a fuzzy standardisation can be used to reflect uncertainty (Section 2.3.1.3, Figure 5-1). At present, marine spatial decision support tools most commonly adopt the ‘Boolean rules’ and ‘Suitability classes’ approaches, such as for the planning of offshore renewable energy developments on European, national and island group scales (Abramic et al., 2021; Marine Scotland Science, 2018; WindEurope, 2019). However, these applications do not follow the uncertainty hierarchy in Figure 5-1: criteria with high decision rule uncertainty are standardised using Boolean or classification approaches, creating the risk of conveying a misleading impression of confidence in the decision rule.

Ignoring decision rule uncertainty can lead to one of two situations. Either the constraint level indicated by socio-economic activities is overestimated, which leads to an underestimation of suitable areas: it may appear as if no locations are suitable for new development. This can hinder the achievement of renewable energy targets. Or, the socio-economic value of an area is underrepresented, which can be a risk if a project, informed by the suitability map, is sited in an area of high socio-economic value, which presents a conflict risk. The underrepresentation of socio-economic values in the process can result in procedural injustices (Avila et al., 2021; Jenkins et al., 2016). It will also affect the extent to which siting decisions adhere to planning policies, e.g. “the extent to which any proposal interferes with access to and along the shore, to the water, use of the resource for recreation or tourism purposes” (REC & TOURISM 2, Scotland’s National Marine Plan).

The disregard of decision rule uncertainty also has a spatial dimension. Overvaluing or undervaluing certain regions compared to other regions may lead to the omission of local values in the decision-making process. For example, when including a recreational use layer in the constraint mapping process at a national level, a high concentration of recreational activity in a densely populated region may overshadow lower values in more remote regions. This could lead to the risk of locally high value areas in remote regions and islands being overlooked, where protection of sites of national importance may be prioritised over sites that have important local values (as found to be the case for onshore and offshore wind projects in England and Wales, Cowell, 2010, Rydin et al., 2018). The underrepresentation of certain groups compared to others can lead to recognitional injustices (Rudolph et al., 2018).

Explicitly accounting for this decision rule uncertainty during the standardisation step of the suitability mapping process can enhance transparency in the process and improve procedural justice. Decision rule uncertainty can be considered using fuzzy techniques. This chapter will also investigate if the “Local Weighted Linear Combination” technique developed by Jacek Malczewski, could be of use to account for spatial differences in values for marine spatial decision support. This technique uses a locally adapted value function to standardise the input values of criteria layers, in contrast to the conventional ‘global’ approach that uses the same value function across the whole study area (Malczewski, 2011).

5.2 Aim and research questions

The aim of this study is to understand if a better consideration of decision rule uncertainty and spatial differences in values can be achieved with novel fuzzy standardisation techniques, to improve procedural and recognitional justice during the mapping process. The study will explore the applicability of the novel fuzzy techniques for socio-economic spatial data layers that do not have a straightforward relationship with site suitability for novel renewable energy development. Sensitivity analyses will be used to find out whether different standardisation techniques, using the same input data layers, can lead to different decision support outcomes, which would have implications for distributional justice.

Research questions:

- How can fuzzy standardisation techniques account for decision rule uncertainty?
- Can the local fuzzy technique be used to avoid recognitional injustices for remote and island communities?
- Do differences in standardisation techniques lead to a different selection of suitable locations for development?

5.3 Methods and results

The method and results are presented in a combined format so that the results for each technique can be read in combination with the description of the technique. This section is split up into three sections: the first introduces the input layers as well as data preparation steps. The next section examines three global fuzzy techniques (Section A), and the final section focuses on two local fuzzy techniques (Section B).

5.3.1 Input layers and data preparation

The global fuzzy techniques examined in Section A were applied to standardise five different layers described in Table 5-1. All these layers represent criteria that vary continuously across space (not categorical data), and they were converted into raster format, so that the study area was split up into grid cells. Except for the wind speed layer, the selected layers are assumed to have a high decision rule uncertainty in terms of the relation between socio-economic value represented in the layers and offshore wind farm constraint to development. This assumption was made because they are mobile activities of which intensity of use varies greatly in space and time. Therefore, they could adapt, but there might be barriers to adapting because of a range of contextual factors. Moreover, uncertainties remain regarding the social and economic impacts and benefits of renewable energy developments (Bonar et al., 2015). The wind layer was included to represent a technical constraint to development, as opposed to the other layers that represent socio-economic constraints. After standardisation, the five layers were combined to form an overlay that represents a combined constraint level for offshore wind farm development.

For Section B, the recreational dataset and Scotmap dataset were used for examining the local fuzzy techniques, which are also described in Table 5-1.

Table 5-1 Input layers/criteria for standardisation

	Name	Dataset	Unit	Source
1	Wind speed	Annual average wind speed at 100m height	m/s	ABPmer, 2008
2	Recreational dataset	Density of Scottish marine recreational and tourism activities	# Activities that overlap spatially	LUC, 2016
3	Shipping dataset	Vessel density map derived from AIS data	Total ship presence time per unit area, annual average for the years 2017-2019 (hours per square km per month)	EMODnet Human Activities Vessel Density Maps (Falco et al., 2019)
4	Scotmap dataset	Commercial fishing activity for under 15 m Scottish vessels	Relative fishing value	Scotmap (Kafas et al., 2014)
5	Mobile fishing dataset	ICES dataset on fishing intensity for mobile gear	Mean KW fishing hours averaged over the years 2013-2017	OSPAR request 2018 for spatial data layers of fishing intensity/pressure (ICES, 2018)

For the shipping layer, some grid cells close to ports had extremely high vessel density values compared to other grid cells, because of signals picked up from stationary vessels. This masked smaller differences between lower value grid cells further out at sea. The choice was made to reclassify the top 1% of vessel density values to the next highest value, so that spatial differences between lower value cells were more visible. The data preparation step for the shipping layer is documented in App. 5.1.

All analyses were undertaken in R (R Core Team, 2021), using the package ‘sf’ (Pebesma, 2018) for vector operations, ‘raster’ for raster operations (Hijmans et al., 2015), ‘tmap’ for spatial data visualisation (Tennekes et al., 2021), ‘ggplot2’ for data visualisation (Wickham, 2016) and ‘egg’ for plot alignment (Auguie, 2019).

5.3.2 Section A: Applying the global fuzzy techniques to the input layers

Section A start with an introduction to the fuzzy techniques, followed by their application to the input layers.

5.3.2.1 Description of standardisation techniques

The classification approach for standardisation ('Discrete Classes') was compared with three fuzzy techniques: the piecewise linear or 'Fuzzy Classes' approach, the score range procedure or 'Fuzzy Linear' approach and the risk averse or 'Fuzzy Risk Averse' technique (Table 5-2). For each of these standardisation techniques, the value function is defined, which represents the relationship between the raw scores of the input layers and the assigned constraint levels. Higher constraint levels indicate a higher consenting risk for the developer.

Table 5-2 Description of standardisation techniques included in this study

Technique	Description	Assumptions
'Discrete Classes'	Converts continuous data into distinct classes	Class intervals indicate 'jumps' in level of constraint
'Fuzzy Classes'	Continuous change in constraint level between class intervals	Class intervals indicate breakpoints in linear relationship between criterion and constraint
'Fuzzy Linear'	Linear change in constraint level	Linear relationship between constraint level and input criterion score
'Fuzzy Risk Averse'	Nonlinear curve to represent relation between input criterion score and constraint level	An increase in score of the criterion layer leads to a proportionately larger increase in constraint level

'Discrete Classes' approach

For the first standardisation technique included in the study, the layers were standardised into constraint classes of 'Low', 'Medium' and 'High'. As outlined in Chapter 2, class intervals can either be obtained by defining decision rules or through statistical classification techniques (see Figure 2-10). An appropriate classification technique was chosen depending on the dataset, as specified in Table 5-3. The classification was executed using the 'ClassInt' package in the R environment (Bivand et al., 2020).

Table 5-3 Classification techniques applied to each criterion layer

	Criterion layer	Classification technique	Justification
1	Annual average wind speed at 100m height	Decision rule: Low constraint for wind speeds higher than 9 m/s, medium constraint for wind speeds lower than 9 m/s	Technical requirement of existing wind technology, needing minimum wind speeds to operate economically (Marine Scotland Science, 2018; Sinden, 2007)
2	Density of Scottish marine recreational and tourism activities	Fisher-Jenks algorithm (Fisher, 1958)	Skewed dataset, so natural breaks in the data were used to group the data into classes
3	Vessel density map derived from AIS data	Manual classification based on initial quantile classification	The data is heavily skewed, so the class intervals were defined in a manner that allowed a representation that accentuated the main shipping routes traversing the Scottish EEZ (Marine Scotland Science, 2018)
4	Commercial fishing activity for under 15 m Scottish vessels	Fisher-Jenks algorithm (Fisher, 1958)	Skewed dataset, so natural breaks in the data were used to group the data into classes
5	ICES dataset on fishing intensity for mobile gear	Fisher-Jenks algorithm (Fisher, 1958)	Skewed dataset, so natural breaks in the data were used to group the data into classes

EEZ: Exclusive Economic Zone

Application of the classification technique to the five criterion layers ($k = 1,2,\ldots,5$) allowed the identification of the class intervals a_{k0}, a_{k1}, a_{k2} and a_{k3} for each criterion k respectively. Each class was assigned a value of 1,2 or 3 representing low, medium and high constraint, as described in Equation (5-1).

$$v(a_{ik}) = \begin{cases} a_{ik} = 1 \text{ (Low) } if\ a_{k0} \leq a_{ik} < a_{k1} \\ a_{ik} = 2 \text{ (Medium) } if\ a_{k1} \leq a_{ik} < a_{k2} \\ a_{ik} = 3 \text{ (High) } if\ a_{k2} \leq a_{ik} < a_{k3} \end{cases} \quad (5\text{-}1)$$

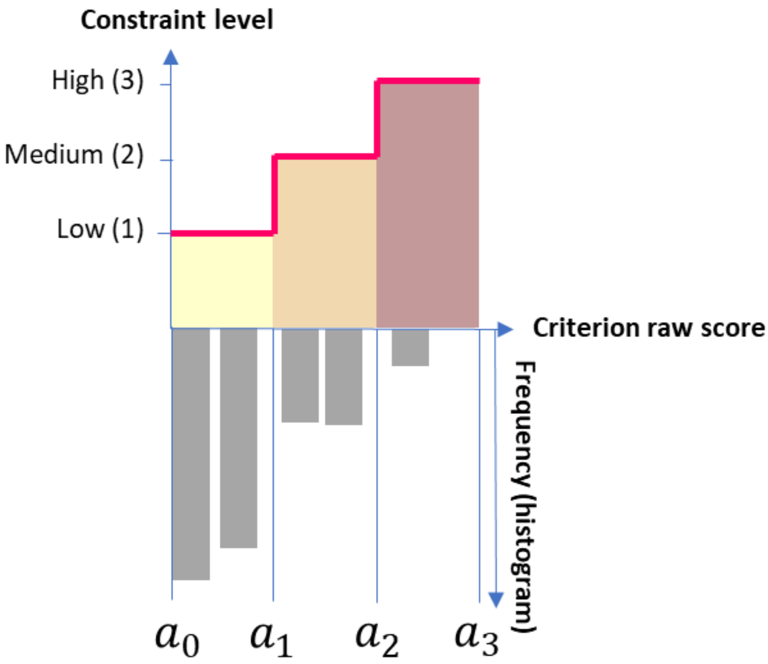


Figure 5-2 Illustration of the 'Discrete Classes' technique

'Fuzzy Classes'

This technique is based on the piecewise linear approximation described in Stewart & Janssen, 2013, designed for situations where there is imprecise or incomplete information. The breakpoints (highlighted with circles in Figure 5-3) are chosen by the user, and in this application of the technique, they are the class intervals used for the 'Discrete Classes' approach (indicated with vertical blue lines in Figure 5-2 and Figure 5-3: a_{k0}, a_{k1}, a_{k2} and a_{k3}).

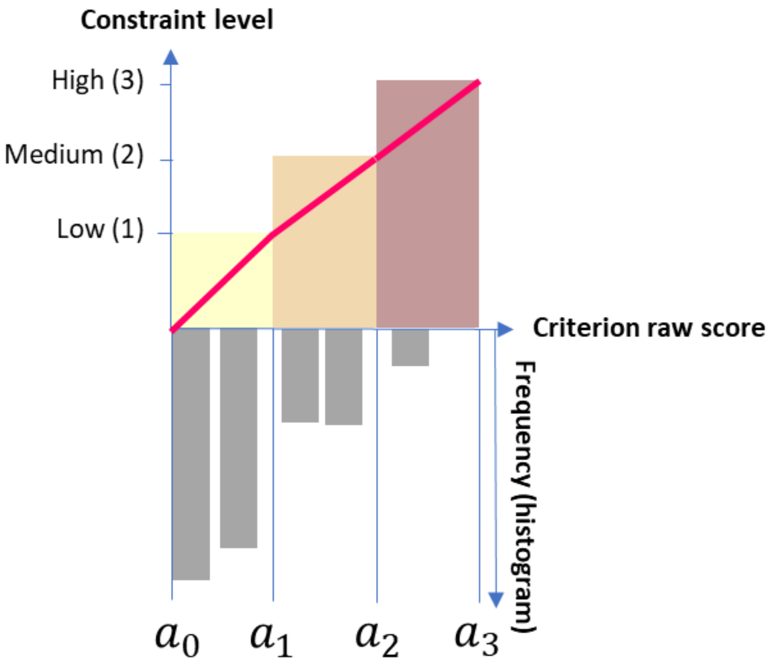


Figure 5-3 Illustration of "Fuzzy Classes" approach, based on the intervals from the 'Discrete Classes' approach

This is represented with the following value function to obtain a level of constraint $v(a_{ik})$ for each criterion score a_{ik}:

$$v(a_{ik}) = \begin{cases} \dfrac{a_{ik} - a_{k0}}{a_{k1} - a_{k0}} \ if \ a_{k0} \leq a_{ik} < a_{k1} \\ \dfrac{a_{ik} - a_{k1}}{a_{k2} - a_{k1}} + 1 \ if \ a_{k1} \leq a_{ik} < a_{k2} \\ \dfrac{a_{ik} - a_{k2}}{a_{k3} - a_{k2}} + 2 \ if \ a_{k2} \leq a_{ik} < a_{k3} \end{cases} \tag{5-2}$$

If a_{ik} is the criterion score of the k-th criterion ($k = 1,2, \ldots ,5$) for the i-th alternative/raster cell ($i = 1,2, \ldots , m$), where m is the total number of raster cells, then the value function, $v(a_{ik})$, is the constraint level of that raster cell respective to criterion k (Malczewski and Rinner, 2015). a_{k0}, a_{k1}, a_{k2} and a_{k3} are the class intervals for criterion k, and are used here as the breakpoints for the function.

'Fuzzy Linear'

The 'Fuzzy Linear' approach is also known as the 'score range procedure', a type of linear scale transformation of raw criterion scores into suitability values that is commonly used in spatial decision support (Eastman et al., 1993; Heywood et al., 1995; Malczewski, 2011, 2000). In the ArcGIS software environment, it is termed the "fuzzy linear" membership function (Environmental Systems Research Institute Inc, 2016). For the purposes of allowing a direct comparison with the 'Discrete Classes' and 'Fuzzy Classes' techniques where the maximal value that can be attained is 3, the equation is multiplied by 3 so that the maximum value for the 'Fuzzy Linear' technique is also 3. Hence, the value function standardises the raw criterion scores into constraint values according to the following equation:

$$v(a_{ik}) = 3\left(\frac{a_{ik} - \min_i\{a_{ik}\}}{\max_i\{a_{ik}\} - \min_i\{a_{ik}\}}\right) \quad (5\text{-}3)$$

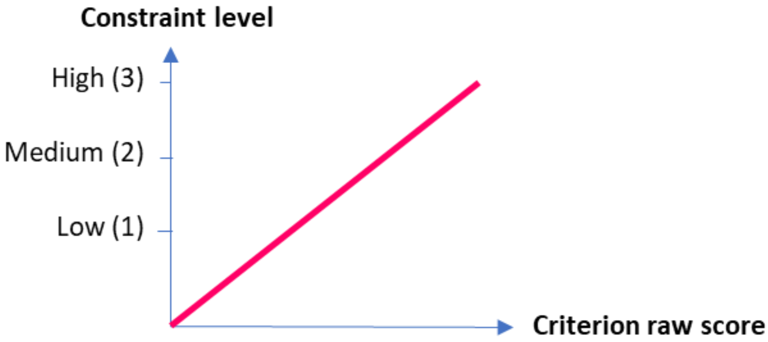


Figure 5-4 Illustration of the 'Fuzzy Linear' technique

'Fuzzy Risk Averse'

A 'Fuzzy Linear' approach assumes that a percentage increase in the raw criterion score a_{ik} leads to the same percentage increase in constraint level $v(a_{ik})$. However, some criteria may be more suitably represented with a non-linear function, for example if a small percentage increase in a criterion represents a larger percentage change in suitability for offshore renewable energy development. This can be incorporated into decision support by adding a parameter ρ to Eq. (5-3), that can be used to define the decision maker's approach to risk (Malczewski and Rinner, 2015) (Eq. (5-4)). The shape of the curve depends on the parameter ρ, which reflects the degree of risk.

$$v(a_{ik}) = 3\left(\frac{a_{ik} - \min_i\{a_{ik}\}}{\max_i\{a_{ik}\} - \min_i\{a_{ik}\}}\right)^{\rho} \quad (5\text{-}4)$$

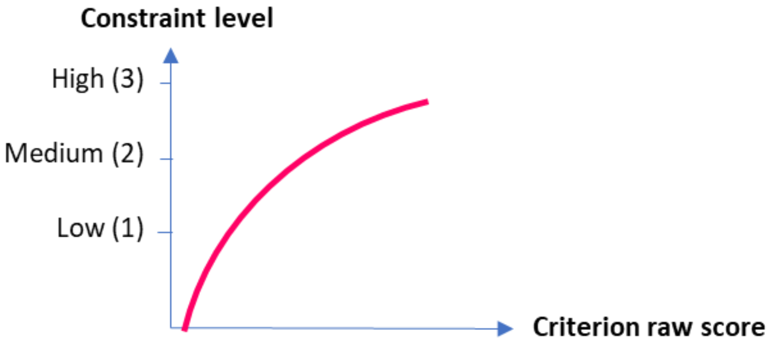


Figure 5-5 'Risk Averse' standardisation technique illustrated

For this study a risk averse approach (curve in Figure 5-5) was included as a technique and labelled "Fuzzy Risk Averse", represented with $\rho = \frac{1}{2}$. A value of $\rho < 1$ implies an increase in the criterion score will lead to proportionately larger increase in constraint level or consenting risk.

5.3.2.2 Application of the techniques to the input layers

The described techniques were applied to the five input layers described in Table 5-1.

Wind layer

Figure 5-6a illustrates the four different techniques applied to the wind speed layer to standardise it into a constraint layer. Since all the layers used in the analysis are raster layers, a histogram could be used to depict the relative distribution of cells (which make up the raster) for different wind speed values (Figure 5-6b). The vertical blue line that cuts across the histogram (Figure 5-6b) shows how the input data from the wind resource dataset is classified into two classes: low and medium constraint. The distribution of the grey bars show that the low constraint class contains the highest number of grid cells, and the remaining grid cells are in the medium constraint class. App. 5.2.A lists the class intervals that were used for each of the layers. Even though they were constructed in different ways, the "Fuzzy Risk Averse" value function follows a similar trajectory to the 'Fuzzy Classes' function. This observation was not found for the other layers - it is related to how the vertex of the 'Fuzzy Risk Averse' value function coincidently coincides with the breakpoint of the 'Fuzzy Classes' function.

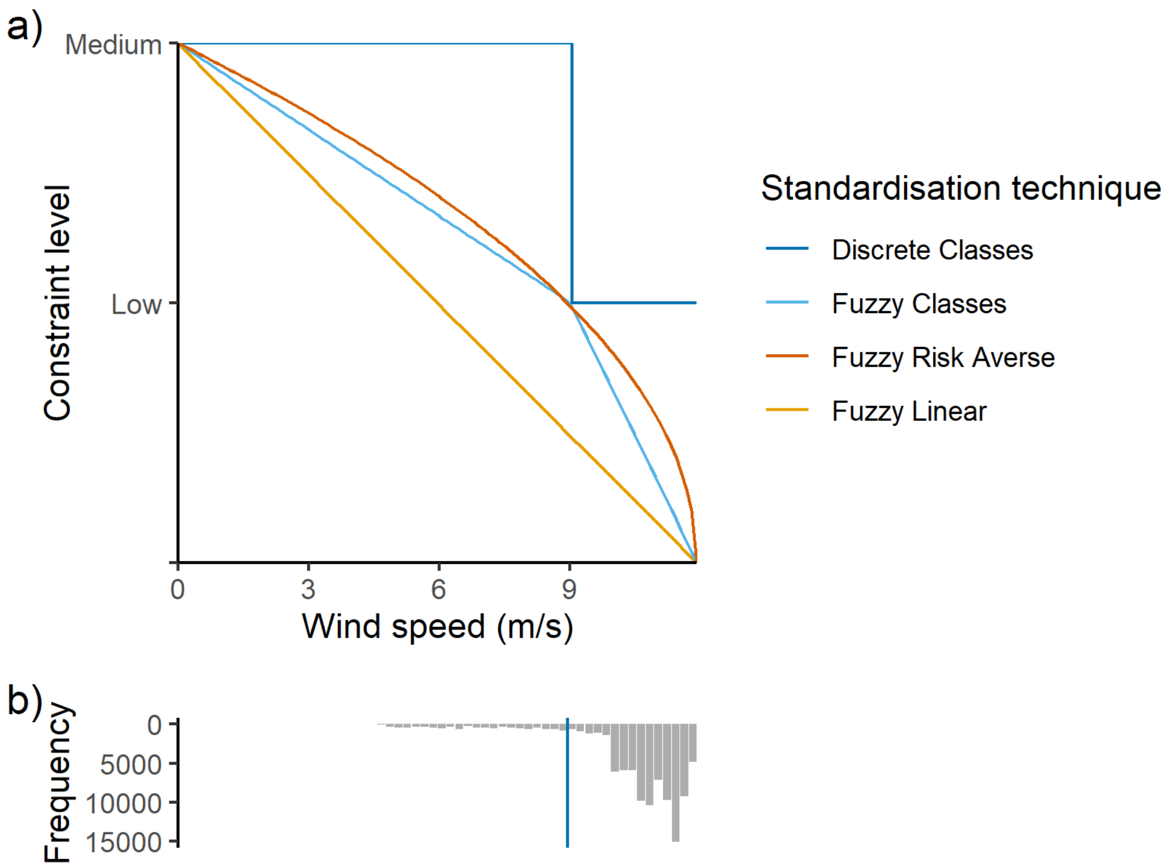


Figure 5-6 a) Value functions for the four different techniques used to standardise the wind layer and b) Histogram of the input data

The four standardised constraint layers are shown in Figure 5-7. Comparing the discrete classes with the fuzzy techniques, finer-scale spatial differences are visible, such as a gradient in wind speed with distance from the coast Figure 5-7b-d.

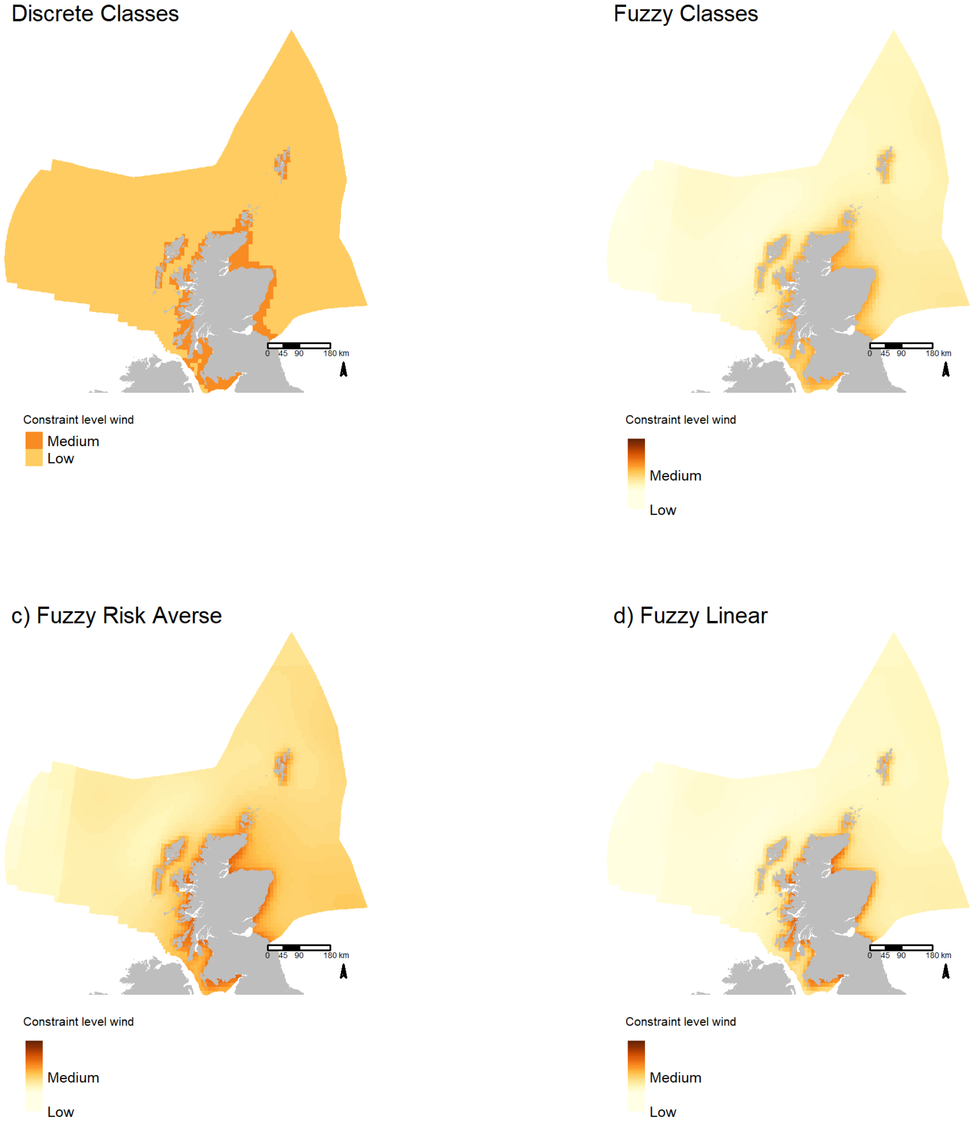


Figure 5-7 Constraint layers constructed using four different standardisation techniques for the wind speed layer

Recreation layer

For the recreation layer, the distribution of the grey bars indicates the highest number of cells are attributed to a low constraint level, and the medium and high constraint level classes contain a lower number of cells (see Figure 5-8b).

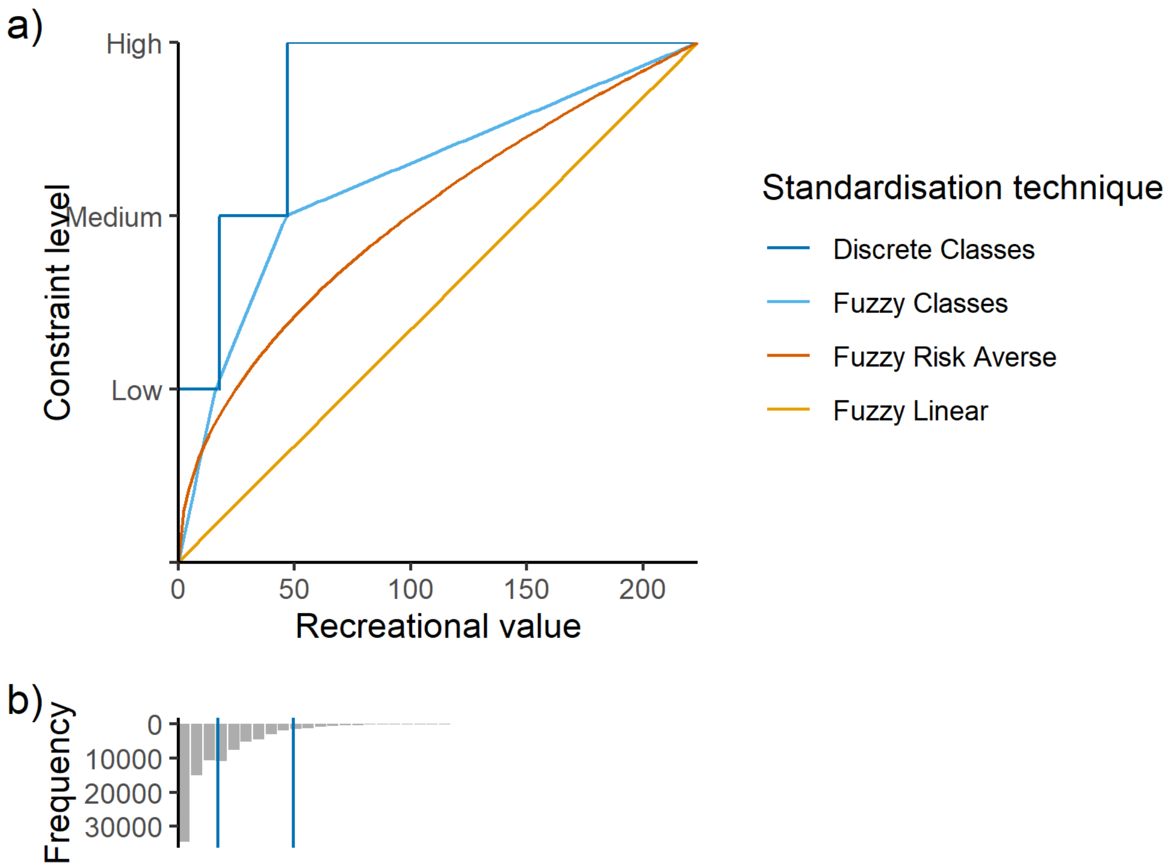


Figure 5-8 a) Value functions for four different techniques used to standardise the recreational layer and b) Histogram of the input data

The resulting constraint layers in Figure 5-9 illustrate that the most visible differences between the discrete classes and the fuzzy techniques are apparent in the areas classified as low constraint. The ‘Fuzzy Linear’ technique standardised the input layer in a way that represents a lower constraint level/consenting risk than the other techniques, which is also reflected in the value function in Figure 5-8a.

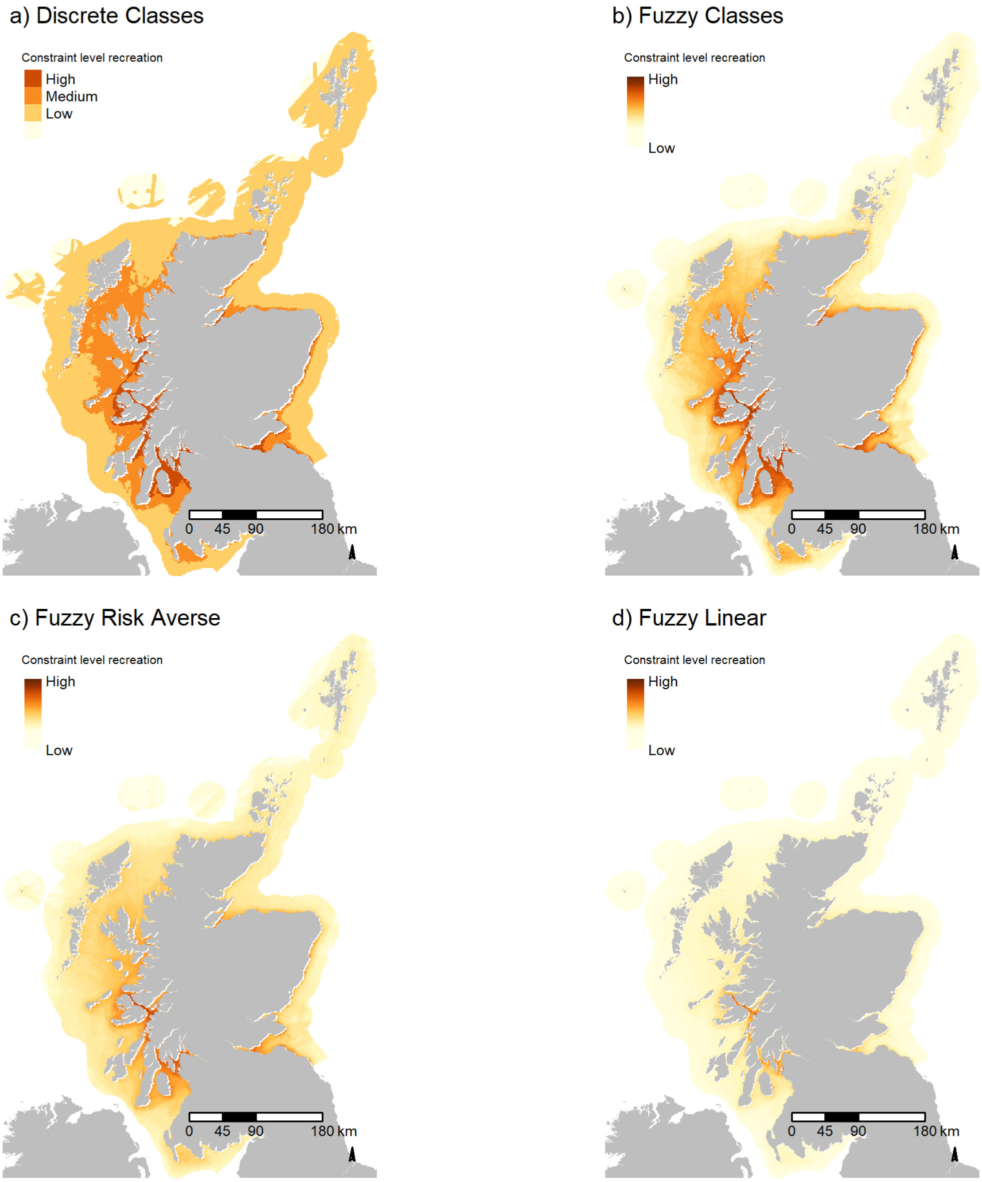


Figure 5-9 Constraint layers derived from the recreational dataset

Different standardisation techniques highlight differing spatial patterns, with the ‘Discrete Classes’ and ‘Fuzzy Classes’ techniques allowing a differentiation between large areas, whilst the ‘Fuzzy Risk Averse’ and ‘Fuzzy Linear’ techniques highlight extremes. In Figure 5-9a it is possible to distinguish between higher activity levels on the west coast of Scotland and lower activity in the Northern Isles, similar to what is represented in Figure 5-9b. Figure 5-9c and Figure 5-9d highlight areas of intense recreational use in the Sound of Mull, which are not distinguishable from surrounding areas in Figure 5-9a-b.

Shipping

As with the recreation layer, the 'Discrete Classes' standardisation grouped the highest frequency of grid cells into the low constraint class, as can be seen in Figure 5-10b.

Figure 5-10 a) Value functions for the four different techniques used to standardise the shipping layer and b) Histogram of the input data

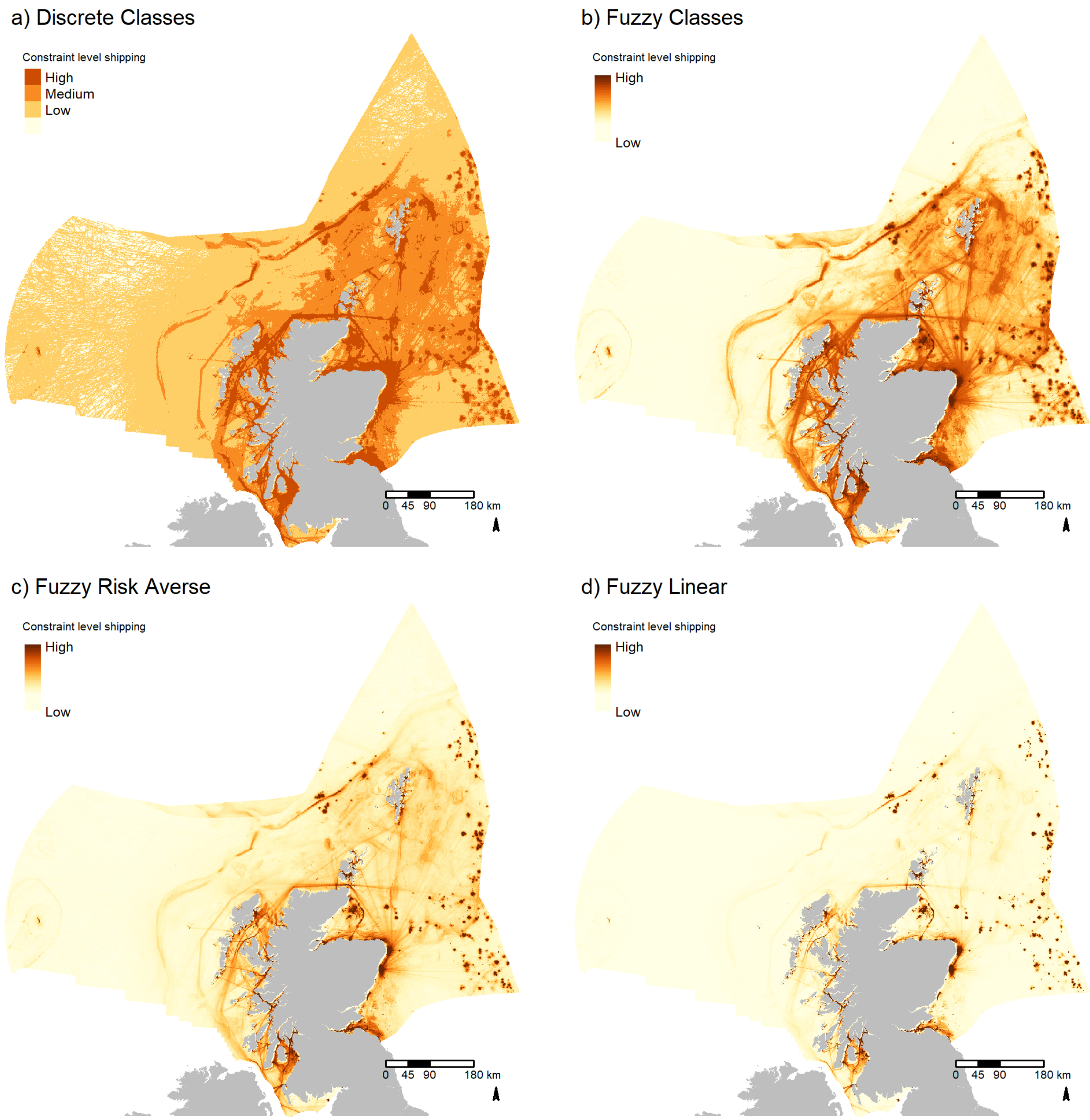


Figure 5-11 Standardised layers for the shipping dataset

Similar to the recreation dataset, the standardisation of the shipping dataset using the ‘Discrete Classes’ and ‘Fuzzy Classes’ techniques allow a representation of broader spatial patterns, while the ‘Fuzzy Risk Averse’ and ‘Fuzzy Linear’ techniques highlight extreme values of vessel intensity, especially the ‘Fuzzy Linear’ technique. Linear elements, such as the ferry route between Aberdeen and Shetland are represented more clearly with the ‘Fuzzy Classes’ and ‘Fuzzy Risk Averse’ technique than the other two techniques. The same holds for the circular vessel density identifiable around the Rockall Bank to the west of the Outer Hebrides. For the ‘Fuzzy Linear’ standardisation the areas that contrast the most with surrounding cells are the oil rigs and the ports, as well as the wind farm development area in the Moray Firth along with the Caithness-Moray transmission cable that was under construction during the study period (2017-2019).

Scotmap small vessel fishing

As with the other two socio-economic layers, the highest number of grid cells are in the low constraint layer (Figure 5-12b), and the maps indicate differences within the low constraint category are more readily discerned with the fuzzy techniques than the 'Discrete Classes' technique (Figure 5-13). Highly constrained areas are identifiable with all techniques.

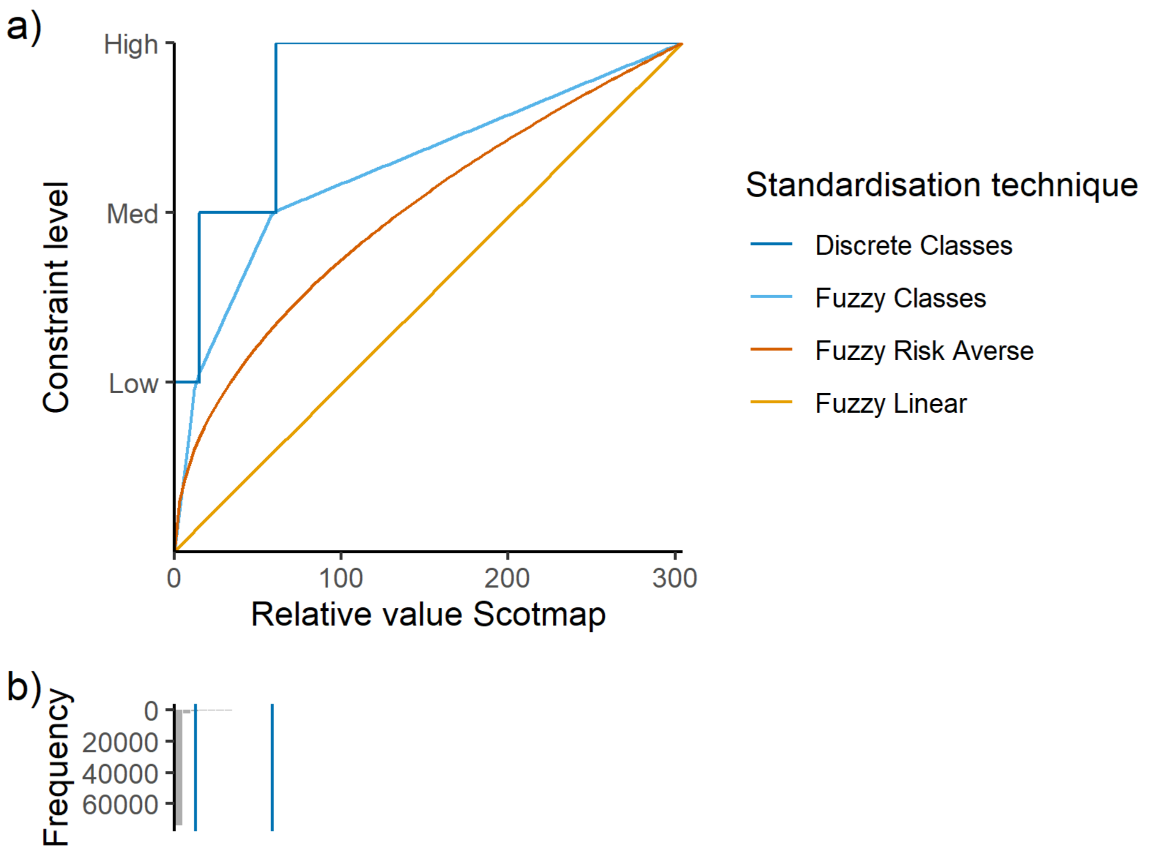


Figure 5-12 a) Value functions for the four different techniques used to standardise the Scotmap layer and b) Histogram of the input data

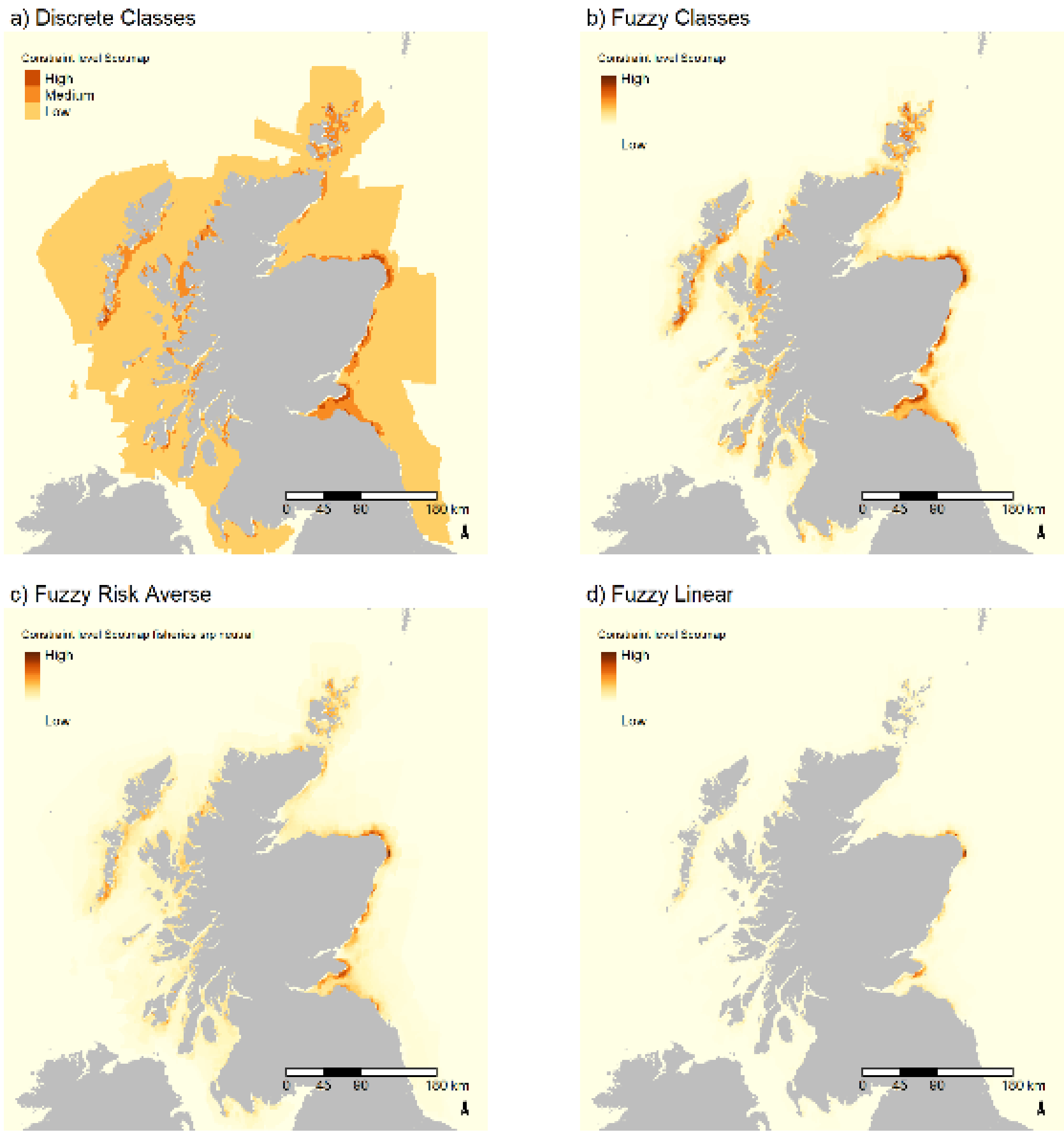


Figure 5-13 Standardised layers for the Scotmap dataset

The ‘Discrete Classes’ technique masks finer-scale spatial differences that are discernible with the ‘Fuzzy Classes’ and ‘Fuzzy Risk Averse’ techniques e.g. in the Firth of Forth, Moray Firth and around Arran. In the ‘Fuzzy Linear’ standardisation, areas of high relative value can be identified (Peterhead, Fraserburgh, Fife), but middle range values are more difficult to distinguish from low values (Figure 5-13).

Mobile fishing layer

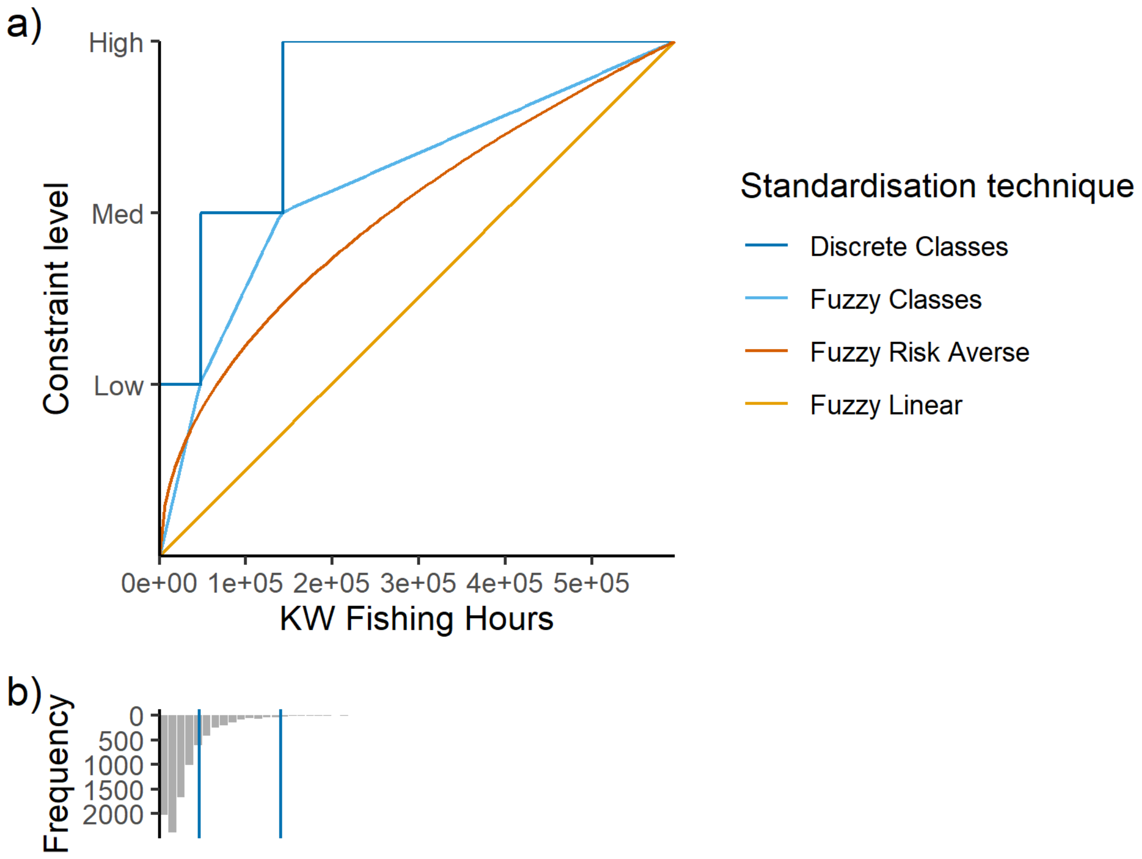


Figure 5-14 a) Value functions for the four different techniques used to standardise the mobile fishing layer and b) Histogram of the input data

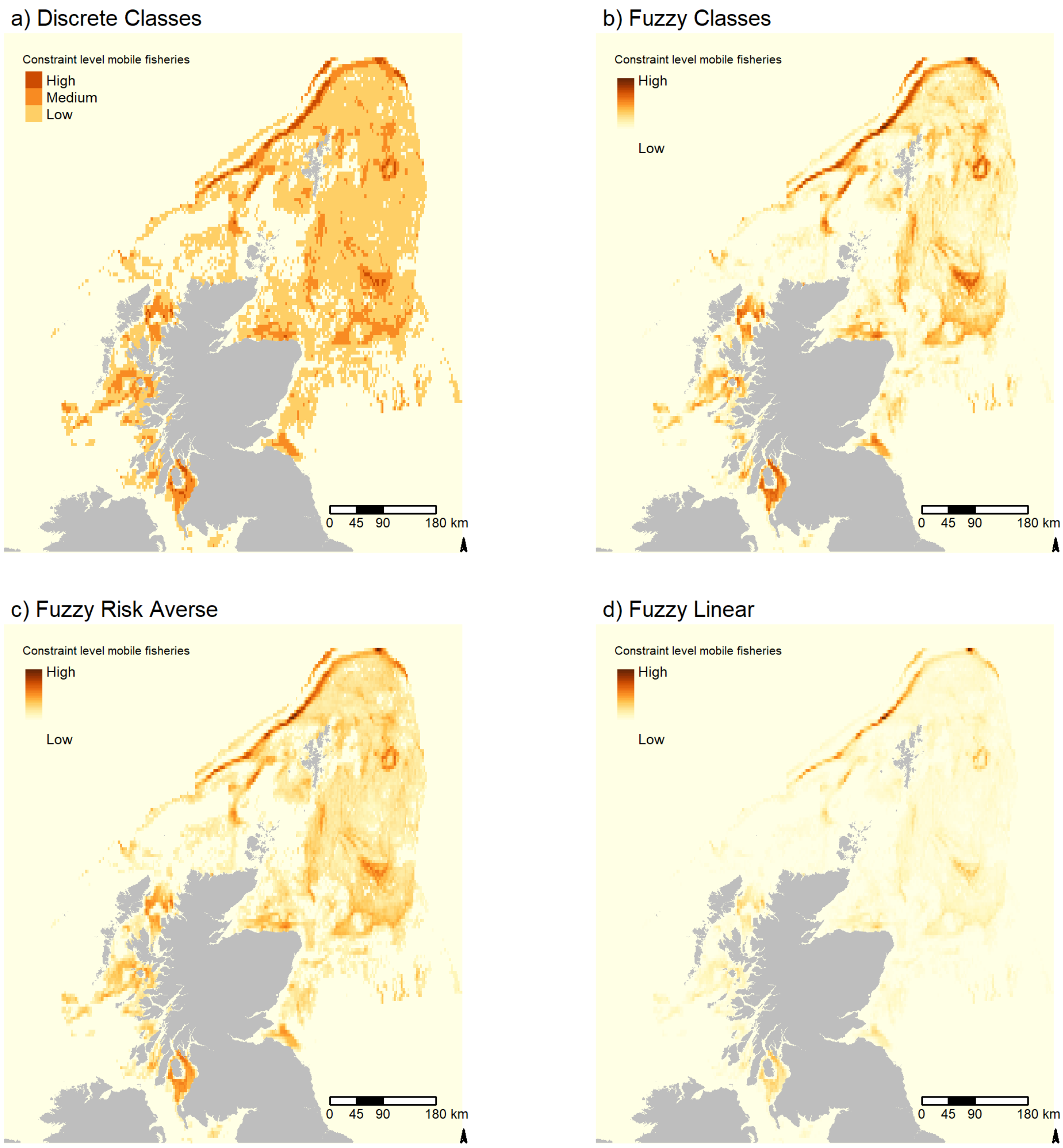


Figure 5-15 Standardised layers for the mobile fisheries dataset

For the four techniques, the standardised layers for the mobile fisheries dataset have similar spatial patterns, but constraint levels between them differ (Figure 5-15). The 'Discrete Classes' layer has the highest total constraint, and the 'Fuzzy Linear' is the least constrained.

5.3.2.3 Overlay of the five standardised layers

To enable a linear overlay of the layers, grid cells with missing values were reclassified to 0 for each of the five layers. The grid cell values in the resulting constraint map are a sum of the grid cell values of each of the input layers (see Eq. (5-5).

$$V(A_i) = \sum_{k=1}^{n} v(a_{ik}) \tag{5-5}$$

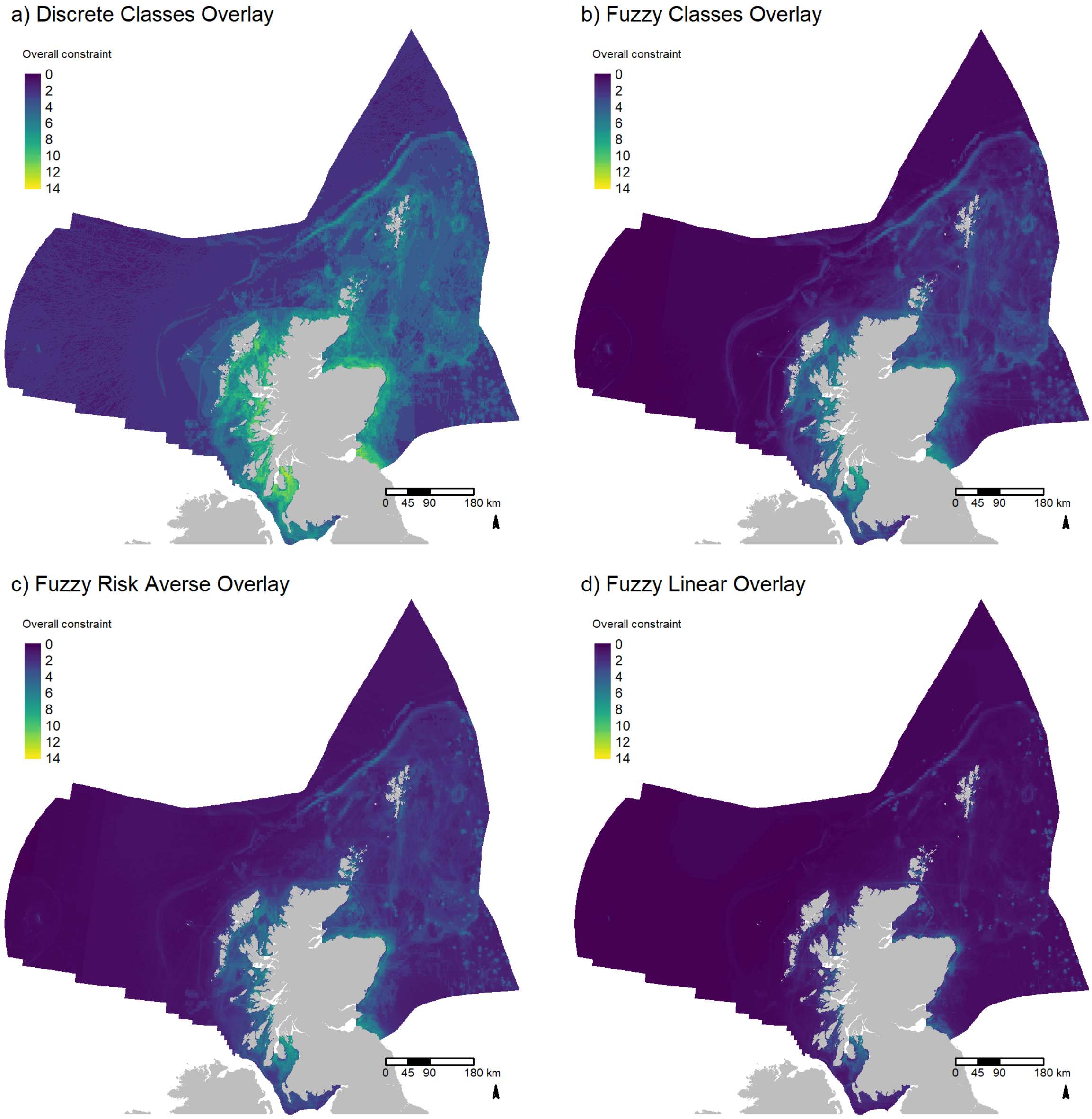


Figure 5-16 Overlays of the five layers for the four techniques

The differences between the resulting overlays from the four techniques indicate that the standardisation technique chosen will influence the spatial decision support outcome (Figure 5-16). Comparing the four overlays, the ‘Discrete Classes’ technique results in the most constrained overlay and the ‘Fuzzy Linear’ technique the least constrained (Figure 5-16). All four techniques represent the same broad-scale spatial patterns across the Scottish EEZ. However, finer-scale patterns differ. On the ‘Fuzzy Linear’ and ‘Fuzzy Risk Averse’ overlays (Figure

5-16c-d), the shipping route that passes to the west of St Kilda is not as identifiable as in the overlays for the ‘Discrete Classes’ and ‘Fuzzy Classes’ techniques (Figure 5-16a-b).

A qualitative comparison between the spatial patterns of the techniques using visual analysis is summarised in Table 5-4. The ‘Fuzzy Classes’ technique represented the most types of spatial patterns which other techniques underrepresented. However, it did not highlight extremely high areas of socio-economic activity, which was represented with the ‘Fuzzy Risk Averse’ or ‘Fuzzy Linear’ techniques. As with the ‘Fuzzy Classes’ technique, the ‘Discrete Classes’ technique identified broad spatial patterns and linear features, but finer-scale patterns were underrepresented.

Table 5-4 Comparison of the spatial patterns represented by the techniques

Technique	Represents	Underrepresents
‘Discrete Classes’	• Broad spatial patterns • Linear features	• Finer-scale patterns, especially within low constraint areas • Extremes
‘Fuzzy Classes’	• Broad spatial patterns • Linear features • Finer-scale patterns, especially within low constraint areas	Extremes
‘Fuzzy Risk Averse’	• Finer-scale patterns, especially within low constraint areas • Extremes	• Broad spatial patterns • Linear features
‘Fuzzy Linear’	• Finer-scale patterns, especially within low constraint areas • Extremes	• Broad spatial patterns • Linear features

5.3.2.4 Sensitivity analysis

To understand whether the differences between the standardisation techniques affect the selection of suitable sites, the locations of the lowest constraint cells identified by the four techniques were compared. However, the study area was reduced, because if the whole exclusive economic zone (EEZ) was included in this comparison, it would select cells where only the shipping and wind layers have values, in the western ‘empty’ region of the EEZ (the orange/purple zone, Figure

5-17a). Figure 5-17a shows the extents of each of the five layers – the wind and shipping layers (coloured purple and orange respectively) cover the whole EEZ (exclusive economic zone). The mobile fisheries layer (yellow) is limited to areas closer to the coast, as with the recreation (blue) and inshore fisheries (pink) layers. Comparing the techniques with a study area that includes the entire EEZ would not be meaningful, as the areas of least constraint would not consider values in the nearshore constraint layers. Therefore, the study area was reduced to the cells which contained a constraint value for at least three of the five layers. Based on this condition, the study area was reduced to the yellow area in Figure 5-17b, representing the areas where between 3-5 layers have non-zero values (the yellow, blue and pink areas in Figure 5-17a).

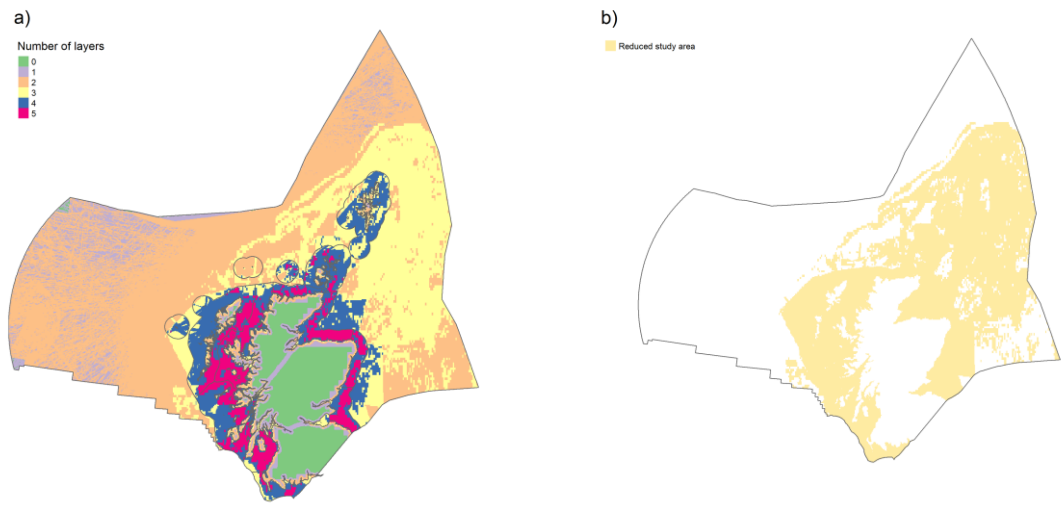


Figure 5-17 a) Map depicting the number of layers that have a non-zero value for the Scottish EEZ region included in this study b) Reduced study area based on the extent of a minimum of 3 layers, indicated in yellow

To compare the techniques, a selection of x number of 'best scoring' (lowest constraint) cells was made for each overlay. x was based on the number of cells that populated the lowest constraint level class for the 'Discrete Classes' overlay. This is the number of cells all scoring the same lowest combined constraint level of 3, which is the cells where three layers have a value of 1, and two have a value of 0, corresponding to the condition where at least three of the five layers have a non-zero value. For the reduced study area (Figure 5-17b), the x number of lowest scoring constraint cells in the overlay amounted to 658 445 cells, which is equal to 41 152.81 km^2. This same number of lowest scoring cells was selected for the other three techniques (Table 5-5).

Table 5-5 Table with cut-off values used to compare selection per technique

Technique	Constraint level	Number of lowest cells selected (x)
Discrete Classes	0.00-3.00	658 445
Fuzzy Classes	0.00-1.53	658 445
Fuzzy Averse	0.00-1.73	658 445
Fuzzy Linear	0.00-0.50	658 445

For each technique, a layer was created that indicated the locations of the x number of lowest scoring cells (Figure 5-18).

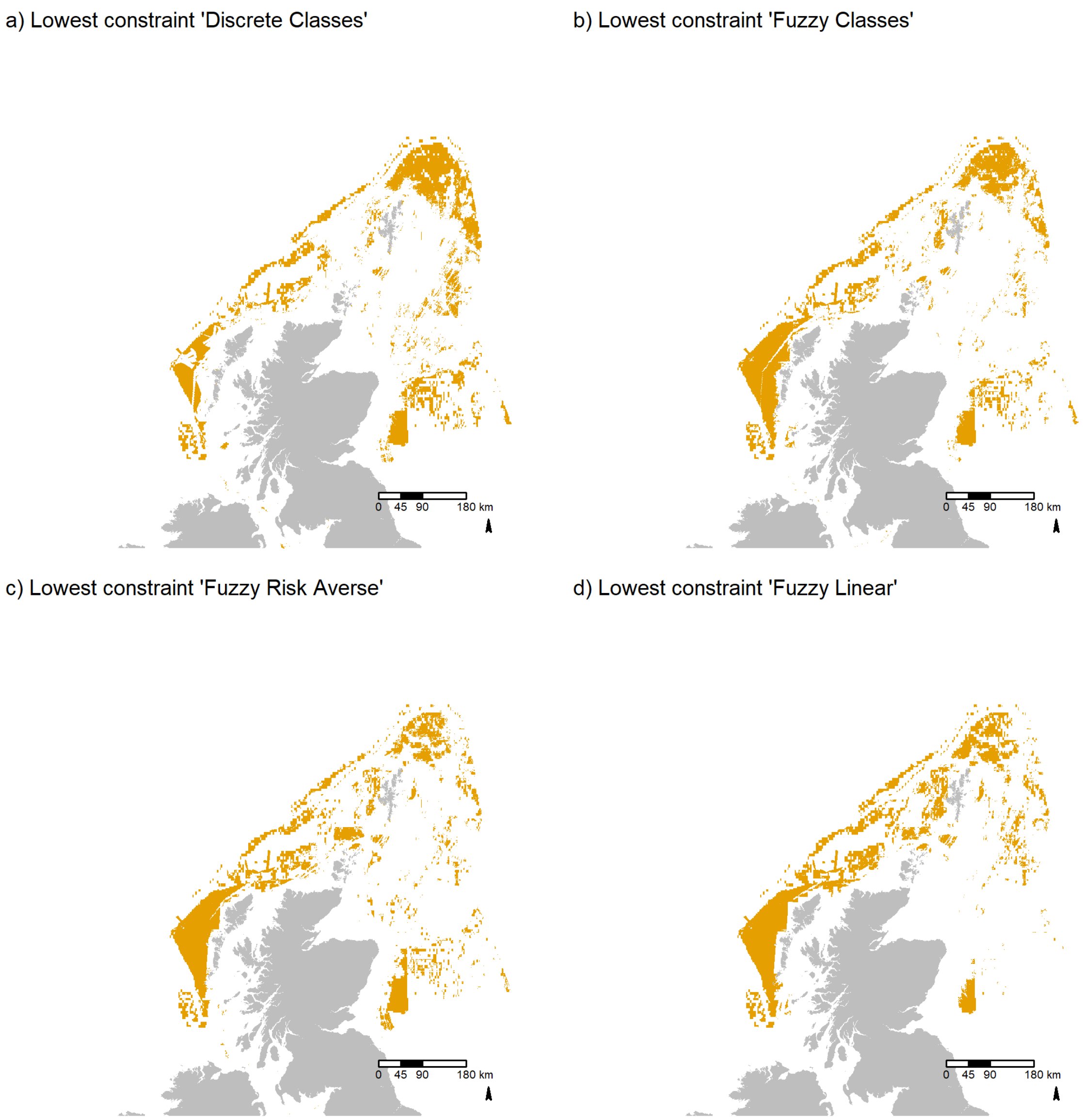


Figure 5-18 'Best place' selection for the four different techniques based on the five input layers used to construct the overlay

Areas of similarity can be identified when comparing Figure 5-18a-d: areas offshore on the East Coast, areas west of the Outer Hebrides and northeast off Shetland. The ‘Discrete Classes’ and ‘Fuzzy Classes’ techniques identify more cells to the northeast of Shetland than the ‘Fuzzy Risk Averse’ and ‘Fuzzy Linear’ techniques, which identify a larger area north of the North Coast, north of Orkney and west of Shetland. Differences between the discrete classes technique and the other techniques are discretised in Figure 5-19.

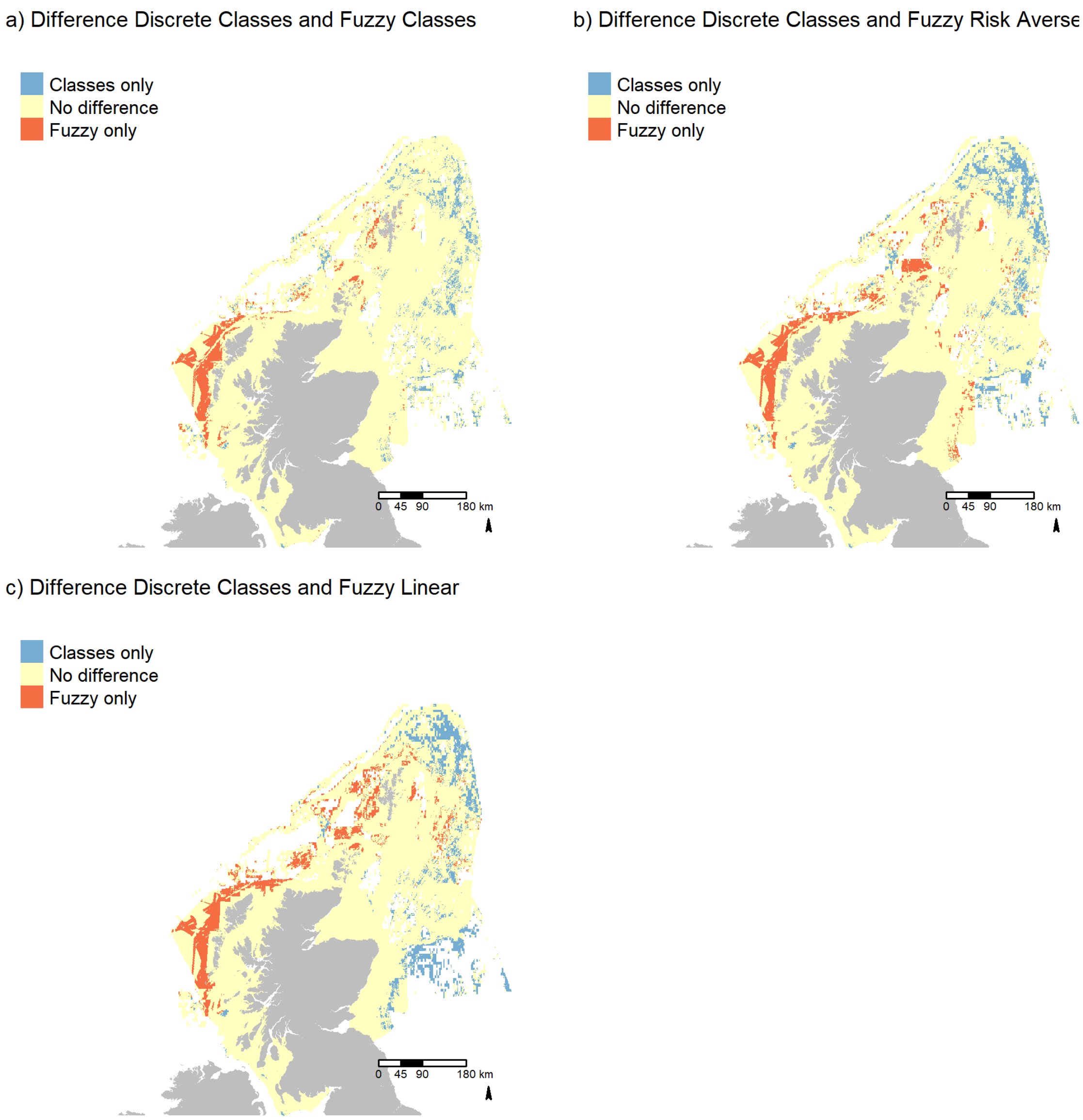


Figure 5-19 Comparing the 'best place' selection with the ‘Discrete Classes’ technique

Spatially, the ‘Discrete Classes’ technique identified more suitable cells to the east of Scotland (blue areas), while the fuzzy techniques identified more suitable cells on the western side of the study region (red areas). After layer per layer removal and re-insertion to allow a better understanding of the resulting spatial patterns, it was apparent that the spatial patterns represented by the blue (areas identified as suitable with the 'Discrete Classes' technique only) represent the combined spatial patterns of the mobile fishing dataset and the shipping dataset, which have a high variability in that region. In contrast, the spatial patterns represented by the red areas to the west of the Outer Hebrides come from the recreational use dataset (see Figure 5-9a). This indicates the difference between techniques is influenced by the spatial patterns of the included data layers.

The percentage difference between which cells were selected for the 'Discrete Classes' technique and each fuzzy technique was calculated. A one-at-a-time method of sensitivity analysis (p. 210 Malczewski & Rinner 2015) was applied by evaluating differences between the techniques for different combinations of layers. The percentage difference was compared with an overlay including four layers, as well as overlays including only three layers. Overall, the largest difference was observed between the 'Discrete Classes' and the 'Fuzzy Linear' technique (16.14%, Table 5-6, Figure 5-19c). The lowest difference is between the 'Discrete Classes' technique and the 'Fuzzy Classes' technique (9.12%, Table 5-6, Figure 5-19a), and there was a 13.63% difference between 'Discrete Classes' and 'Fuzzy Risk Averse' (Table 5-6, Figure 5-19b).

Table 5-6 One-at-a-time analysis results show the percentage difference with the discrete classes technique for each of the fuzzy techniques, per layer combination

# Layers	Combination	Fuzzy classes (%)	Fuzzy Risk Averse (%)	Fuzzy Neutral (%)
5	ospar, rec, sm, wind, shp	9.1(1)	13.6(2)	16.1(3)
4	ospar, rec, sm, wind	19.1(3)	16.9(1)	18.2(2)
3	ospar, rec, sm	12.4(3)	9.4(1)	12.1(2)
3	ospar, rec, wind	10.1(2)	8.9(1)	12.1(3)
3	ospar, sm, wind	13.3(3)	12.0(2)	11.2(1)
3	rec, sm, wind	14.5(2)	11.3(1)	20.3(3)

(ospar: Mobile fisheries, rec: Recreation, sm: Scotmap, wind: Wind, shp: Shipping, rank between techniques per combination shown in brackets)

The difference between the fuzzy techniques and the 'Discrete Classes' technique is not consistent for different layer combinations (Table 5-6). For the combination of all five layers, the ‘Fuzzy Classes’ technique shows the least variation from the ‘Discrete Classes’ standardisation (9.1%), but this is not the case for all the other combinations: when four layers are included, the ‘Fuzzy Risk Averse’ is the least different from the ‘Discrete Classes’ standardisation (16.9%) and the ‘Fuzzy Classes’ technique is in fact the most different from the ‘Discrete Classes’ technique (19.1%). For the combinations where only three layers are included, two combinations have the same ranking between the three fuzzy techniques (“ospar, rec,wind” and “rec,sm,wind” combinations), and the other two both have the ‘Fuzzy Classes’ technique as the most different from the ‘Discrete Classes’ technique (12.4 and 13.3%). This implies no generalisations can be made when comparing the techniques as it depends on which layers they are applied to.

5.3.3 Section B: Applying the spatially explicit (local) standardisation techniques

The previous four fuzzy techniques applied the same value function to each grid cell, also termed a ‘global’ value function (Malczewski and Rinner, 2015). A global value function assumes the relationship between consenting risk (constraint level) and the input score are the same throughout the study area. To understand the applicability of the ‘Local Fuzzy’ technique, global value functions are compared with local value functions that consider spatial differences in the relationship between input score and constraint level. The ‘local’ spatial scale relevant to hosting communities can be defined in two ways, either as discrete, non-overlapping units such as economic regions or zones (fixed neighbourhoods), or using the moving window or kernel function approach (Fotheringham et al., 2000; Lloyd, 2010; O’Sullivan and Unwin, 2010). Both neighbourhood techniques were applied to marine spatial socio-economic datasets to evaluate whether they can improve the suitability mapping process.

Table 5-7 Description of fuzzy local standardisation techniques

Technique	Description	Assumptions
‘Fuzzy Local’ – fixed neighbourhood	Standardisation differs depending on which ‘neighbourhood’ the data is in	Value function assumed to be different for different neighbourhoods which have discrete boundaries

'Fuzzy Local' – moving window	Standardisation uses a moving window approach, where the value function used to standardise a criterion value at a given location will depend on the criterion values in its vicinity	Differences in value functions are assumed to differ in space gradually (no discrete boundaries)

5.3.3.1 Applying a fixed neighbourhood local standardisation

To explore the method of applying a 'fixed neighbourhood' to the dataset, Scottish territorial waters (out to 12nm) were subdivided into Scottish Marine Regions, which is the governance level at which regional marine planning partnerships have been established (Figure 5-20).

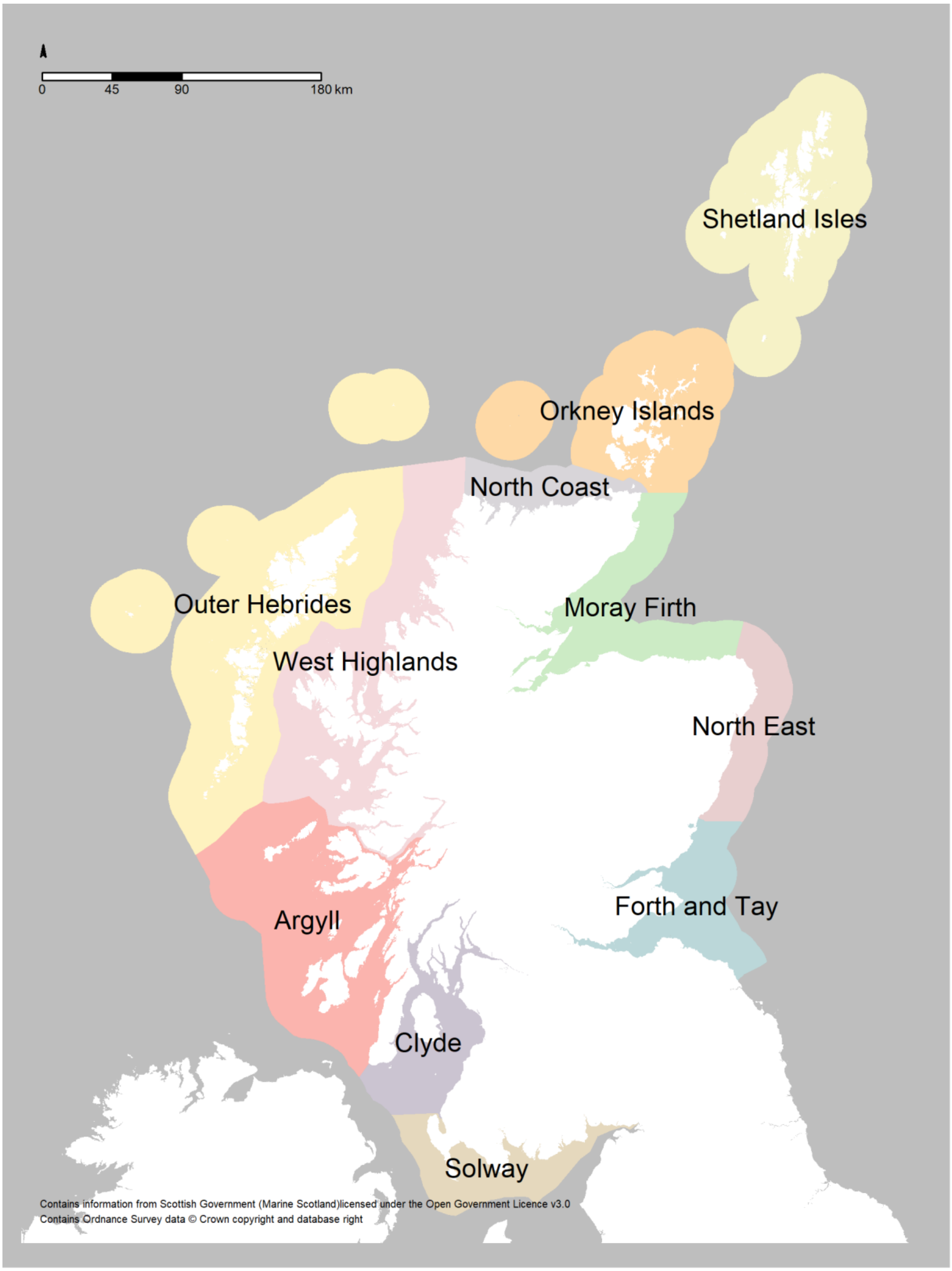


Figure 5-20 Eleven Scottish Marine Regions

The Scottish marine recreation and tourism dataset consists of 23 recreation categories, and the analysis of the four global fuzzy techniques in Section A used the layer combining all 23 categories into one measure of activity level (Table 5-1). However, for applying the 'Local Fuzzy' technique, eight categories were selected to be included for the study out of the 23 recreation categories in the Scottish marine recreation and tourism dataset. The other categories were eliminated as they were either on land, not specific (e.g. the category “General recreation and tourism”), or spatially limited to a specific location (no nation-wide coverage). Categories that were not considered reliable representations by the data collectors were also removed (LUC, 2016, p. 31). The eight categories with the highest total constraint were selected from the remaining categories (Figure 5-21). The procedure was applied to all included recreational layers, but for reporting the results, one activity was chosen to illustrate the procedure. Out of all activities, the wildlife and birdlife watching activity had the highest total density across the 12nm zone (all Scottish marine regions combined, see Table 5-8 and Figure 5-22a), so this activity was analysed in more detail.

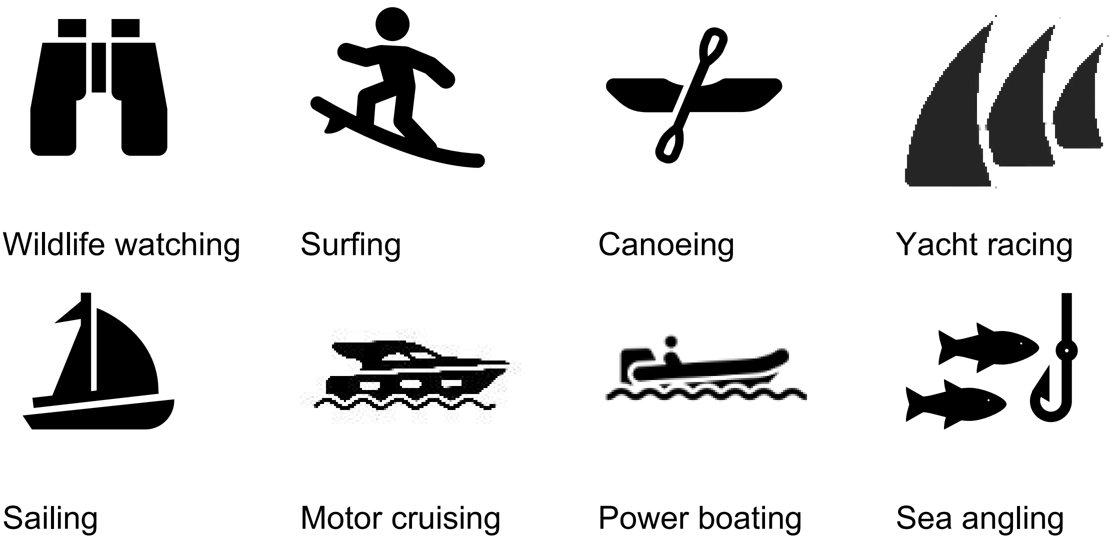


Figure 5-21 Eight recreational categories selected for the analysis

The minimum ($\min A_k$), maximum ($\max A_k$) and total activity density (Eq. (5-6) were calculated for each layer using the *cellStats* function in the ‘raster’ package.

$$A_k = \sum_{i=1}^{m} a_{ik} \tag{5-6}$$

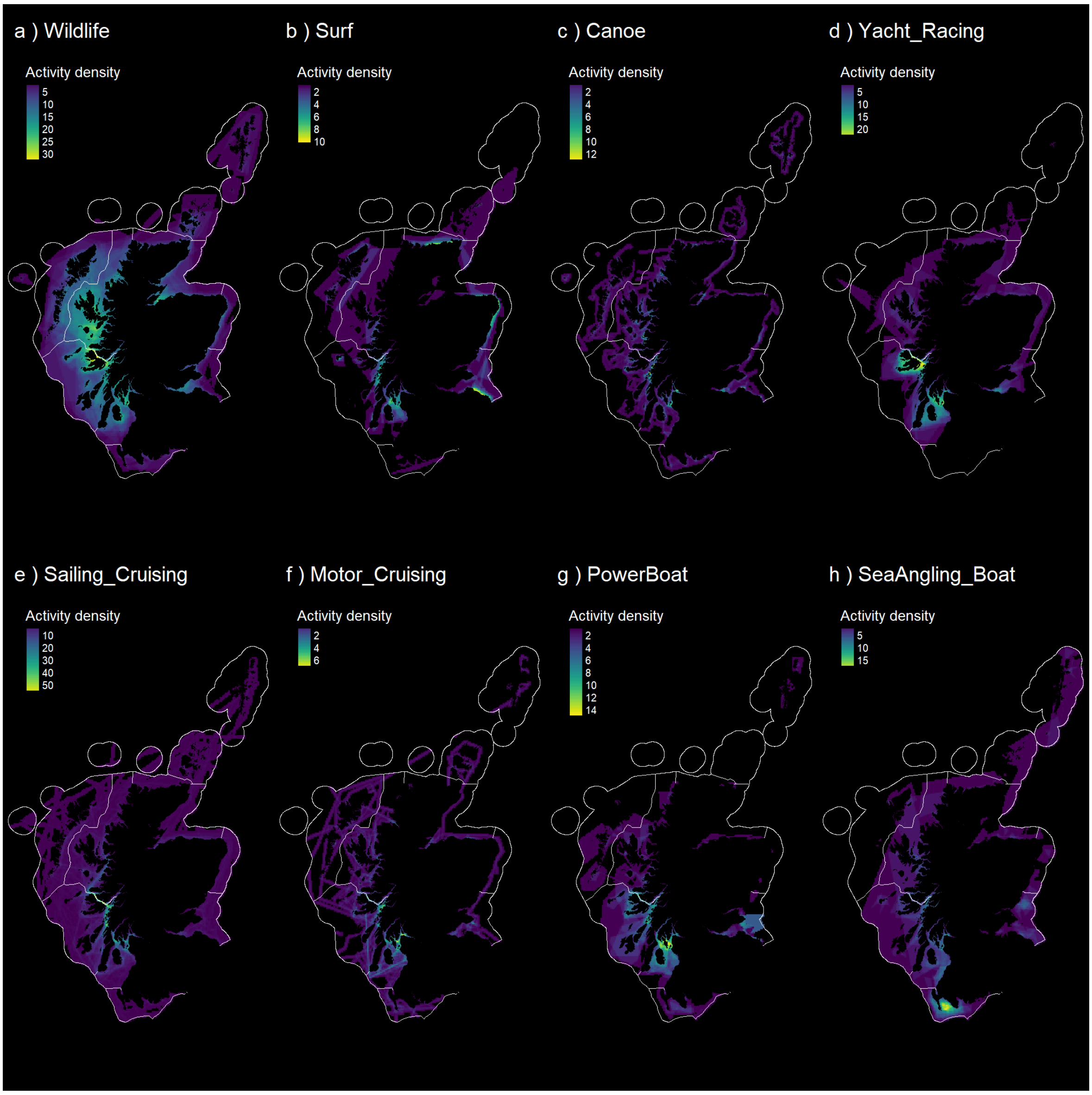


Figure 5-22 Recreational activities included in the study

Figure 5-22 displays the activity density of all eight activities. A black backdrop was used for the land and the boundaries of the layer, to more clearly display where the activity hotspots are. The highest activity densities across recreational categories are found in the West Highlands region or the Argyll region, except for the sea angling layer which has an activity hotspot in Luce Bay in the Solway Firth. The contrast between purple and black allows the spatial coverage of the different datasets to be derived – wildlife watching has the highest spatial coverage. The yacht racing category is missing data in Shetland. For most layers, spatial patterns on a regional scale are not visible on the national scale maps. After wildlife watching, sailing (cruising) had the second highest overall density, and the highest range (Table 5-8).

Table 5-8 Summary characteristics of included activities

Activity	$\min A_k$	$\max A_k$	Range A_k	Total density within 12 nm zone (A_k)
Motor cruising	0	7	7	3751.21
Canoeing	0	13	13	6410.10
Surfing	1	10	9	17466.00
Power boating	1	15	14	19341.83
Sea angling (by boat)	1	19	18	26082.32
Yacht racing	1	25	24	28101.88
Sailing (cruising)	0	58	58	29490.12
Wildlife watching	1	33	32	125723.19

To apply the first fixed neighbourhood standardisation technique, the study area was split up into neighbourhoods (q) using the Scottish marine region boundaries (Figure 5-20). The local range per marine region was calculated using Eq. (5-7), as defined by Jacek Malczewski, 2011. This equation was applied to the data using the *extract* function from the 'raster' package in R.

$$r_k^q = \max_{iq}\{a_{ik}^q\} - \min_{iq}\{a_{ik}^q\} \tag{5-7}$$

The local range r_k^q for criterion k (Eq. (5-7) is the difference between the minimum and maximum values in each subset q, or neighbourhood, of the 'global' dataset. The qth subset includes locations $q = 1,2,\dots,11$ from the global set $i = 1,2,\dots,m$ and $m > q$ (Malczewski, 2011).

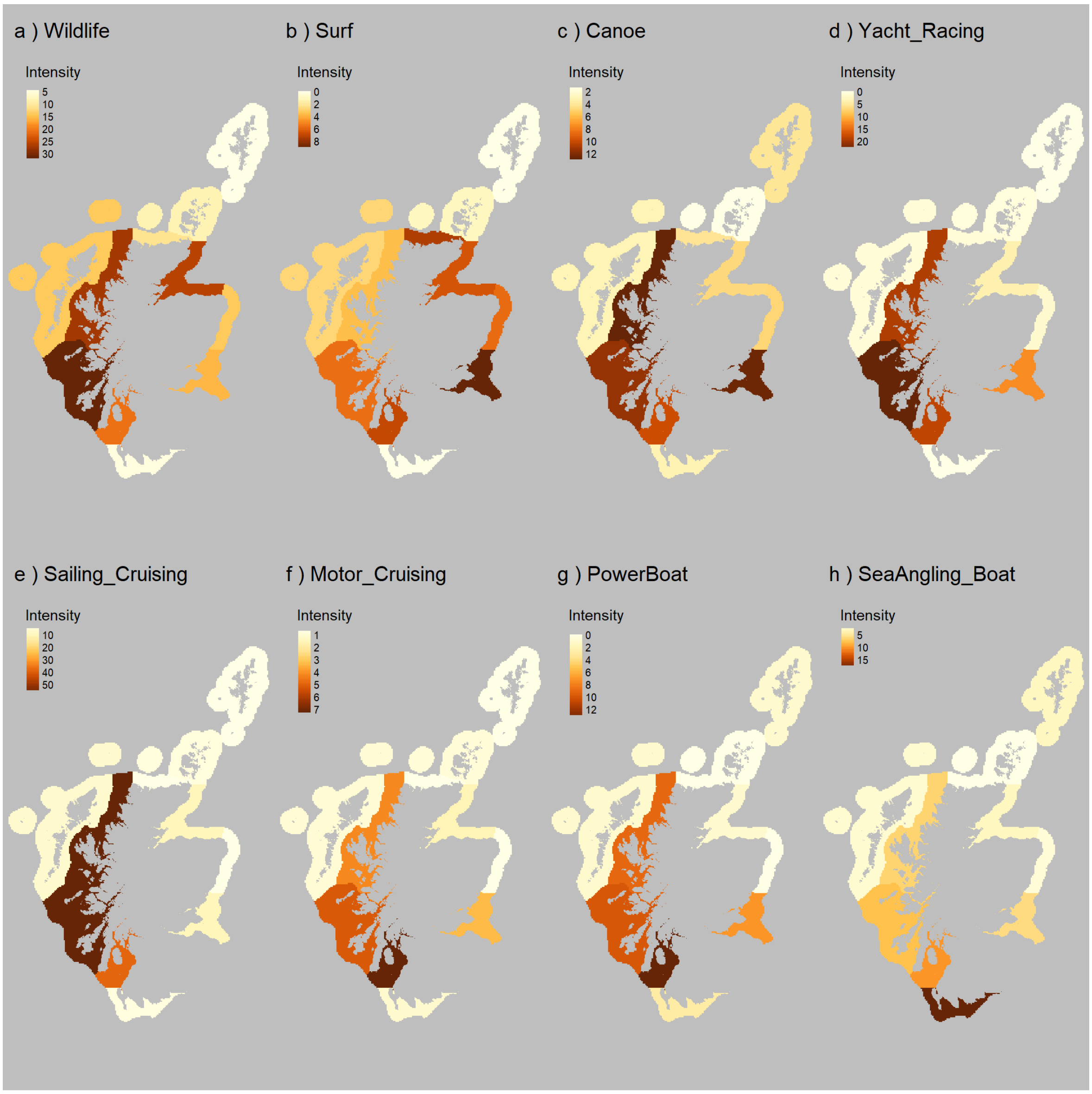


Figure 5-23 Local ranges for each of the eight recreation categories

Local ranges for each activity per Scottish Marine Region are shown in Figure 5-23 and tabulated in App. 5.2B. The yellow-orange-brown colour scheme is used to show the layers which have undergone a transformation (as opposed to the black-purple-yellow colour scheme which is used to show the original input data). The geographical variation in activity density between the regions can be discerned: Shetland, Orkney and the Outer Hebrides are the regions with the lowest range compared to other regions such as the Forth and Tay or the Argyll regions.

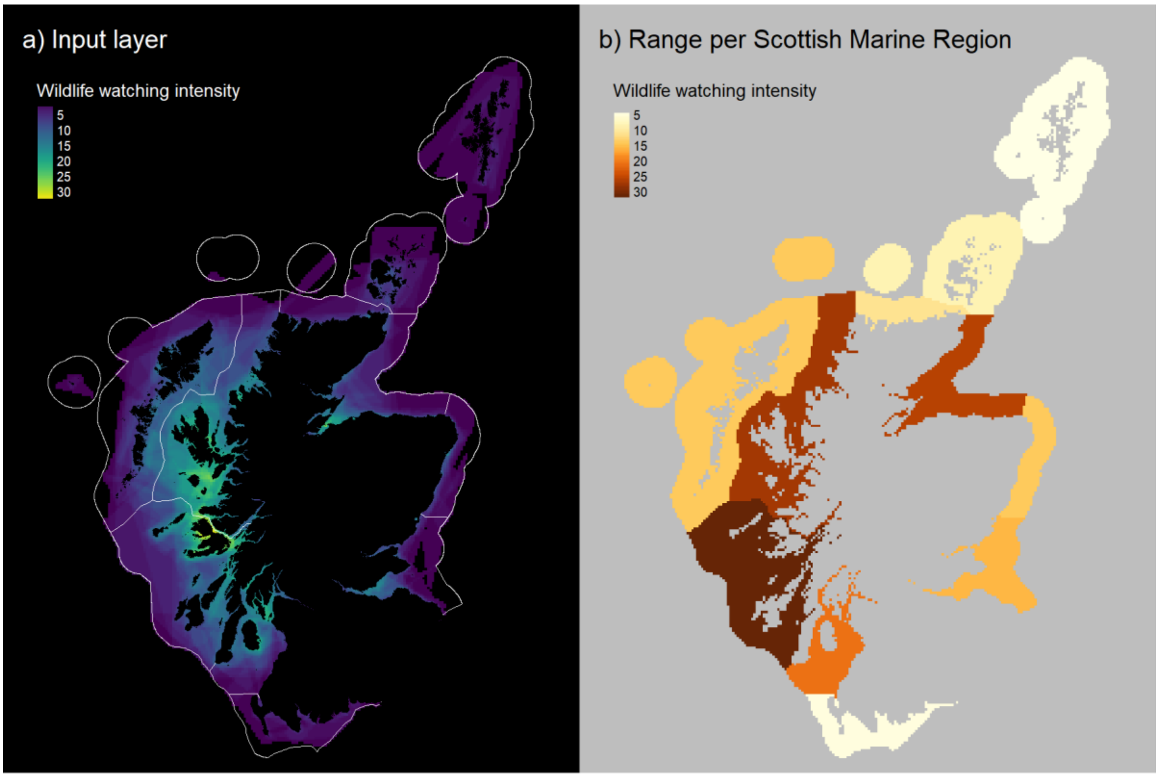


Figure 5-24 a) Input map for wildlife watching and b) Range of activity intensity per Scottish Marine Region

Figure 5-24a depicts wildlife watching intensity. Most activity is concentrated close to the coast (yellow and green areas). The Sound of Mull has the highest intensity of recreational use, and overall the west Coast (West Highlands and Argyll) has higher intensities of wildlife watching than other regions. The wildlife intensity is summarised per Scottish Marine region in Figure 5-24b. The largest range is found in the Argyll region (31.6, App. 5.2B) and the lowest in Shetland (4, App 5.2B), which is reflected in Figure 5-24b.

The local ranges for each of the eight categories were then used to standardise the input layers using a local value function, which depends on the local range rather than the global range. The global range was defined for the linear score range procedure earlier in Eq. (5-3), which was used for the 'Fuzzy Linear' technique. Eq. (5-8) is defined in the same way as Eq. (5-3) but using the local range rather than the global range:

$$v(a_{ik}) = \frac{a_{ik}^{q} - \min_{iq}\{a_{ik}^{q}\}}{r_k^q} \tag{5-8}$$

r_k^q is the local range as defined in Eq. (5-7). The standardised values range from 0 to 1, where 0 is the lowest value and 1 is the maximum level of constraint, which is used to represent areas of high recreational value.

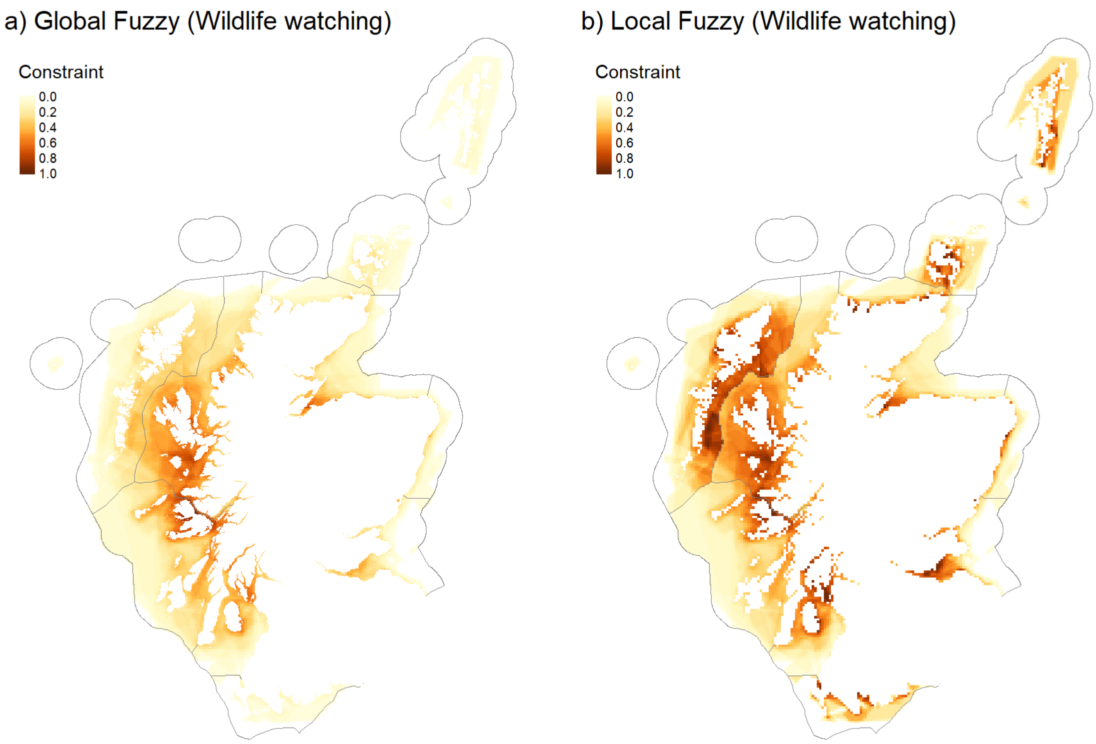
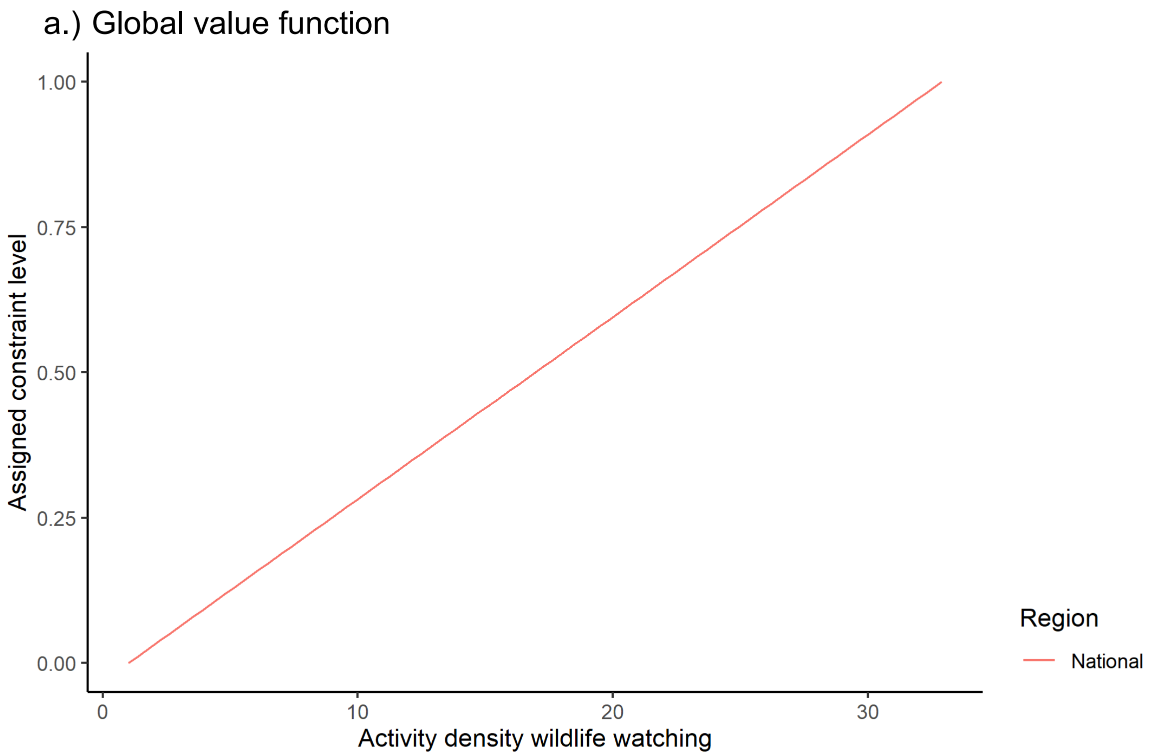


Figure 5-25 a) Standardisation of the wildlife layer using the ‘Global Fuzzy’ technique b) Standardisation of the wildlife watching layer using the ‘Local Fuzzy’ technique, using the Scottish Marine Regions as discrete neighbours

Figure 5-25a-b allow comparisons to be made between the ‘Global Fuzzy’ approach to standardisation and the ‘Local Fuzzy’ technique. The standardised layer using the ‘Local Fuzzy’ technique (Figure 5-25b) elicits differences in wildlife watching value within marine regions. For example, in Figure 5-25a no distinction is possible in wildlife watching value between regions within Shetland, whilst Figure 5-25b visualises a concentration of wildlife watching activities in the southeast of Shetland. The ‘Local Fuzzy’ technique allows ‘hotspots’ within regions to be identifiable on a national scale. The difference between the two techniques is visualised using value functions in Figure 5-26a-b. For the ‘global’ fuzzy technique one value function is used for the entire 12 nm zone in Scottish waters (Figure 5-26a), and the value function is constructed based on the national maximal wildlife watching intensity value. For the ‘Local Fuzzy’ standardisation, a different value function is used for each marine region, based on the maximum value per marine region. Figure 5-26b illustrates that Argyll has the highest maximum value, and Shetland the lowest, which also explains why on the ‘Global Fuzzy’ standardisation in Figure 5-25a it is not possible to see spatial differences within the Shetland region. The value maps for the other seven activities can be found in App. 5.3.



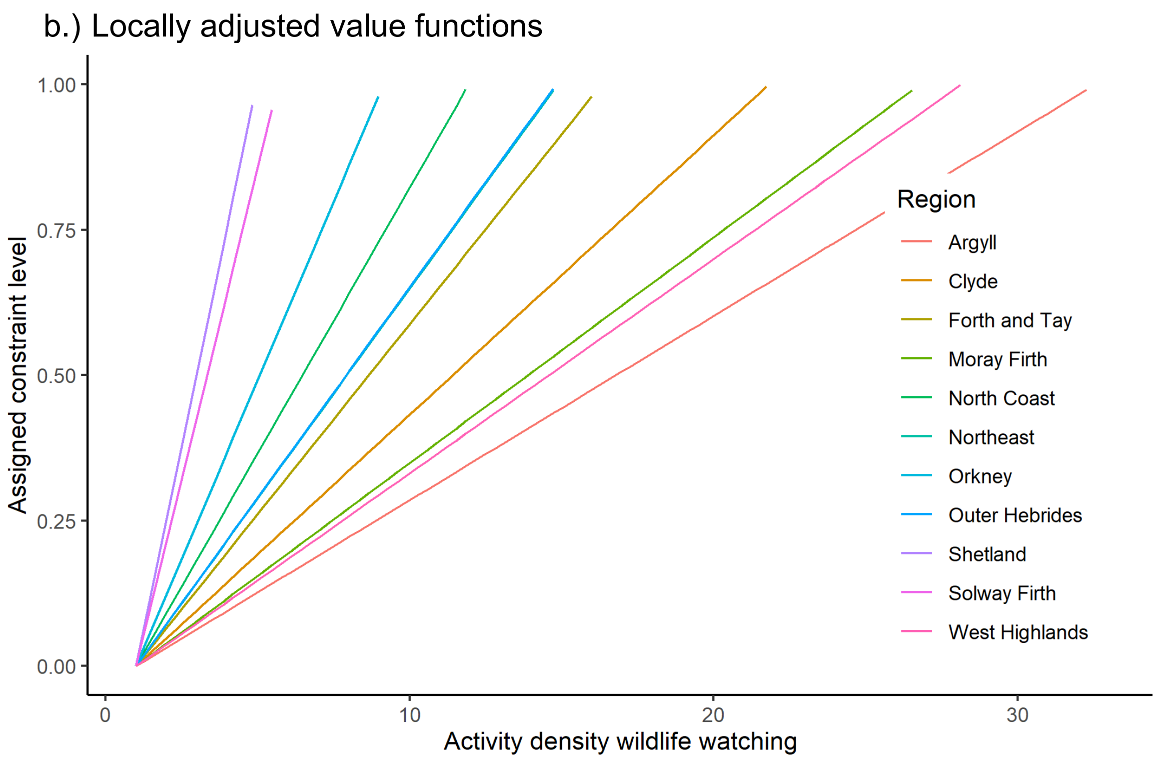


Figure 5-26 a) Global value function used to construct the global fuzzy layer and b) Value functions per Scottish Marine Region as used to construct the local fuzzy layer

Spatial weights

Eq. (5-8) ensures differences *within* regions are considered, but it does not consider absolute differences in recreational value between regions, which is represented in the global value function. To also take into account differences *between* regions in the local value function, a scaling factor can be applied to the value function, also called a spatial weight (Fischer, 1995; Ligmann-Zielinska and Jankowski, 2008). In multi-criteria decision support, after standardisation, weights can be assigned to individual layers before they are combined in an overlay to indicate relative importance of one layer over another (Malczewski and Rinner, 2015). However, here, the inclusion of spatial weights in the value function can be regarded as part of the standardisation process to influence how alternatives are converted into suitability values. This requires the definition of a global weight w_k. To ensure the weights do not infer differences in relative importance between the layers as this is not the purpose of this type of weighting, the global weights for each activity were all assigned equally and added up to 1 for the eight categories (Eq. (5-9)).

$$w_{k=}0.125, \sum_{k=1}^{n} w_k \; = 1 \qquad (5\text{-}9)$$

To obtain the local weight w_k^q, as defined by Jacek Malczewski, 2011, the global weight w_k is scaled according to the ratio between the local range and the global range as follows:

$$w_k^q = \frac{\frac{w_k r_k^q}{r_k}}{\sum_{k=1}^{n} \frac{w_k r_k^q}{r_k}}, 0 \leq w_k^q \leq 1, and \; \sum_{k=1}^{n} w_k^q = 1 \qquad (5\text{-}10)$$

This spatial weight is then added to the value function to obtain the ‘Weighted Local Fuzzy’ technique:

$$v(a_{ik}) = w_k^q \frac{a_{ik}^q - \min_{iq}\{a_{ik}^q\}}{r_k^q} \qquad (5\text{-}11)$$

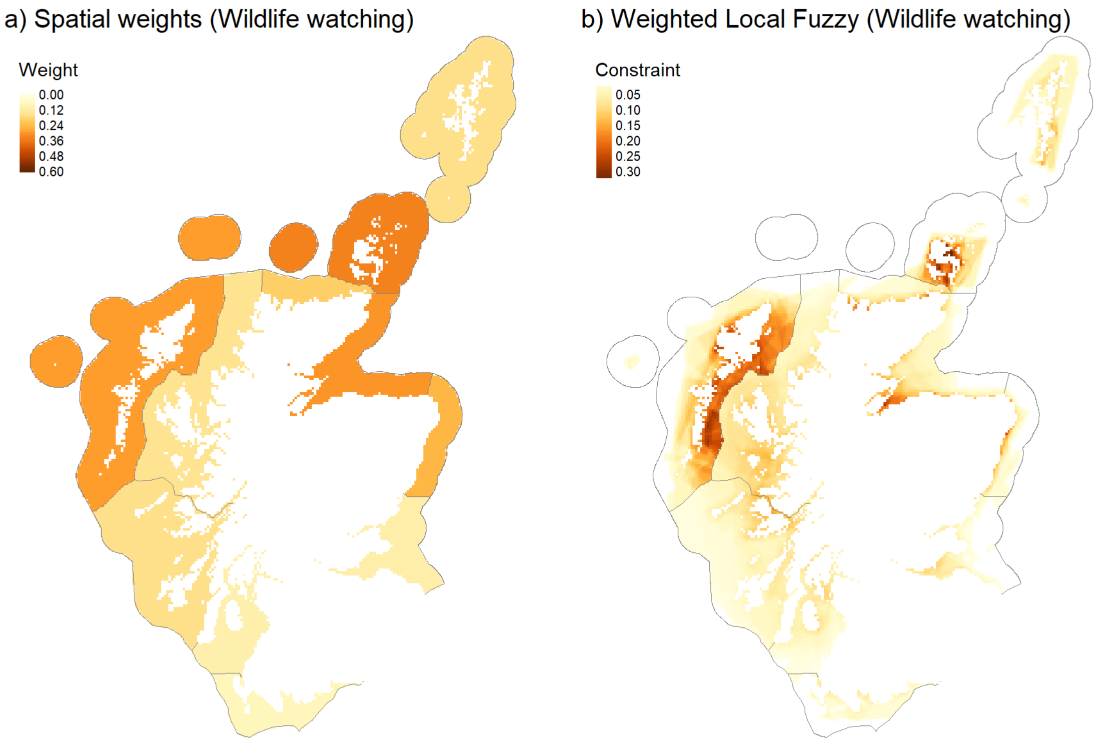


Figure 5-27 a) Spatial weights and b) Weighted local fuzzy standardisation

The spatial weights per marine region (Figure 5-27a) were constructed using Eq. (5-10). They reflect the relative importance of the wildlife watching layer compared to other activities within each marine region. Figure 5-27a indicates that wildlife watching had the highest intensity, compared to the other seven activities, in the Hebrides, Orkney, Moray Firth and Northeast Coast regions (see also Figure 5-23 and A5.2B). Figure 5-27b is a weighted 'Local Fuzzy' standardisation calculated with Eq. (5-11) using the spatial weights shown in Figure 5-27a. It shows the effect of applying a spatial weight to the local fuzzy value function. As with the unweighted 'Local Fuzzy' standardisation in Figure 5-25b, differences within regions are more discernible than with the 'Global Fuzzy' approach. However, even though the equation for the spatial weight factors in the differences between regions to account for national-level differences, the resulting spatial weights rather emphasise the regions (Hebrides, Orkney, Moray Firth, Northeast Coast) where the considered activity (wildlife watching in this case) has a high activity level compared to the other 7 recreational activities that occur in those regions. This indicates that the bottom half of Eq. (5-10) is reflected more prominently in the spatial outputs than the top half.

The weighted local value functions (Figure 5-28) take on a different shape than the unweighted local functions (Figure 5-26). The gradients of the linear curves depend on both the maximum of wildlife watching intensity per region as well as the maximum recreational value per region of the other recreational categories. The mapped spatial weights for the other recreation categories can be found in App. 5.3. The Local, Weighted Local and Global standardisation layers for the other categories can be found in App. 5.3.

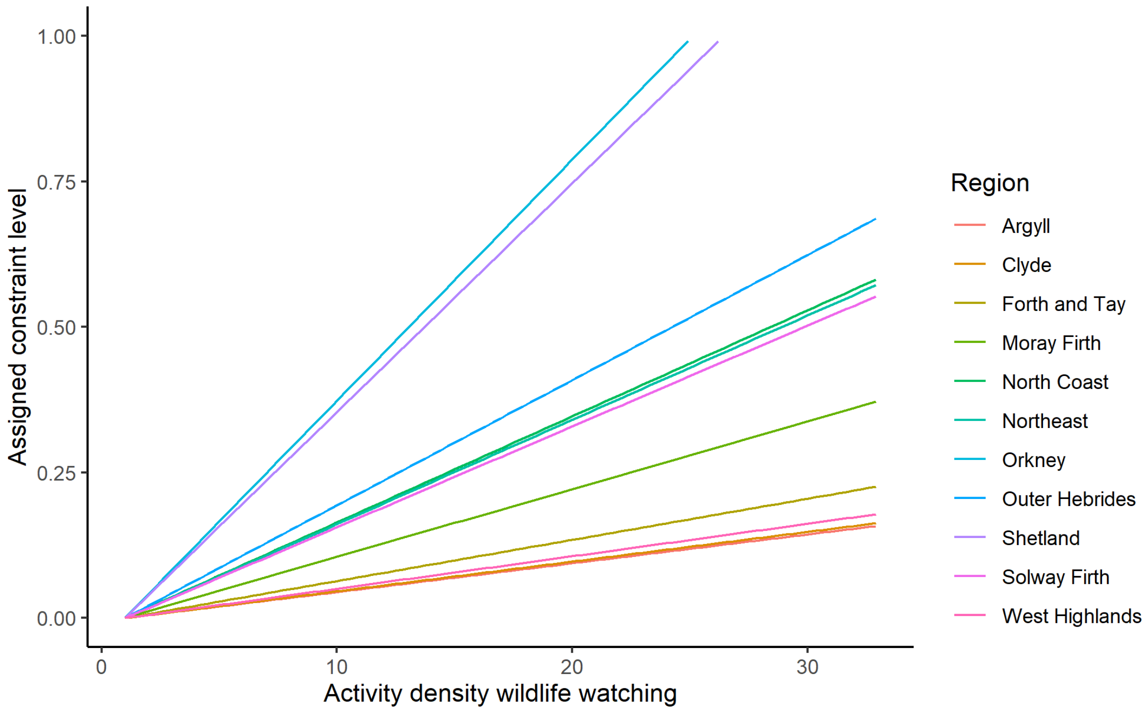


Figure 5-28 Weighted local value functions for standardising the wildlife watching layer

To understand the difference between the ‘Global Fuzzy’ approach and the ‘Local Fuzzy’ and ‘Weighted Local Fuzzy’ techniques, difference maps were created (Figure 5-29).

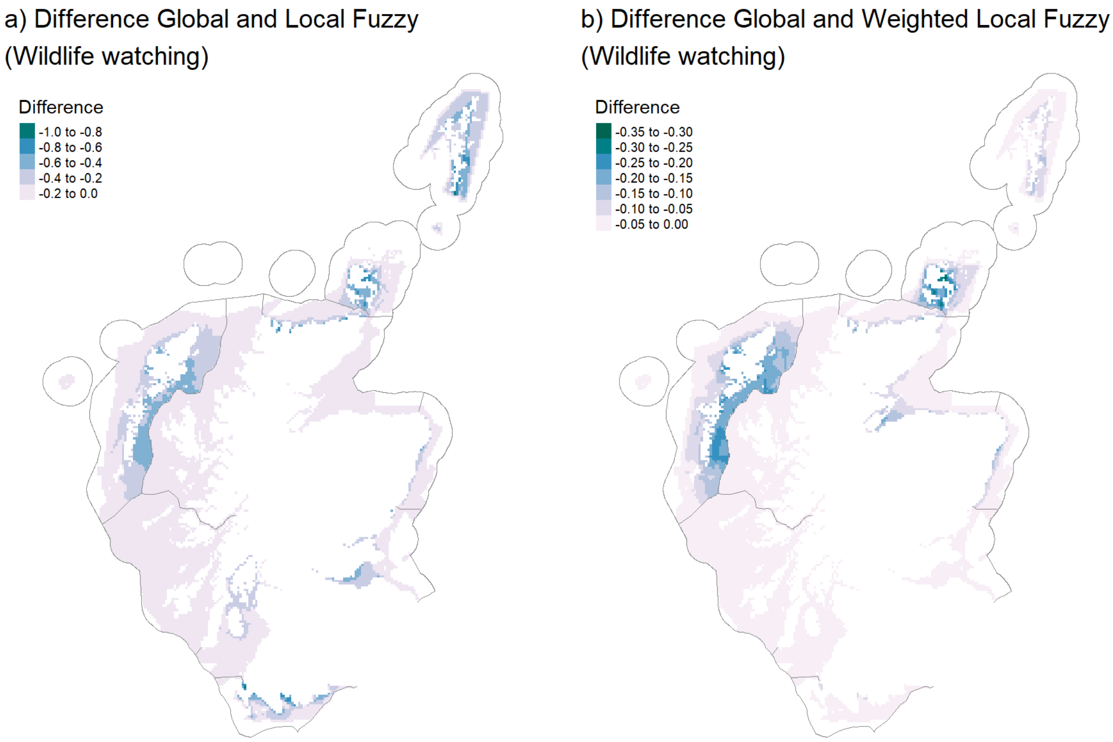


Figure 5-29 a) Difference between the global fuzzy technique and the weighted local fuzzy technique b) Difference between the global fuzzy technique and the unweighted local fuzzy technique (for the wildlife watching layer)

Values in the blue-green end of the colour spectrum reflect a larger difference between the ‘Global Fuzzy’ standardisation compared to the ‘Local Fuzzy’ techniques. The differences are negative, meaning the global techniques assigned a lower constraint level to the grid cells than the local techniques. Figure 5-29b indicates the highest difference is found in the Outer Hebrides and Orkney for the comparison with the ‘Weighted Local Fuzzy’ technique. Differences are more spread out across regions when comparing the ‘Global Fuzzy’ technique with the ‘Local Fuzzy’ technique (differences in Shetland, Orkney, Outer Hebrides, North Coast, Solway Firth, Forth and Tay, Figure 5-29a). The difference between Figure 5-29a and b can be explained by the different spatial weights assigned to the marine regions which depend on how important wildlife watching is as an activity compared to other activities in the marine region. For example, wildlife watching is not the most important activity in Shetland (see A5.2), so wildlife watching is not given a high spatial weight for the Shetland region compared to other regions. Therefore it has a lower difference in constraint level compared to other regions in Figure 5-29b.

Local and global weighted linear combinations (WLC)

To obtain an overall value layer for all recreational activities, a local weighted linear combination (WLC) was used, as described in Jacek Malczewski, 2011 and repeated here:

$$V(A_i^q) = \sum_{k=1}^{n} w_k^q v(a_{ik}^q), n = 8 \tag{5-12}$$

This value function was compared with a global weighted linear combination:

$$V(A_i\ ) = \sum_{k=1}^{n} w_k\ v(a_{ik})\,, n = 8 \tag{5-13}$$

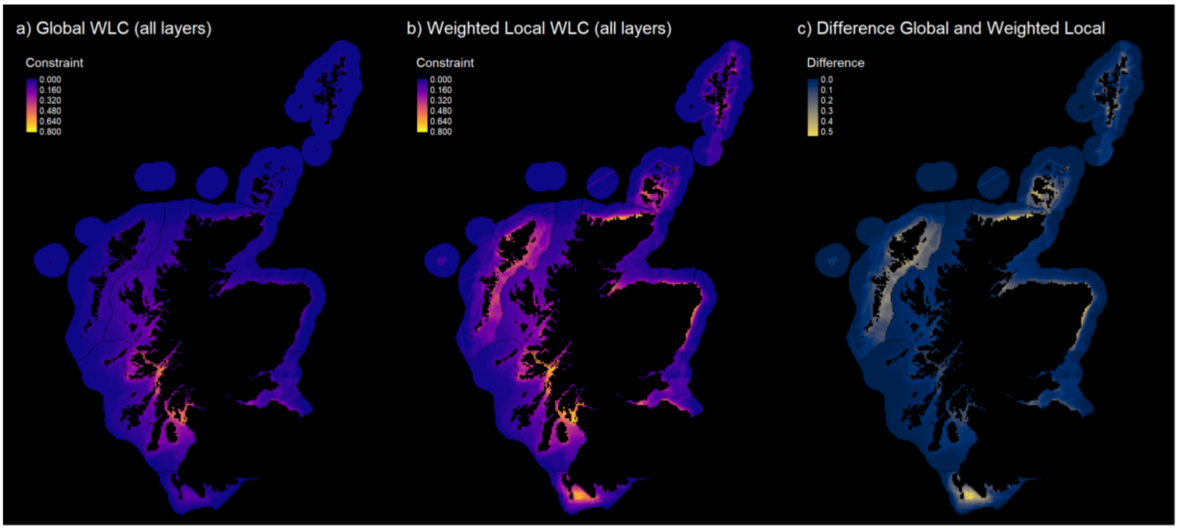


Figure 5-30 Overlays using a) the global fuzzy technique b) the local weighted fuzzy technique and c) difference between both techniques

Figure 5-30 enables a comparison of the techniques (‘Global Fuzzy’ and ‘Weighted Local Fuzzy’) using the overlay of all eight standardised recreation layers combined. The ‘Weighted Local Fuzzy’ is taken forward for further analysis rather than the unweighted ‘Local Fuzzy’ as it also considers relative importance of the different recreational categories per region. When combining the ‘Global Fuzzy’ layers, the most apparent spatial pattern is the high recreational activity densities in the Argyll region (Figure 5-30a). In Figure 5-30b, differences within regions are also represented, including the difference between the east and west coasts of the Hebrides, the concentration of activities around Orkney’s Mainland, and the relatively spread-out nature of recreational activities around Shetland. The difference between both overlays only has positive values (Figure 5-30c), which indicates that for each cell, the local overlay (WLC) has a higher value than for the global WLC. This implies the ‘Local’ technique translates the recreational input values into higher constraint values than the ‘Global’ technique, meaning it assumes they represent higher consenting risk.

Sensitivity analysis

Differences were analysed both visually with a difference map, and with a quantitative sensitivity analysis. To understand how the global and local technique value different places across the 12nm zone differently, the most valuable 10% was selected and compared for the two value maps (Figure 5-30a and b). The areas selected in Figure 5-31a using Figure 5-30a are mostly found in the West Highlands and Argyll regions, whilst those for Figure 5-31b using the ‘Weighted Local’ technique (Figure 5-30b) are more spread out between regions. The total difference in selection of area between the two techniques (‘Fuzzy Global’ and ‘Fuzzy Weighted Local’) is 12.6%, and the locations of these differences are illustrated on Figure 5-31c.

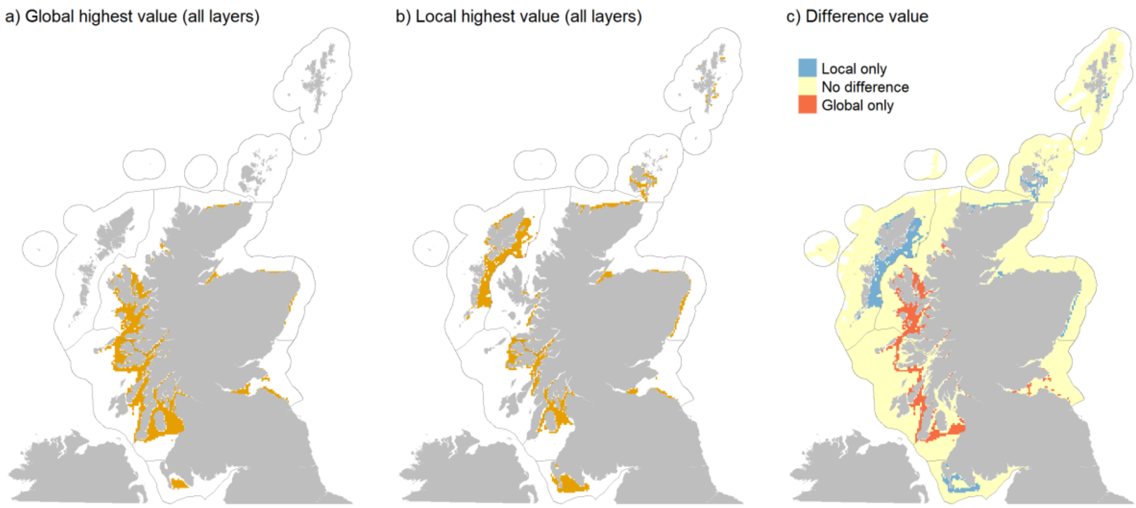


Figure 5-31 Sensitivity analysis two techniques using the overlays

5.3.3.2 Applying a moving window approach

For the moving window approach, the local range is calculated using a moving kernel surrounding a given grid cell (Malczewski, 2011). To understand how a local value function could be applied with a moving window rather than with a fixed neighbourhood, it was tested out on the Scotmap dataset. Scotmap was a participatory mapping project which ran from 2007-2011, and characterised space use of fishing vessels under 15m (Kafas et al., 2017). For the testing of the four global standardisation techniques, the total relative value across all types of fishing was used as a layer (Table 5-1). For testing the ‘Local Fuzzy’ technique, the layers representing static (creel) fishing were included, which targeted crab, lobster or *Nephrops*. The number of vessels was used as a metric here rather than relative value, as ‘number of vessels’ is a similar metric as the recreational value used for the fixed neighbourhood analysis.

Kernel size (size of the ‘moving window’) was defined based on the average time spent steaming from the home port. Average time spent steaming from the home port was parametrised based on a literature study to find representative values for the hours of steaming from the home port by fishers, as well as the steaming speed. A study in 2019 characterised the activity of Scottish inshore static gear fisheries, and estimated average steaming speed to be 8 knots (Mendo et al., 2019a, 2019b). To understand fishing activity around Islay, fishers were interviewed in 2009 and smaller boats were said to steam for up to two hours from their home ports, and larger boats between 4-6 hours (Scottish Power Renewables, 2010).

Based on this information, kernel size was selected based on a traveling time of 6 hours at 8 knots, giving a maximum distance travelled of 48 nm away from the home port, for vessels between 5.6 and 11.8 m in size (Scottish Power Renewables, 2010). The home port is assumed to be in the centre of the kernel, which means the kernel size should then be 2*48 nm = 96 nm ≈ 177 km (Figure 5-32).

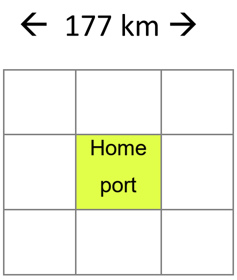


Figure 5-32 Illustration of calculation kernel size

Comparative kernels were also created, based on 2- and 4-hours steaming time as well as 6 hours (Table 5-9). The kernels were created with the *focal* function using the 'raster' package in R. Three kernels with different sizes were applied as moving windows to the Scotmap dataset.

Table 5-9 Kernel characteristics

Assumed steaming time (hours)	Kernel size (km)
2	59
4	118
6	177

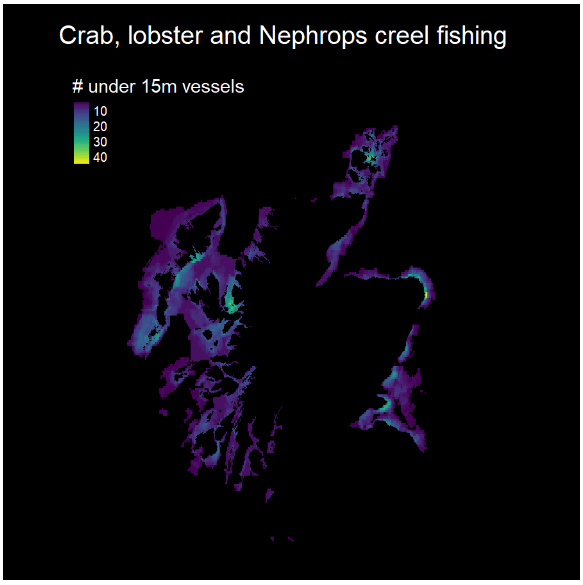


Figure 5-33 Number of under 15 m vessels (3 or more) for crab, lobster and *Nephrops* creel fishing in Scottish waters (2007-2011)

Figure 5-33 illustrates the spatial distribution of under 15 m vessels engaged in crab, lobster or *Nephrops* creel fishing between 2007-2011. High vessel densities are found in the Inner Sound of Skye, off the east and southern coasts of the Outer Hebrides, in Orkney, close to Fraserburgh and Peterhead, and in the Fife region. Shetland was not part of the study region of this data collection project.

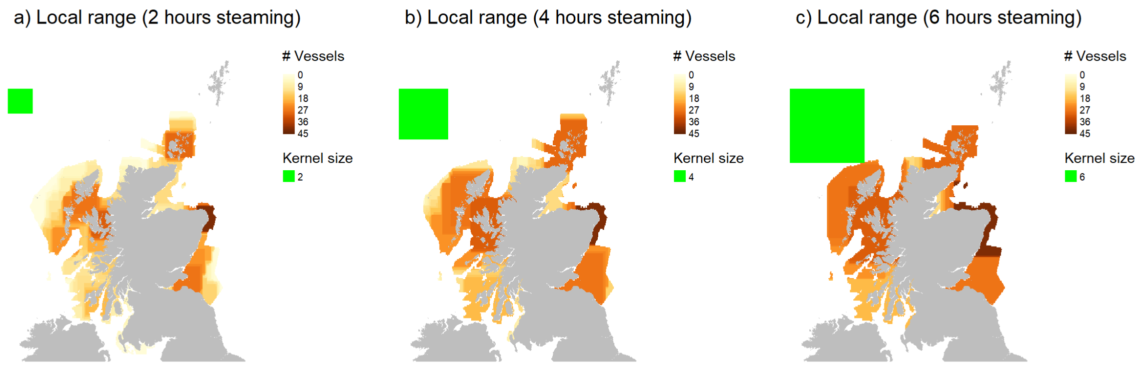


Figure 5-34 Applying different kernel sizes to the dataset. The green square in the western corner of each map panel indicates the kernel size in relation to the spatial data

Figure 5-34 shows the local range calculated using Eq. (5-7) with three different kernel sizes. Visual inspection indicates that the range for the 2 hours steaming time kernel size (Figure 5-34a) most accurately reflects the occurring spatial patterns on the input map (Figure 5-33), while the ranges calculated using the larger kernel sizes did not allow an identification of lower values between high values on the coastline (e.g. the lower values to the west and to the south of Fraserburgh and Peterhead which can be discerned from Figure 5-34a and Figure 5-33).

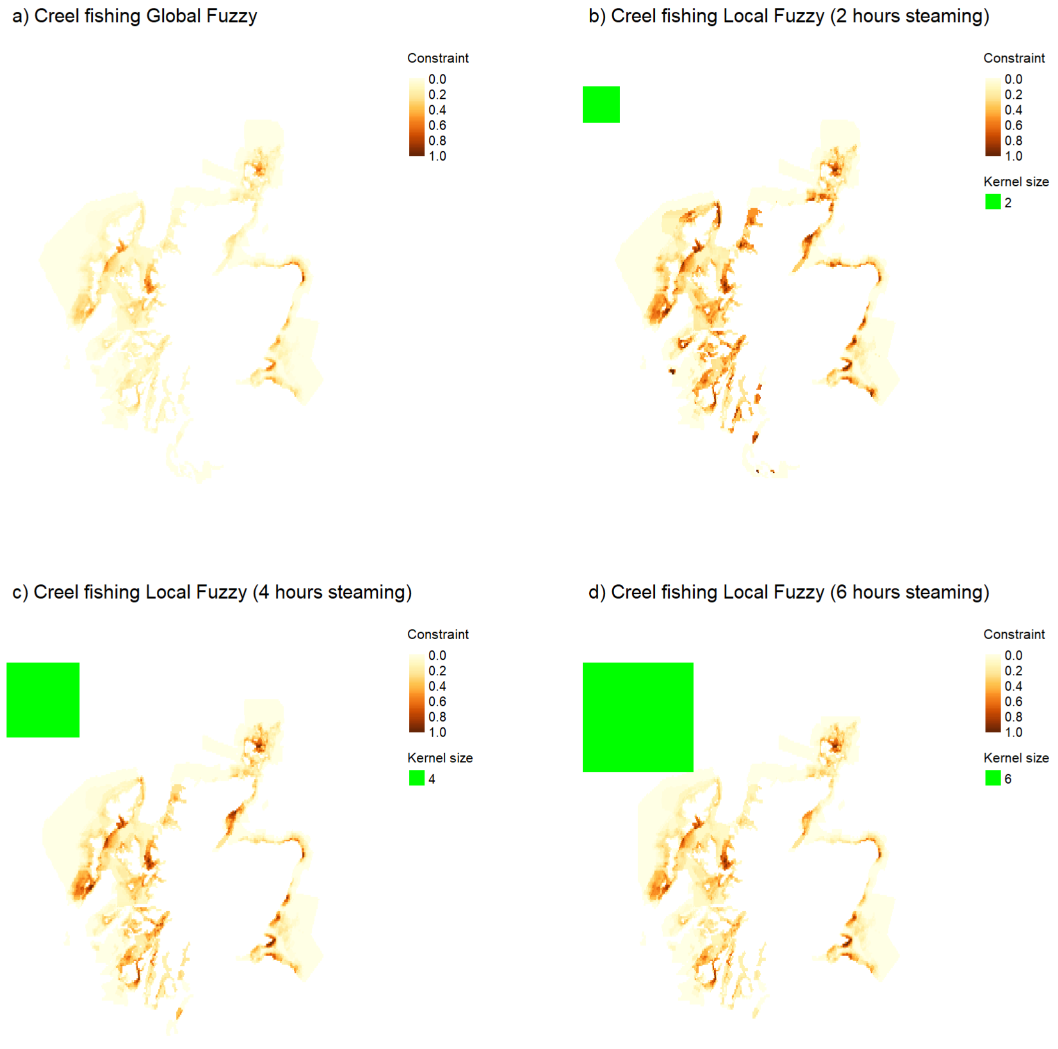


Figure 5-35 Locally explicit value maps for creel fishing by under 15m vessels

The ‘Local Fuzzy’ value function (Eq. (5-8)) was used to standardise the Scotmap layer into suitability layers, using the kernels as neighbourhoods (Figure 5-35b-d). The dominant spatial patterns of high vessel density discernible in the ‘Global Fuzzy’ layer (Figure 5-35a) (Inner Sound of Skye, east and southern coasts of the Outer Hebrides, Orkney, Fraserburgh, Peterhead and Fife) are also visible in the three ‘Local Fuzzy’ layers with the differing kernel sizes (Figure 5-35b-d). The additional hotspots of creel fishing emerging in the layers standardised with the kernels are standardised into equally high constraint levels as the hotspots identifiable in Figure 5-35a. The smallest kernel size indicating 2 hours of steaming from a home port led to the highest number of constrained areas along the coastline. In contrast to the results of applying the fixed neighbourhood technique to the recreation dataset, a visual comparison between the ‘Global

Fuzzy' and 'Local Fuzzy' techniques when applying the kernel approach to the Scotmap dataset do not indicate any differences between the Central Belt region and more remote regions: the differences are more equally spread out across the Scottish coastline.

5.4 Discussion

This study focused on the standardisation step of the suitability mapping process and evaluated three global fuzzy techniques and two local fuzzy techniques on their ability to consider decision rule uncertainty and spatial differences in value scales during the consideration of socio-economic activities. There was between 9-21% difference in which areas were selected as 'most suitable' between the fuzzy techniques and the 'Distinct Classes' technique, indicating that the choice of technique has implications for decision outcomes. A comparison between the three global fuzzy techniques indicated that some techniques underrepresented certain types of spatial patterns compared to other techniques. In summary, the 'Fuzzy Classes' technique represented the broadest range of spatial patterns, indicating its suitability for use in high uncertainty situations. For the local fuzzy techniques, the identified 'high value' areas for recreational activities were different when the local value functions were used compared to the global value function, offering an opportunity to explore which values are important to represent in the siting process.

5.4.1 Spatial patterns represented by the three 'global' fuzzy techniques

The 'Fuzzy Classes' approach combines the advantages of 1) displaying broad patterns in the data using statistical classification techniques and 2) retaining finer-scale details such as linear features by defining a continuous function rather than discrete classes. In a situation of decision rule uncertainty, where the decision maker is unsure of how socio-economic activities will be affected by proposed renewable energy developments, this standardisation technique was found to be most appropriate as it displays the highest number of types of spatial patterns compared to the other techniques, which might be necessary when it isn't known which spatial pattern is the most important to represent in the decision-making. However, this study also demonstrated that different layer combinations led to different rankings between the techniques, therefore it could still be useful to use the method presented here to compare standardisation techniques, including the ‘Fuzzy Classes’ technique, before choosing one.

Grouping continuous data into discrete classes masks extreme values (Dent et al., 2009). This is reflected in findings here, as extreme values were not visible in the layers standardised using the ‘Discrete Classes’ and ‘Fuzzy Classes’ techniques. Yet, extremes in the data may also be relevant for decision support applications. If extremes are not distinguishable and ‘averaged out’, it could underrepresent the risk of affecting an area that is intensely used for recreation and tourism activities, which presents a procedural justice issue.

In contrast to the ‘Discrete Classes’ and ‘Fuzzy Classes’ techniques, the ‘Fuzzy Risk Averse’ and ‘Fuzzy Linear’ techniques highlighted extreme values in the dataset. Since the ‘Fuzzy Linear’ and ‘Fuzzy Risk Averse’ techniques do not group data into classes, they are similar in approach to what is known as ‘unclassed choropleth maps’, which is when continuous spatial data is visualised without a grouping of data intervals in the legend (Dent et al., 2009). This leaves the interpretation of the values on the map to the reader, without highlighting broad patterns with statistical classification techniques (Dent et al., 2009; Peterson, 1979).

Where data is skewed, which marine socio-economic data tends to be (see also Marine Scotland Science, 2018), especially with the gradient from the coast, displaying ‘raw’ data without considering patterns in the data could lead to the overemphasis on extreme values. This may mask differences between areas with lower socio-economic values, which are then underrepresented, affecting procedural justice. Therefore, when there is high decision rule uncertainty regarding which socio-economic activity levels relate to which level of constraint for a proposed development, the ‘Fuzzy Linear’ and ‘Fuzzy Risk Averse’ techniques were not deemed appropriate for use, as they are sensitive to skewed data, and high decision rule uncertainty also implies it would not be possible to define a discrete cut-off level to use for identifying outliers. If there is enough decision rule certainty to identify outliers, they could be taken out of consideration which could lead to a less skewed dataset.

This study focused on how to integrate socio-economic activities represented as heat maps into spatial decision support. When interpreting the spatial outputs it became apparent that experiential knowledge of the study area was also necessary when deciding on an appropriate technique, such as knowledge about regular shipping routes, or about irregular events such as construction projects at the time of data collection. Overall, the fuzzy techniques were more successful in retaining linear features characteristic of heat maps derived from mobile activities (such as shipping routes) than the ‘Discrete Classes’ technique. Specificities such as shipping routes will affect the suitability of a site for renewables development.

5.4.2 Implications for distributional justice

The way in which choice of standardisation technique affects the decision support outcome, i.e. what locations get selected as the most suitable for renewable energy development, will affect distributional justice. The sensitivity analysis indicated that the difference between using the ‘Discrete Classes’ technique and the fuzzy techniques ranged between 9-21%. Moreover, the identified areas by the two types of techniques were also distant from each other in space, so differences were demonstrated both spatially and quantitatively. For procedural justice, considering which standardisation technique to use is important regardless of the outcome, and the sensitivity analysis indicates the standardisation step also has distributional justice implications. A similar finding was demonstrated by Avila et al., 2021, who make an explicit link between justice and cartography in relation to wind farm and solar farm siting in Mexico.

5.4.3 ‘Local Fuzzy’ technique visualises underrepresented values

As well as comparing the ‘Discrete Classes’ technique with a set of fuzzy techniques, this study evaluated the application of the ‘Local Fuzzy’ technique which standardised input values in a way that accounted for differences in value scales between regions. Compared to the overlay using the ‘Global Fuzzy’ technique which assumes the ranges of the input layers across regions have the same value, the ‘Weighted Local Fuzzy’ standardisation overlay differed especially for regions outside of the Central Belt, the geographic term given to the area centred around the cities of Edinburgh and Glasgow which have the highest population densities in Scotland (Pawel, 2017). Sensitivity of these more remote regions to different standardisation techniques can have implications for recognitional justice of remote and island communities. New developments are more likely to choose less constrained, more remote regions, so incorporation of the values of remote and island communities will be pivotal.

Using a spatially varying value function as demonstrated here could reduce objections to proposed developments by improving the consideration of regional socio-economic values. This can help novel developments comply with the High-level Marine Objective in Scotland's National Marine Plan which states: "There is equitable access for those who want to use and enjoy the coast, seas and their wide range of resources and assets, and recognition that for some island and peripheral communities the sea plays a significant role in their community". The 'Local (Weighted) Fuzzy' technique can be used during the data exploration phase to better understand spatial patterns in the data. Moreover, it allows comparison between the Scottish Marine Regions, which can be informative as more regional marine planning partnerships become established (Scottish Government, 2021c).

For the moving window application of the 'Local Fuzzy' technique, an attempt was made to characterise the home range of static fisheries around Scotland's coastline using the kernel size. Home range is a term used in ecology to refer to the area within which organisms remain, even if they are free to roam (Burt, 1943; Powell, 2000). This concept has been applied to human activities before in the context of urban geography (Acedo and Johnson, 2020). Here it could be used to describe the activities of marine users. The scale of the home range could then be seen as their operational scale, defined as the scale at which processes are occurring (Lam and Quattrochi, 1992).

This technique applied to the Scotmap dataset did not visually reveal underrepresented spatial patterns in remote regions, as with the 'fixed' neighbourhood technique applied to the recreational data. This implies the 'Local Fuzzy' technique may not be necessary for the Scotmap dataset for creel fishing, and a potential reason for this is that creeling effort is more equally distributed across Scottish coasts than recreational activities may be, and is already operating at capacity (‘gear saturation’, Marine Scotland, 2017). However, this does not mean that the relative socio-economic value of a creel vessel does not differ for different coastal communities. Some isolated communities may be highly dependent on the catch of these smaller boats (Bakker et al., 2019), but this difference is not represented with the dataset used in this study.

To the author’s knowledge, this is the first attempt at applying a local standardisation technique (Malczewski, 2011) to a marine context with heat maps representing socio-economic activity, at a national level. The two criteria layers that were used to apply the local standardisation in Malczewski, 2011 were slope (%) and distance to roads (km), at a scale around 1/8th the size of the smallest Scottish Marine Region (the North Coast). In this study, the two datasets used were heatmaps representing socio-economic activities. Since heatmaps are created using discrete polygons, lines, or points, they cannot be treated in the same way as ‘naturally’ continuous variables such as distance or slope. It was found that the technique did not appear to add value to interpreting the Scotmap dataset, indicating it is not a relevant technique for all applications. This study demonstrates how applying the ‘Local Fuzzy’ technique allows an analysis of subnational spatial patterns using a national dataset, and that it can overcome the risk of overlooking social values of peripheral communities. However, further research is required to determine where this GIS technique could add value to marine management approaches such as marine spatial planning.

In Section A, piecewise linear, nonlinear and linear techniques were compared. In Section B, only a linear version of the ‘Local Fuzzy’ function was tested, which assumed there is a linear relationship between the input scores and constraint values. Further research could compare linear and nonlinear value functions in a ‘Local Fuzzy’ technique context, as was done for the global fuzzy techniques. This would allow a better understanding of what type of value functions are appropriate for the decision situation.

As well as a fixed neighbourhood approach using the marine regions, a moving windows standardisation could also be applied to the recreational dataset to further explore and understand spatial patterns, as was done with the Scotmap dataset. To find an appropriate kernel size, per activity an estimation would be needed of the ‘home range’ typical to that activity, e.g. how far the recreational user travels to be able to do the recreational activity, and how far from the starting point the recreational user travels whilst undertaking the recreational activity.

During the data collation stage of this dataset, information was already collected from recreation and tourism-related businesses in relation to where their customers come from (e.g. from within a radius of 10 miles or from further away). Also, respondents representing recreational users/tourists were asked to indicate how much they spend per trip to the coast on diesel or bus/train fares (LUC, 2016). Further analysis/revisiting of this data can provide an indication of ‘home range’ per type of activity. For future data collection efforts, directly consulting the recreational users on what they consider their ‘home range’, can allow a parametrisation of the kernel size when applying a ‘Local Fuzzy’ standardisation approach for composing the constraint layer. The approach adopted by Acedo & Johnson, 2020, who delineated home ranges of participants by collecting information on how far they travelled for their routine activities, could be a useful starting point for this (Acedo and Johnson, 2020). In relation to the siting of novel energy developments, accounting for the home range could be useful in this context because if a novel development were to prevent recreational activities from taking place in one area, this information could enable a judgement of whether this rules out recreational activities for users, because alternative areas are too far, or whether another area close by could be used to carry out the recreational activity in instead.

5.4.4 Visualising value functions alongside output maps in an open access workflow

The open-access workflow developed in R which was used for the development and analysis of the standardisation techniques can ensure transparency of the process. The workflow, developed in the R environment, allows the user to choose between a range of standardisation techniques depending on the decision rule uncertainty inherent to the decision situation. The presentation of the mapping outputs in panels also allows easy comparisons between standardisation techniques. This can allow the tool developer to make an informed decision when choosing how to standardise input layers for use in suitability mapping.

Communicating how socio-economic data is used in decision-making was highlighted as a best practice recommendation for considering socio-economics when planning for renewable energy developments (Freeman, 2020). Transparency is also relevant to procedural justice (Jenkins et al., 2016; Ryder, 2018).

Yet even though the developed code is open access, this does not necessarily make it accessible to all interested parties. An important element of procedural justice in spatial decision support is the inclusion of local knowledge. To facilitate this, the techniques proposed in this study could be incorporated into a web tool, for example by using the 'shiny' package in R, to allow users to visualise the data in different ways and decide on a preferred technique, without needing to be familiar with the R coding environment. This would allow the social utility of the techniques to be evaluated.

Applications of fuzzy techniques in marine spatial decision support are common, especially through the use of the 'Fuzzy membership' functionality in the pay-walled ArcGIS software environment (Dias et al., 2020; Gimpel et al., 2015). This study has transferred this functionality into the open access R environment, as well as developing novel standardisation techniques to complement existing techniques already available with ArcGIS. The R environment enables a wider reach for the techniques and can facilitate a collaborative process to further improve this functionality through the sharing of the code on GitHub.

When socio-economic activities are standardised in a certain way to be included in suitability/constraint mapping, certain assumptions are made around the relationship between the intensity of socio-economic use of an area and anticipated constraint level for a proposed development. This study demonstrates that visualising spatial outputs and value functions side by side during suitability mapping can allow assumptions for both spatial and non-spatial user inputs to be made explicit during the mapping process.

The formulated value function can also be interpreted as a visualisation of the assumed trade-off relationships that would exist between existing uses and the proposed development. Trade-off relationships have been quantified before using bioeconomic modelling, by defining an objective function that was formulated to allow a maximisation of the economic value of both sectors (White et al., 2012). As opposed to bioeconomic modelling, the value functions used in this study depend on expert judgement. This allows the incorporation of non-quantifiable social values into decision support, and the form of the value function can be chosen in dialogue with interested parties so that plural values can be considered (McHarg, 1969, p. 105; Palola et al., 2022), similar to how the analytical hierarchy process method is used to determine the preferred weighting of suitability layers (e.g. Abramic et al., 2021).

As well as insights into the suitability of fuzzy techniques for incorporating decision rule uncertainty and underrepresented values into decision-making, this study also presents a workflow. This workflow allows the tool developer to explore the data that is to be incorporated into decision support and make a comparison of the different techniques available. It visualises assumed trade-offs between an emerging sector and existing activities at sea using value functions and lays out how different techniques can be explored and compared. The technique that presents the social values in the most appropriate way can be chosen in consultation with interested and potentially affected parties, so that more informed decisions can be made during the constraint mapping process.

5.5 Limitations of study

This study used a selection of socio-economic data layers to analyse their representation in the suitability mapping process. However, the actual suitability map outcome will also depend on the other layers included in the model, such as technical and environmental considerations. Future research could investigate the sensitivity of mapping outcomes to the choice of standardisation technique using a set of layers that represent a more holistic picture of the factors that are considered during the siting of offshore renewable developments.

To analyse the sensitivity of suitability mapping to differences in standardisation techniques, this study used an overlay combining 3-5 criteria layers. In practice, more than 20 different layers are usually combined to form a suitability map. The results presented here might only apply when a small number of layers are combined. Further research would benefit from a larger selection of layers in the overlays used to test the sensitivity of suitability map outcomes to the standardisation techniques.

5.6 Conclusion

Compared to onshore applications, spatial multicriteria decision analysis at sea has the added challenge of capturing uses of the marine space that are transient and dynamic (Valavanis, 2002). Taking a fuzzy, spatially explicit approach to standardisation for suitability mapping could improve the representation of these activities when finding space for emerging sectors. This study has demonstrated that a transparent decision-making process can be facilitated by combining spatial outputs of data interpretations with the use of value functions, using free software.

Making informed decisions on which standardisation technique to adopt can reduce the risk of undervaluing/overvaluing alternatives considered for site selection, which can help ensure procedural justice whilst also accommodating the achievement of energy targets. This can prevent delays and objections in the planning process. Socio-economic data layers have been called ‘the missing layer’ in marine spatial planning (A. Copping, 2019; Freeman, 2020; Gee et al., 2017; Pennino et al., 2021; St. Martin & Hall-Arber, 2008; Stelzenmüller et al., 2017; Tolvanen et al., 2019; Trouillet, 2019), and this is attributed to a lack of knowledge on how they should be interpreted and included in marine planning (Cahill et al., 2016). The findings presented here can assist future inclusion of socio-economic activities into marine spatial decision support.

6 General discussion

In this final chapter, the outcomes of the thesis are discussed in relation to the following overarching research questions:

1. What is optimal siting?
2. What data and information can be used to inform optimal siting?
3. How can this data and information be translated into spatial decision support?

The three questions are used as subheadings to discuss how the thesis addressed each one of them. Section 6.4 provides a summary of findings from the thesis and suggestions for future research. A reflection on methods developed in this thesis and their limitations is also presented, followed by an analysis of the literature this interdisciplinary thesis drew upon. The chapter ends with a final conclusion.

6.1 What is optimal siting?

Choosing a site for a novel development can be approached from different angles, as reviewed in the introduction (from a financial perspective, environmental perspective, or a marine spatial planning perspective). As well as identifying ways in which optimal siting can be achieved in Chapter 1, Chapter 2 unpicks the process itself, to enable reflection upon the different perspectives on what optimal siting entails. Chapters 3 and 4 identified that during the siting process, engagement was regarded to be as important as the decision outcome itself, such as the way in which interested parties were included. Also, design decisions, such as cable protection method and turbine layout, played as important a role as location choice.

As presented in Chapters 3 and 4, this study indicates that while the environmental impact assessment (EIA) process is suitable to understand how ecological receptors such as benthic species and seabirds could be affected by a new project, the same cannot also be said for ‘human receptors’. This framing of the two types of receptors is also relevant for the concurrent siting process, as they will be considered during the siting process with the intent of avoiding impacts. Attempting to bring these two contrasting types of receptors together within the same assessment framework of an environmental statement is felt to be problematic, due to the different theoretical perspectives relevant for the different assessment types (Moon and Blackman, 2014). The impact assessment for ecological receptors is based on natural science, where predictions are made using the scientific method, which can be interpreted as a positivist perspective on impact assessment (Crotty and Crotty, 1998; Moon and Blackman, 2014).

This perspective is not deemed appropriate for 'human receptors', for which different forms of knowledge that cannot be obtained through the scientific method might also need to be considered. This perspective is captured with the critical realism ontology, which acknowledges that a combination of different methodologies are needed to reach an understanding of the world (Mingers, 2006). Critical realism recognises that knowledge acquired through social science is context-dependent and not generalisable like knowledge acquired through natural science (Flyvbjerg, 2001; Mingers, 2006). A critical difference between natural science and social science is highlighted by Flyvbjerg, 2001, p. 33:

"the question of what are to be counted as "relevant" facts within a given discipline [within the social sciences] …is determined by both the researchers' interpretations and by the interpretations of the people whom the researchers study…The natural sciences…do not have a corresponding problem because their objects of study are not self-interpreting entities: they do not talk back"

This quote highlights how for 'human receptors', consultation steps throughout the EIA process as well as other aspects of the licensing process such as pre-application consultation, are necessary to account for procedural justice in the process. Even though the consultation steps are a key component of the EIA process, the ultimate assessment of the significance of impacts depends on magnitude of impact and sensitivity of receptor only, which accounts only for distributional justice. The assessment of the significance of impact is a key outcome of the EIA and is often used as the main form of evidence in licensing decisions, but currently mostly considers bio-economic data to account for fisheries interests – socio-economic data is underrepresented. At the strategic planning level, procedural justice and socio-economic impacts are more explicitly included in decision-making, such as through marine planning, socio-economic impact assessments or business and regulatory impact assessments.

Throughout this PhD thesis, the multiple dimensions of justice were identified as a suitable framework for interpreting optimal siting. They bring to the fore how optimal siting not only relates to the decision outcome i.e. the location, but how the siting process itself is central to optimising siting decisions. The three tenets of justice, distributional, procedural and recognitional justice, can be applied as a framework to evaluate how decision-making processes such as marine spatial planning (MSP) include and engage with interested parties, as a distinct approach to how ecological features are considered.

Despite the multifaceted nature of justice, the just energy transition agendas of governments worldwide are primarily focusing on issues directly related to industrial energy production: accommodating workers in coal and oil extracting sectors and providing access to opportunities in emerging renewable energy generation sectors (European Commission, 2020b; Just Transition Commission, 2021; The Green Tank and CEE Bankwatch Network, 2021). Space competition between emerging transition-related sectors and existing marine sectors are not specifically addressed in this context. Yet, energy justice concerns have been highlighted for the fishing industry in this thesis, as well as in other publications (Haggett et al., 2020; Rudolph et al., 2018). Competition for space is expected to increase (Jouffray et al., 2020), therefore the specific aspects of energy justice highlighted here are likely to become increasingly relevant to the future planning of marine spaces.

6.2 What data and information can be used to inform optimal siting?

Chapter 3 demonstrates that bio-economic data was not sufficient to characterise the complexities of fisheries space use and its links with onshore activities, which require an understanding of socio-economics and cultural aspects, especially for remote and island communities.

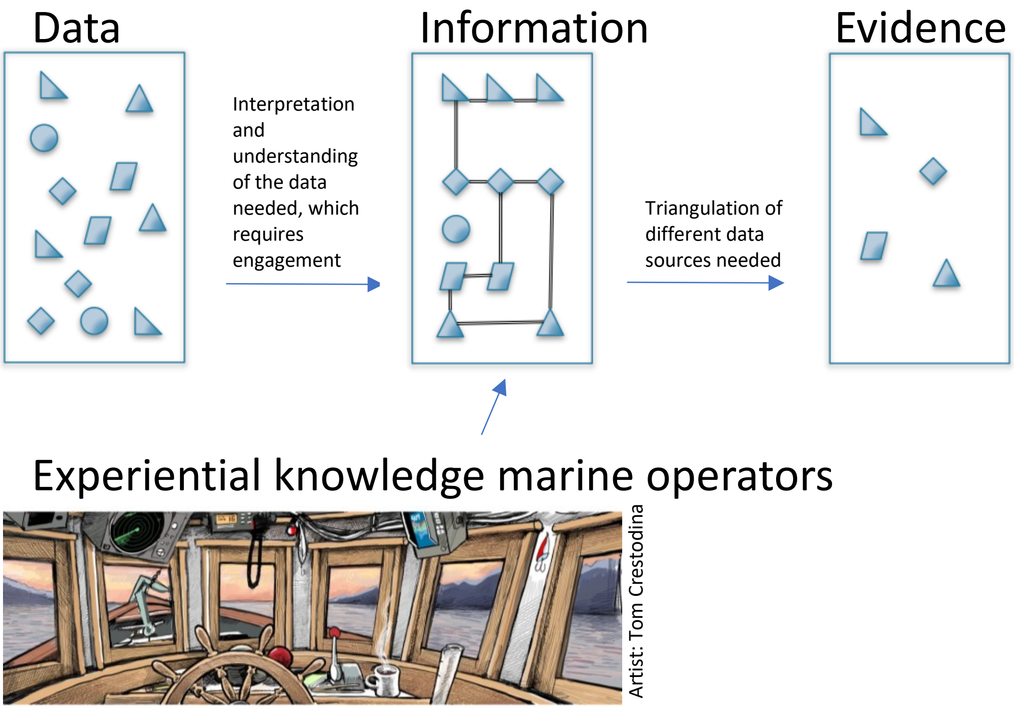


Figure 6-1 Illustration to distinguish experiential knowledge from data as two ways of gathering information, adapted from Fig 1-16. Artwork by Tom Crestodina.

Moreover, it became apparent through the research presented in Chapter 3 that an understanding of the data was as important as the availability of the data before it could successfully inform decision-making (Figure 6-1). Chapter 3 revealed that a mutual understanding between the fishing industry and the decision makers for renewable energy and cable developments enhanced procedural justice. Availability of data does not guarantee an understanding of the data, so the two are highlighted as distinct steps in Figure 6-1. This distinction also applies to the different possible interpretations of recreational use values in Chapter 5, as the same input data can be interpreted on a regional level or on a national level, leading to different representations of relative recreational value. Chapter 2 also elaborates on the distinction between data and information that can be used for decision support by outlining a set of criteria suitability indicators. The indicators can help to make the decision maker more aware of the any data limitations or assumptions. For example, spatial planning in the marine environment commonly relies on a) data that may not have been collected for that purpose and b) proxy data, so limitations need to be made explicit, highlighting the importance of the data processing step. Moreover, the framework described in Chapter 2 can inform the design of future data collection efforts that aim to inform planning decisions.

As well as acknowledging the limitations of data used for marine decision-making, some limitations can be overcome by triangulating multiple sources of information to reach a better understanding. This includes experiential knowledge held by existing marine users (Figure 6-1), who are a potential source of information pertaining to fisheries space use, the state of the seabed, the behaviour of the tides and trends in the distribution of commercial fish species, especially in a local context. The distinction between experiential knowledge and data illustrated in Figure 6-1 alludes to a critique of the information hierarchy proposed by Ackoff (Ackoff, 1989) , which implies that all knowledge comes from data, which does not hold true in all cases (Weinberger, 2010). However, as discussed in Chapter 4, similar to how data requires processing, a translation step is needed to enable experiential knowledge to be integrated into decision-making, to demonstrate its credibility.

Chapters 3 and 4 indicate that when making decisions about where to locate a novel development, if a developer only had access to data, and no members of the fishing industry were engaged with, it could lead to procedural justice concerns and, depending on the quality of the data, a lack of understanding of the fisheries potentially active in the project area. However, limitations to the capacity of members of the fishing industry to engage with developers were also identified, including a lack of time and resources. This underscores the importance of employing fisheries liaison officers by developers or their consultants, throughout the different phases of a project, who can communicate with the fishing industry and gauge if 1) there is enough available data that can be used to characterise fisheries, 2) an understanding can be reached to what the data represents and what its limitations are, and 3) the compiled information can be combined to effectively characterise fisheries space use. Chapter 4 highlighted that fisheries liaison officers were an essential link in the engagement process but were difficult to recruit locally, indicating there may be limitations to achieving this link in practice.

Chapters 3 and 4 also indicated procedural justice can be further improved when fisheries representative bodies have the capacity to manage their own database of fisheries data. In this way, they can be a point of contact early in the project planning phase to inform developers of fisheries space use. However, managing a database and being in touch frequently with the renewable energy and cable industry also requires resources, which can be more challenging for smaller-scale fisheries.

Decisions at a project level are preceded by decisions at a strategic level, and Chapter 4 indicated that at a strategic level, procedural justice for the fishing industry has improved over time. Since distributional justice for the fishing industry will be most affected by decisions at a strategic level, this aspect of procedural justice has strong links with achieving distributional justice. For Scotland’s sectoral marine plan for offshore wind, fisheries representation included involvement of representatives in the planning process as well as being represented with fisheries data in the iterative process of suitability mapping, both of which were highlighted to be essential.

6.3 How can this data and information be translated into spatial decision support?

Using suitability mapping to combine the interests of multiple species and actors when siting a development allows trade-offs between the proposed development and existing users to be integrated into the decision support in the form of value functions. This allows the optimal location to be defined with levels of suitability informed by different types of values. Economic metrics, ecological species data or recreational use values can be translated into a common indicator, allowing different interests to inform a decision. An explicit link between trade-offs and standardising layers using value functions for suitability mapping was demonstrated in Chapters 2 and 5. Chapter 5 demonstrates a technique that allows differences in values between regions to be considered, during siting at a national scale using national-scale datasets. This can improve recognitional justice for remote and island communities that may be underrepresented in national data mapping efforts.

6.4 Summary of findings and suggestions further research

Table 6-1 summarises findings and further research recommendations at the different decision-making levels, for data and information needs, and how the research can inform a just energy transition. For strategic-level decision-making, procedural and recognitional justice can be progressed using the procedural framework and fuzzy techniques developed in this thesis. At project-level, the three dimensions of justice were used to understand how existing practice fosters energy justice, and what the barriers are. The analysis of data used to inform decision-making at project level indicates that the complexity of fisheries space use requires a triangulation of data sources to be used, in combination with experiential knowledge of marine operators.

Table 6-1 Summary of key findings and research recommendations of the PhD thesis

	Key findings	Recommended further research
Strategic policy level (macro-siting)	When planning policies are applied to a spatial decision problem, they can be interpreted in different ways. Procedural framework from CH2 could be used to • increase transparency of spatial decision support tools • enhance accessibility to the siting process by establishing a clear link between objectives, how they are informed by planning policy, and how they are underpinned with data The risk of underrepresenting remote and island communities in national-level spatial decision support could be addressed using the standardisation technique developed in CH5 that elicits regional values at a national scale	• Evaluate the effectiveness of planning policies for improving spatial decision-making using the framework developed in CH2 • The marine planning process could be analysed in the same way as project level siting and impact assessment, using the justice dimensions adopted in CH4 • Further evaluate the spatially explicit and fuzzy standardisation techniques developed in CH5 using a real-life decision situation to understand further its potential applications, and develop an interactive tool for layer visualisation
Project level (micro-siting)	• As well as the siting of a development, different installation methods will have different implications for the fishing industry • Engagement by fishers is constrained by a lack of resources, which can be overcome by employing fisheries liaison officers	Framework from CH2 could be used by developers to map out how legislation has informed their siting decisions, which could inform the licence application

Table 6-1 (continued)

	Key findings	Recommended further research
Data, knowledge and evidence	• CH3 highlights the need for social data to characterise fisheries, as a complement to existing bio-economic metrics • Gaps in fisheries data can be addressed by triangulating a combination of datasets with local knowledge • Data held by fisheries representative bodies can help foster engagement as well as an understanding of the data • The increasing availability of high-quality data needs to be paired with an understanding of the complexities of fisheries space use	• Further research is needed on how triangulation of multiple data sources, also known as ensemble analysis, can be used to characterise fisheries space use more comprehensively at a project level • Investigate how links between fishing at sea and onshore communities could be represented in decision-making
Just transition	The consideration of different dimensions of justice when considering potential impacts of the energy transition to the fishing industry highlighted best practice as well as potential barriers to achieving a just energy transition Procedural justice, in terms of involving interested parties in the decision-making process concerning the development of renewables, has improved over time. However, uncertainty around the number of future projects the fishing industry will need to share the marine space was identified as a barrier to a just energy transition As well as being involved in the process and by being represented with data, procedural and recognitional justice also relate to a mutual understanding between two sectors interested in the same space, and an understanding of the data	Apply the framework from CH4 to other case studies to further understand how it can be used to evaluate the justness of the energy transition As well as a qualitative analysis, context-dependent indicators per justice dimension could allow a comparison between case studies and a comparison over time

6.5 Reflection on adopted research methods

The research questions this PhD thesis sought to answer are applied in nature, as they relate to processes that are currently on-going around the world, a type of research also known as ‘real world research’ (Robson & McCartan, 2016). This thesis sought to understand how decisions in the marine planning, consenting and licensing were approached, including the challenges and opportunities involved to further embed concepts of justice into the decision-making process. Specific chapters as well as the PhD thesis overall adopt a mixed method approach, recognising that the siting of proposed offshore renewable energy and cable developments is a complex problem that requires an understanding of multiple perspectives (Bryman, 2006; Robson and McCartan, 2016; Whyte and Thompson, 2012). Table 6-2 gives an overview of the main methods adopted throughout this PhD thesis, with an evaluation of their strengths and challenges.

Findings in this PhD thesis were obtained through five main methods: framework development and application, case study analysis, document analysis, semi-structured interviews and GIS analysis. To take advantage of existing research from multiple disciplines, frameworks developed for this thesis allowed unique in-depth analysis of current practice. Focusing this analysis on real-world case studies allowed research findings to be grounded in their context. The fast-moving nature of the focus of research required the author to be up-to-date with current affairs regarding interactions between energy projects and the fishing industry. Even though publicly available documents do not represent all aspects of a decision-making process, they provided a valuable resource to understand the role of data and engagement in practice. Complementing this data source with semi-structured interviews provided the opportunity for the author to relay back their understanding of the process to the interviewees who were experts, to ensure a thorough understanding of the context. Finally, GIS analysis allowed an exploration of the techniques that can be used to include socio-economic values in spatial decision support.

Table 6-2 Evaluation of the mixed methods adopted in this PhD thesis

	Overview	Strengths	Challenges
Framework development (CH2, CH3-4)	Frameworks have been developed in this PhD thesis as a research output (CH2), to evaluate case studies quantitatively (CH3) or as a conceptual lens used to organise research results (CH4).	Ability to combine existing research from multiple disciplines to develop a lens that enables an in-depth analysis of the research questions at hand.	Novel frameworks are not as stable as existing frameworks; they might need to be adjusted when a novel application of the framework presents previously unnoticed limitations.
Case study analysis (CH2, CH3-4)	In CH2, two case studies are used to illustrate the application of a newly developed framework. In CH3-4, a selection of 21 case studies was used to understand the consideration of fisheries during project planning.	Reflection on the relevance of research results for the considered case studies is an integral part of this PhD thesis, which constantly requires the researcher to be conscious of the context in which the studied processes find themselves in.	The fast-moving nature of the research topic means findings related to previously consented projects may not be relevant anymore, as legislation may have already moved on, so the researcher must stay on top of changes in the legislation relevant to the siting of new projects and the consideration of fisheries.
Quantitative and qualitative document analysis (CH3-4)	Publicly available documents pertaining to the strategic siting process for renewable and cable developments in Scotland, as well as project-specific documents, were analysed using both a quantitative scoring framework and a qualitative grounded theory approach.	The large number of available documents provide a valuable source of information on the siting process as well as the different perspectives of different involved parties. It allowed the consideration of empirical knowledge.	Projects or parts of the process that were not publicly available may be underrepresented in the research findings, and project documents mostly represent the perspective of the developer. Therefore, the context of the documents was kept in mind when interpreting the results.

Table 6-2 (continued)

	Overview	Strengths	Challenges
Semi-structured interviews (CH3-4)	Semi-structured interviews with a balanced range of involved actors were conducted to understand different perspectives on the siting process.	Insights from the interviews allowed the project documents of the case studies to be placed into context, and conversations with participants enhanced the level of understanding of the process at hand.	The conversations held with participants related to past and upcoming energy developments. Due to the novel nature of this process of finding space at sea for projects, some interviewees retrospectively changed their views after the interview, which allowed a longitudinal perspective but also required a reinterpretation of the results.
GIS analysis (CH5)	Open-access data was used to compare standardisation techniques for incorporation of data into suitability mapping.	The techniques were developed and analysed using open access R software, allowing reproducibility of both the results and the novel techniques.	Some of the datasets had high resolutions which led to long processing times, so large datasets were reduced to lower resolutions to ease processing of operations for the computer.

6.6 Analysis of bibliography

This PhD thesis drew on literature from marine science (including marine policy and management), social science, environmental impact assessment and research on energy and renewable energy (Figure 6-2).

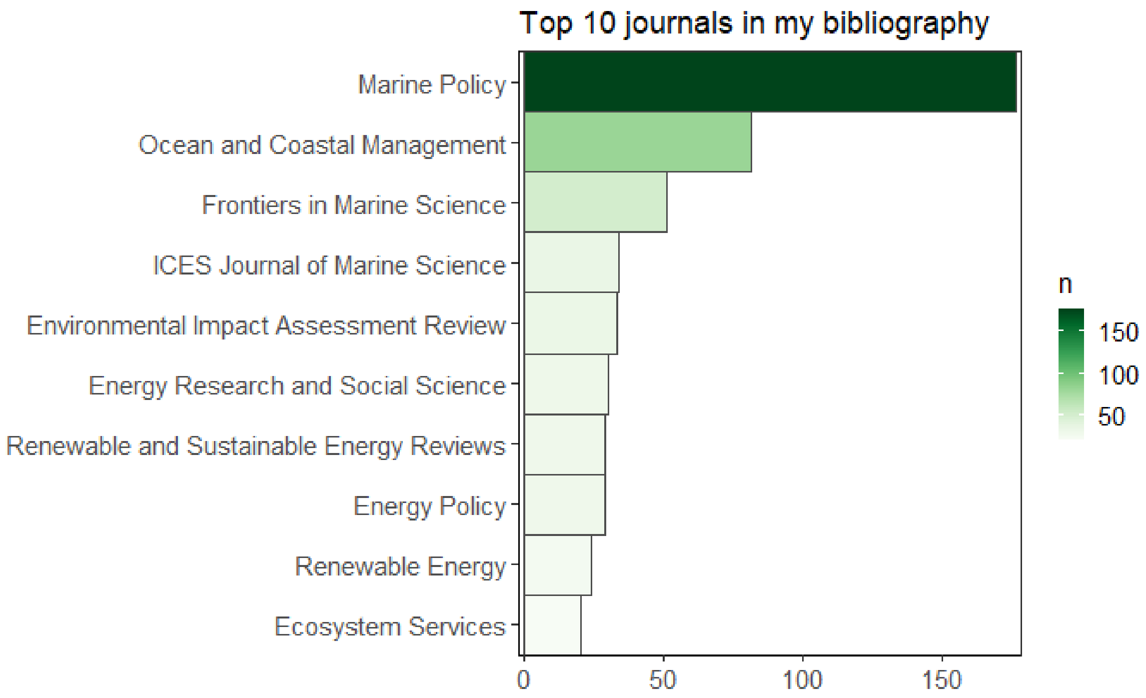


Figure 6-2 Top 10 journals found in reference list (method: Louveaux, 2018)

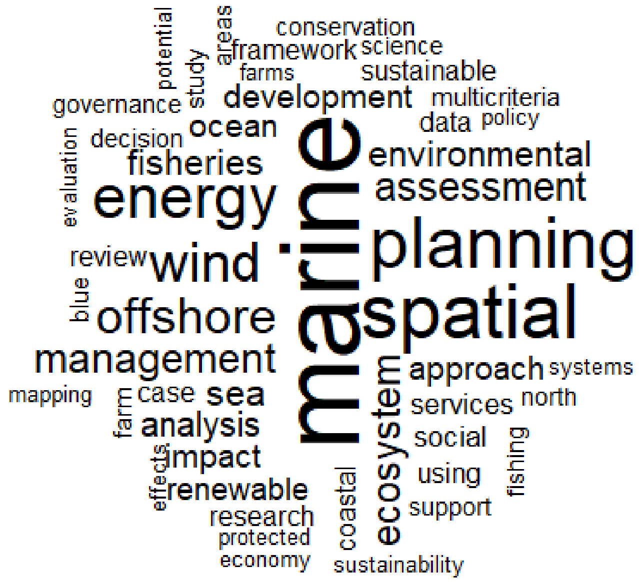


Figure 6-3 Word cloud with 50 most frequent words in the titles of academic articles included in the reference library (method: Louveaux, 2018)

Figure 6-3 shows the 50 most frequent words found in the titles of the publications in this reference list. Terms indicate the focus on renewable energy, environmental aspects, decision-making and sustainability. The unique aspect of this PhD thesis is that research on governance and environmental impact assessment aspects of planning were combined with more technical multi-criteria and spatial decision-making elements. In this way, practical implementation of key findings stemming from this PhD thesis can improve the consideration of future trade-offs between emerging sectors and existing users of the marine space.

6.7 Concluding summary and relevance to other geographic areas and sectors

To conclude, as we seek to achieve a just transition to net zero, the findings of this PhD thesis identify three key considerations within the decision-making processes of energy infrastructure siting:
1) the multifaceted concept of justice is a useful framework to analyse how a just energy transition can be achieved in the face of increased space competition at sea;
2) policies and data can be interpreted in different ways, resulting in differences in perceived 'optimal siting', and these differences can be revealed by placing the siting process in a step-by-step framework, and;
3) effective siting is equally informed through interested parties participating in the process as well as the available data.

While the focus of this PhD thesis was on decision-making related to Scottish waters, outcomes can also be applied to the Celtic Sea, Irish Sea and other areas where similar processes are emerging. As increased space competition between the energy industry and existing marine users is anticipated, the techniques and frameworks developed in this PhD thesis can help ensure energy justice is explicitly accounted for during the siting of novel developments. Just and inclusive decision-making can foster a better mutual understanding between emerging and existing sectors of the blue economy. This has the potential to prevent conflicts in the future and facilitate a just energy transition towards renewable sources.

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Appendices

App. 3.1 Evaluation framework

Indicator 0: Guidance used

Specific attention will be given to whether or not the guidance used to build this framework has been cited, to gauge their relevance to the impact assessment. This refers to the following guidance documents:

FLOWW reports (FLOWW, 2014, 2015)

FIS project (Batts et al., 2017b, 2017a; Shelmerdine et al., 2017)

Document produced by Seafish and UKFEN (Seafish & UKFEN, 2012)

Mitigation guidance from COWRIE project (Blyth-Skyrme, 2010)

Others (specify)

A score of one will be given if the guidance is included, and 0 if it’s not (however, this indicator will not contribute to the total score).

Theme 1: Evidence base

Fish and shellfish receptor

Indicator 1.1: Consideration natural variation fish and shellfish

#	Indicator	Points	Type of scoring
1.1	**Natural variation in distribution of fish/shellfish resource**		**Score between 0-3**
	Not mentioned	0	
	Mentioned but not quantified/specified	1	
	Quantified/specified for some species	2	
	Quantified/specified for all commercial species	3	

Commercial fisheries receptor

Indicator 1.2: Fleet composition

A: Small vessels

#	Indicator	Points
1.2A	**Information on home port of small vessels**	
	Home port of <12m vessels not specified	0
	Home port of <12m vessels not specified, and this is justified	1
	Home port of >12m vessels specified for some vessels	1.5

	Home port of <12m vessels specified	2

B: Large vessels

#	Indicator	Points
1.2B	**Information on home port of large vessels**	
	Home port of >12m vessels not specified	0
	Home port of >12m vessels not specified, and this is justified	1
	Home port of >12m vessels specified for some vessels	1.5
	Home port of >12m vessels specified	2

Indicator 1.3: Spatiotemporal footprint

#	Indicator	Points	Type of scoring
1.3.1	**Spatial resolution vessel activity**		**Score between 0-4**
	Not documented	0	
	Not documented, and this is justified/general ref	1	
	ICES grid square resolution with general (not mapped) references to details within squares	2	
	Finer gridded resolution	3	
	Anonymised vector data	4	
1.3.2	**Spatial extent vessel activity**		**Score between 0-3**
	Not documented	0	
	Not documented, and this is justified	1	
	Spatial extent limited to immediate area of development (proposed intervention area)	2	
	Spatial extent broader than immediate area of development only and justified	3	
1.3.3	**Temporal resolution vessel activity**		**Score between 0-4**
	Not documented	0	
	Not documented, and this is justified	1	

	Data has a high temporal resolution but temporal variation not considered/year-year variation only (<5 years)	1.5	
	Seasonality of vessel activity considered	2	
	Seasonality of vessel activity considered with spatial data	3	
	Multi-annual natural variation considered (>5 years)	4	
1.3.4	**Temporal extent vessel activity**		**Score between 0-3**
	Not documented	0	
	Not documented, and this is justified	1	
	Data considered for one year only	2	
	Data averaged over multiple years	3	

1.3.5	**Fisheries activities specified per gear type?**		**Score between 0-3**
	Not documented	0	
	Not documented, and this is justified	1	
	Specified to some degree, but an explanation is given for why it's not fully considered separately	2	
	Landings and fishing activity are specified per gear type	3	
1.3.6	**Fisheries activities specified per species?**		**Score between 0-3**
	Not documented	0	
	Not documented, and this is justified	1	
	Species specified to some degree (for some species)	2	
	Species/species groups specified	3	
	Effort/landings – data used		**Checklist**
1.3.7.1	Landings per ICES rectangle	1	
1.3.7.2	VMS data	1	

1.3.7.3	AIS data	1	
1.3.7.4	Data (AIS/VMS) specified per vessel size	1	
1.3.7.5	SAR data	1	
1.3.7.6	Days at sea (effort)	1	
1.3.7.7	Average price per tonne landed (value)	1	
1.3.7.8	Effort/landings information collected with stakeholders	1	
1.3.7.9	Surveillance sightings	1	

Indicator 1.4: Socioeconomics

#	Indicator	Points
1.4.1	**Proportion of fisheries income disrupted by intervention?**	
	No data	0
	No data but justified	1
	Qualitative data	2
	Quantitative data	3
1.4.2	**Indicators included that will influence alternative opportunities (e.g. vessel safety, accessibility alternative areas, ability to change gear, …)**	
	No data	0
	No data but justified	1
	Qualitative data	2
	Quantitative data	3
1.4.3	**Benefits of development (for fisheries) described? (e.g. closure)**	
	No data	0
	No data but justified	1
	Qualitative data on a national scale	2
	Benefits described in relation to the scale of the proposed development	2.5
	Benefits described in relation to the scale of the proposed development, fish stocks and fishing vessels, including gear type used	3
1.4.4	**Number of fishers employed that will be affected**	

	Not mentioned	0
	Not mentioned and justified	1
	Included	2
	Specified per home port	3

1.4.5	**New employment opportunities**	
	Not mentioned	0
	Not mentioned and justified	1
	Included	2
	Specified per home port	3
1.4.6	**Number of jobs/businesses in the supply chain industry that will be affected**	
	Not mentioned	0
	Not mentioned and justified	1
	Included	2
	Specified per home port	3
1.4.7	**Processing sector costs and earnings (e.g. from Seafish data)**	
	Not mentioned	0
	Not mentioned and justified	1
	Included	2
	Specified per home port	3
1.4.8	Number of crew	1
1.4.9	Number of full-time equivalent jobs per vessel	1
1.4.10	Fishing Income data	1

Theme 2: Data quality

Table 3 Pedigree matrix using four data quality indicators. Scores can be assigned from 0-3 for four variables

	0	***1***	***2***	***3***	***Based on***
Evidence (E)	Data source not mentioned	Data from an authoritative source (e.g. ICES) but not visibly verified by local stakeholders/other local sources	Data visibly verified with local stakeholders/other local sources (score of 1.5 for verification with a non-local source)	Measured (not modelled) and locally verified data	(Issaris et al., 2012; Stelzenmüller et al., 2015)
Recognized uncertainty (U)	Data limitations and uncertainties not mentioned	Acknowledged data limitations and uncertainties	Quantified data limitations and uncertainties	Compounding error from analysing multiple datasets with (known) uncertainties acknowledged	(Funtowicz & Ravetz, 1990; Shucksmith et al., 2014; Stelzenmüller et al., 2015)

Spatial dimensions (S)	Unknown or uncertain extent and location details	Neither location nor extent are identifiable to a reasonable degree of accuracy	Location or extent accurately identified, but not both	Both location and extent accurately identified	(Shucksmith et al., 2014)
Timeliness (T)	Older than 10 years/not mentioned	Older than 5 years	Older than 2 years	Within last two years	(Shucksmith et al., 2014)

Theme 3: Impact assessment commercial fisheries

For the assessment of direct effects on the fishing industry, the guidance document composed by Seafish and UKFEN have summarized different impact assessment techniques. In this table, they evaluate each technique based on the advantages and disadvantages (Seafish & UKFEN, 2012). Based on these recommendations, a score has been assigned to each technique. These scores will be used for this indicator. If more than one technique is used, the scores can be added up cumulatively.

#	Technique	Score according to recommendation UKFEN
3.1	Proportional area technique	0.5
3.2	Effort as a proxy for landed value	2
3.3	Effort as a proxy for financial performance	2
3.4	Consultation approach	2.5
3.5	Resource valuation	2.5
3.6	Direct method	2
3.7	Other (e.g. CBA)	

App. 3.2 Codebook interview analysis chapter 3

This table lists the codes used to analyse the interviews. The codes are defined according to the different themes, categories and indicators of the evaluation framework used for the document analysis.

Code			Reference (literature or guidance document)	Description
Theme	**Receptor**	**Category**		
Evidence base	Fish and shellfish	Consideration natural variation	Willsteed et al., 2018	Comments on changes in fish stocks
Evidence base	Commercial fisheries	Fleet composition	FLOWW, 2014, Reed *et al.*, 2011; Batts *et al.*, 2017b), St. Martin and Hall-Arber, 2008; Yates and Schoeman, 2013, Blyth-Skyrme, 2010	Comments on which vessel types are engaged in fishing in the area, e.g. large or small vessels, or where their home port is
Evidence base	Commercial fisheries	Spatiotemporal footprint – spatial resolution	Batts et al., 2017, Shelmerdine et al., 2017, Seafish and UKFEN, 2012; Janßen *et al.*, 2018; Trouillet *et al.*, 2019,	Comments on fisheries data, specifically on the granularity of the data, whether or not it is possible to ascertain details in spatial fishing patterns
Evidence base	Commercial fisheries	Spatiotemporal footprint - spatial extent	Willsteed et al., 2018, Seafish and UKFEN, 2012	Comments on fisheries data and whether it encompasses a wide enough study area or not
Evidence base	Commercial fisheries	Spatiotemporal footprint – temporal resolution	Shelmerdine et al., 2017, FLOWW, 2014	Comments on fisheries data and the importance of being able to draw out differences in fishing patterns over time
Evidence base	Commercial fisheries	Spatiotemporal footprint – temporal extent	Willsteed et al., 2018, Seafish and UKFEN, 2012	Comments on fisheries data and which time scale should be used to characterise fishing patterns (e.g. over five years or over 15 years)

Code			Reference (literature or guidance document)	Description
Theme	Receptor	Category		
Evidence base	Commercial fisheries	Spatiotemporal footprint – gear type specified	Shelmerdine et al., 2017, St. Martin and Hall-Arber, 2008	Comments on fisheries data and the relevance of specifying gear type
Evidence base	Commercial fisheries	Spatiotemporal footprint – target species specified	Shelmerdine et al., 2017, St. Martin and Hall-Arber, 2008; Shucksmith and Kelly, 2014; Bartelings *et al.*, 2015	Comments on fisheries data and the relevance of specifying target species
Evidence base	Commercial fisheries	Spatiotemporal footprint – data types	Shelmerdine et al., 2017, Seafish and UKFEN, 2012	Comments on fisheries data types that ought to be included in the characterisation
Evidence base	Commercial fisheries	Socio-economics - general	Blyth-Skyrme, 2010, MS-LOT, 2018; ScotMER, 2018, de Groot et al., 2014; MS-LOT, 2018; Scholz et al., 2011; St. Martin and Hall-Arber, 2008.	General comments on the relevance of socio-economics during fisheries characterisation in the context of finding space for novel developments at sea
Evidence base	Commercial fisheries	Socio-economics – supply chain	Tegelskär Greig, 1999; Alexander, Wilding and Heymans, 2013; de Groot *et al.*, 2014, Seafish and UKFEN, 2012	Comments on the relevance of considering the supply chain during the characterisation
Evidence base	Commercial fisheries	Socio-economics – processing sector	Tegelskär Greig, 1999; Alexander, Wilding and Heymans, 2013; de Groot *et al.*, 2014, Seafish and UKFEN, 2012	Comments on the relevance of considering the processing sector
Data quality	Fish and shellfish	Evidence	Issaris et al., 2012; Stelzenmüller et al., 2015	Comments on the quality of the data used to characterise fish and shellfish
Data quality	Fish and shellfish	Recognised uncertainty	Bijlsma et al., 2011; Funtowicz and Ravetz, 1990; Shucksmith et al., 2014; Stelzenmüller et al., 2015	Comments on the consideration of data uncertainty associated with fish and shellfish data included

Code			Reference (literature or guidance document)	Description
Theme	Receptor	Category		
Data quality	Fish and shellfish	Spatial dimensions	Shucksmith et al., 2014	Comments on the consideration of spatially explicit data on fish and shellfish occurrence
Data quality	Fish and shellfish	Timeliness	Shucksmith et al., 2014	Comments on how recent the used fish and shellfish data is
Data quality	Commercial fisheries	Evidence	Issaris et al., 2012; Stelzenmüller et al., 2015	Comments on the quality of the data used to characterise commercial fisheries
Data quality	Commercial fisheries	Recognised uncertainty	Bijlsma et al., 2011; Funtowicz and Ravetz, 1990; Shucksmith et al., 2014; Stelzenmüller et al., 2015	Comments on the consideration of data uncertainty associated with commercial fisheries data included
Data quality	Commercial fisheries	Spatial dimensions	Shucksmith et al., 2014	Comments on the consideration of spatially explicit data to characterise commercial fisheries
Data quality	Commercial fisheries	Timeliness	Shucksmith et al., 2014	Comments on how recent the used commercial fisheries data is
Impact assessment	Commercial fisheries	-	Seafish and UKFEN, 2012	Comments on the way potential impacts on the commercial fisheries industry are assessed

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App. 3.3 Interview guides

Government stakeholders

What do you think about the data sources used in the fisheries characterisation and how their limitations are acknowledged?

Was sufficient data on inshore fisheries included?

Is there any data missing during siting you think should be included?

Do you think there would be value in having more data available on the link between the affected fishing fleet and onshore buyers and processors?

If yes, at what stage in the project could this be relevant?

Fisheries stakeholders

What is the role of fisheries data in representing fishing interests?

Do you think impacts can be avoided through better siting informed by fisheries data?

To what extent can (static) spatial data capture the dynamics of the fishing industry?

Do you think there would be value in having more data available on secondary economic impacts on hosting ports of the affected fleets?

If yes, at what stage in the project could this be relevant?

Developers

How does fisheries data inform the site selection for a project?

Was sufficient data on inshore fisheries available?

Is there any data missing you think could be included?

Do you think there would be value in having more data available on secondary economic impacts on hosting ports of the affected fleets?

If yes, at what stage in the project could this be relevant?

App. 3.4: Application for ethical approval

Application to the UHI Research Ethics Committee

Application number: OLETHSHE1848

Research Outline

Participant Information Sheet

Consent form

Research outline

Evaluating the current use of fisheries data in siting and impact assessment of marine energy developments

Executive summary

When offshore energy developers want to install infrastructure at sea, they will have to consider the existing users of the marine space. One ubiquitous and long-standing user of the sea is the fishing industry. The way they are incorporated in the site selection process and the environmental impact assessment of the development is influenced by the data that is being used to represent them.

This study will evaluate how fisheries data is currently being used in site selection and environmental impact assessment of offshore developments, including subsea cables, offshore wind, wave and tidal energy infrastructure. A textual analysis using an evaluation framework will be used to evaluate a range of case studies, as well as semi-structured interviews with the relevant stakeholders (fisheries, the developer, the licensing authority).

The outputs from the interviews as well as the textual analysis will be compared with existing literature on the topic. The aim is to find out how different industries (subsea cables, offshore wind, ocean energy) make use of fisheries data, and what the limitations are to the fisheries data currently being used. This will inform a tool that aims to optimise the siting of offshore energy developments, which will specify what kind of fisheries data needs to be included during the decision-making process.

Rationale

In order for economies to reduce dependency on fossil fuels, turning to renewable energy is a necessity (Gasparatos *et al.*, 2017). Investments become financially attractive when economies of scale can take effect (Heery and Noon, 2008). In the case of wind energy, there is more space for this offshore than onshore (Leung and Yang, 2012). Another advantage of offshore renewable energy is its proximity to coastal demand centres (Poudineh, Brown and Foley, 2017). However, financial burdens in the form of delays persist, hindering the 'green' transformation of the electricity generation sector (O'Hagan, 2012). One cause of delays is objections of stakeholders to the project (Martino, Tett and Kenter, 2019).

Stakeholders is a term that can be used to refer to either individuals or organisations that are affected, involved or interested in a new development. Stakeholders can be classed as industry (fisheries, aquaculture, other energy industry developers such as oil & gas, tourism, …), government bodies or agencies or civil society (NGOs, citizen organisations, research community) (Fig. 1, Zaucha and Gee, 2019, chap. 13).

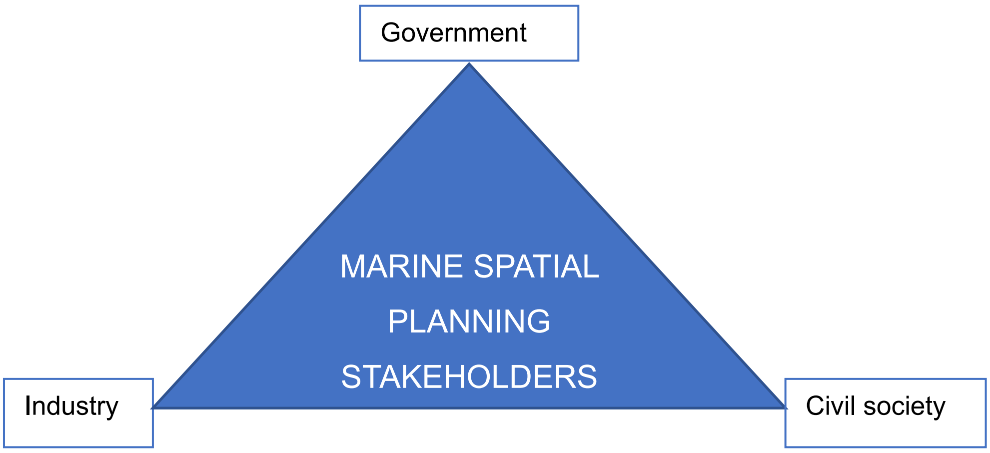

Figure 1 Types of stakeholders (Zaucha and Gee, 2019, chap. 13)

Industry stakeholders that also make use of marine space can be split up into traditional sectors and emerging sectors, see Fig. 2.

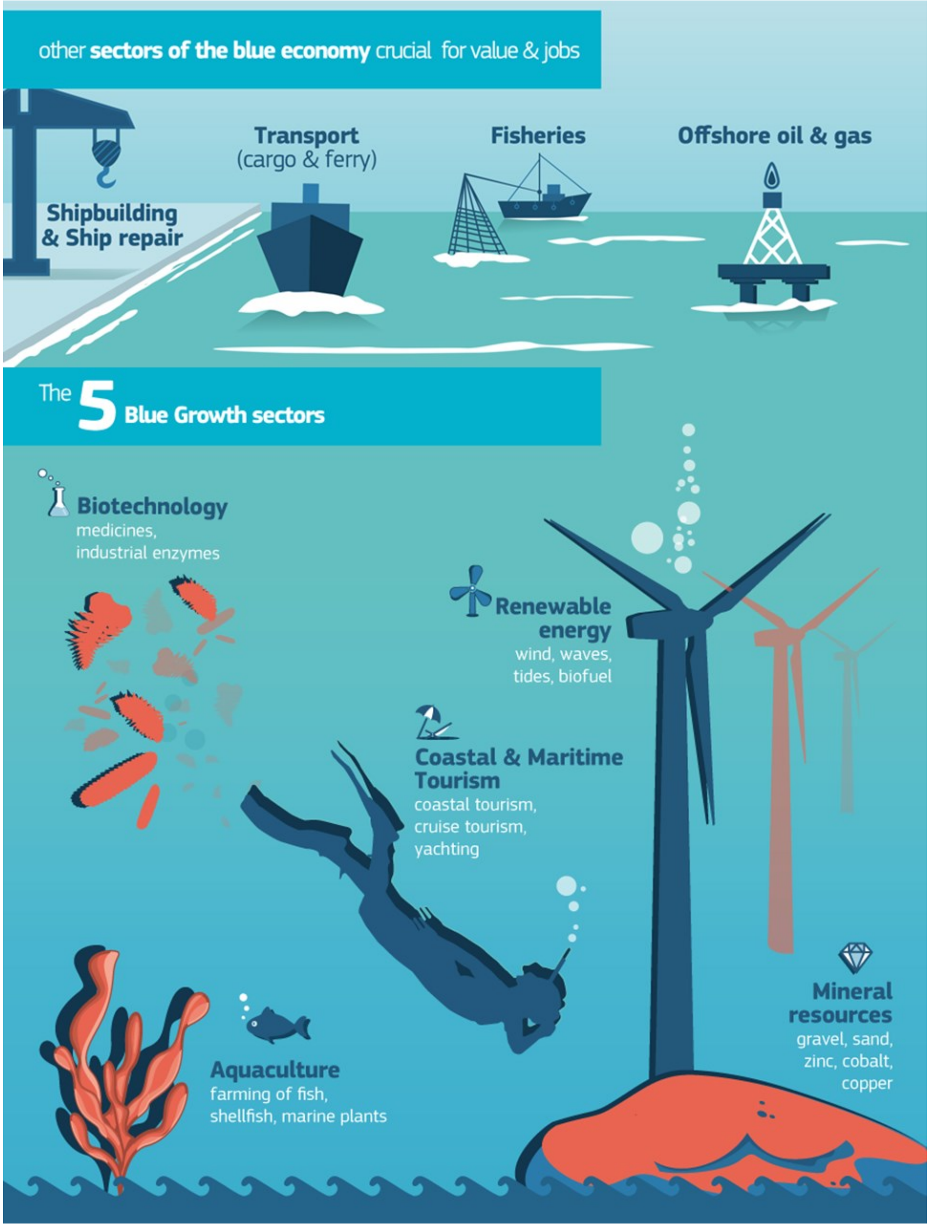

Figure 2 Traditional blue economy sectors and the five emerging sectors according to the European Commission (European Union, 2014 https://ec.europa.eu/assets/mare/infographics)

This study will focus on fisheries as an industry stakeholder, one of the traditional blue economy sectors. One of the reasons for this is that the inclusion of fisheries stakeholders in the site selection process depends heavily on data, which may be missing or at the wrong scale. This is because fisheries are very dynamic in both space and time, in contrast to more static industries such as aquaculture (their activities revolve around fixed sites). Another use of marine space is for recreation, but this is usually limited to near-shore activities, whereas fisheries extend further offshore as well - they are more ubiquitous.

With regards to an offshore development, the location of the project may result in a loss of access by fishers to their fishing grounds (Gray, Haggett and Bell, 2005; Haggett, 2011).

Following the mitigation hierarchy, an approach applied in impact assessment, it is in the interest of marine developers to avoid impacts (the first step in the mitigation hierarchy) by using the best information available on existing activities at the proposed site. Site selection for developments needs to be underpinned with additional data (Reilly, 2017).

It is considered that financial compensation should be the last resort when there is an impact on a receptor (Glasson, Therivel and Chadwick, 1999). This is in the interest of the receptor (such as the fishing industry), but also for the developer. For energy companies, voluntary financial compensation will be incurred as a cost that will lower their profits and potentially put the commercial viability of the project at risk. Alternatively, this added cost is transferred to the bill payer, increasing the price of the energy provided. However, bill payers include people with a low income, who may already suffer from energy poverty. For this reason developers feel pressured to keep electricity bills as low as possible (Hooper, Ashley and Austen, 2015).

This study aims to look into the current challenges of using fisheries data to avoid impacts and identifying impacts on the fishing industry of potential offshore energy infrastructure sites. In this introduction, the siting and impact assessment process will be explained, as well as possible effects of offshore energy developments on fisheries. Then, the importance of identifying fisheries impact at the scale of fisheries dependent communities will be outlined. This will be linked with the challenges to characterising spatial fisheries activities, followed by an explanation of the importance of stakeholder engagement, and considering existing constraints.

The site selection process

The site selection process can be split up into macro-siting and micro-siting. Macro-siting is where potential locations are reviewed on a national level, and then a particular region is chosen. Consequently, micro-siting is where the specific locations of the turbines are selected within a selected region. For this, more detailed local data is collected (Scottish Power Renewables, 2010).

Different types of energy developments are sited in different ways, also depending on the scale of the infrastructure. For commercial-scale offshore wind farms, the

Crown Estate organizes leasing rounds (see Table 1) for the macro site selection process. The last UK-wide leasing round, round 3, allowed developers to choose a location within allocated zones. These zones have been delineated based on wind energy resource and minimal existing constraints such as protected habitats and fishing grounds. Within a zone developers have room to choose a more specific location. This can be assisted by Zonal Appraisal and Planning (ZAP), a concept outlined by The Crown Estate which takes place on a scale that lies between macro-siting and micro-siting. ZAP allows developers to select suitable wind farm sites within a zone in a systematic way, by also involving stakeholders early on in the decision-making process.

For the Scottish Territorial Waters leasing round, the Scottish Government provided 9 options for wind farm development, based on a sectoral marine plan for offshore wind energy, "Blue Seas Green Energy" (The Scottish Government, 2011). These options are smaller in area than the allocated zones for round 3, so no ZAP is required.

Table 1 Leasing rounds for offshore wind energy developments by the Crown Estate (Flood, 2012)

	Award Date	Capacity	
Round 1	April 2001	15 projects	1.6 GW in total
Round 2	December 2003	15 projects	7.3 GW in total
Round 1 / 2 Extensions	May 2010	4 projects	1.6 GW in total
Scottish Territorial Waters	January 2009	5 projects	4.8 GW in total
Round 3	January 2010	9 Zones	>32 GW in total

For wave and tidal projects, the scale of the development is significantly smaller, so less guidance is provided for developers on a national/regional level. It is expected that the developer will do an assessment on a national scale for suitable locations (macro site selection), as well as the micro-siting.

For subsea cables, the siting depends first and foremost on the two endpoints of the cable. A cable route study investigates and proposes a route between those two endpoints. Through an iterative process based on desk analysis and data collection this route is refined and adjusted until specific locations have been decided upon.

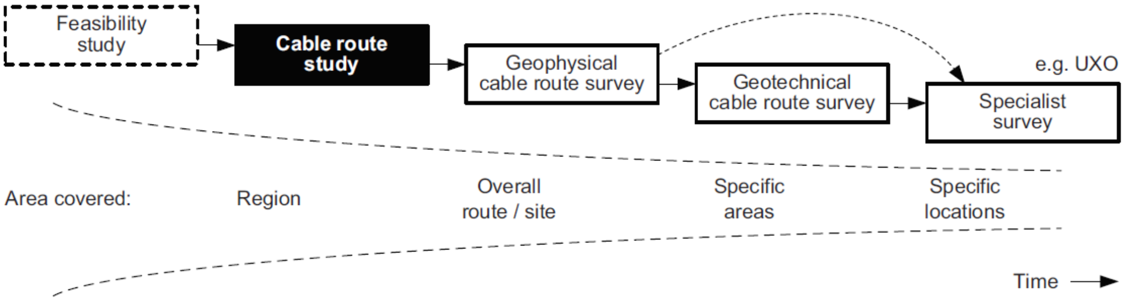

Figure 3 Cable site selection process (Det Norske Veritas AS, 2014, fig. 3.5)

The impact assessment process

Once developers have decided on an approximate site for their development, they have to apply for a license from the relevant authorities. In Scotland, this jurisdiction lies with the Marine Scotland Licensing Operations Team (MS-LOT), who act on behalf of Scottish Ministers. As per the Environmental Impact Assessment (EIA) Directive of 2014, projects falling under the category of Annex II (including transmission cables, the harnessing of wind power and hydroelectric energy production[15]) are subject to member state legislation regarding whether or not an EIA should be included in the consent application (European Commission, 2014).

An EIA is a process designed to examine and predict possible environmental effects of implementing a project, including socio-economic impacts (Glasson, Therivel and Chadwick, 1999). It usually results in an Environmental Statement (ES) which consists of different chapters, including a chapter on site selection and a chapter on the prediction of impacts on commercial fisheries. Even though siting decisions have been made prior to the environmental impact assessment, siting is an iterative process so further refinements will be made during the EIA. These siting decisions will have to be justified in the ES. The impact assessment will predict impacts on various receptors of placing the development at a certain site, however the site is usually described in broad terms to allow small-scale spatial

[15] Submarine electricity cables do not fall under either Annex 1 or Annex 2. Submarine electricity cables are defined here as cables that carry electricity from the substation to the consumer, while transmission cables are used to help move electricity from a power plant to the substation (https://circuitglobe.com/difference-between-transmission-and-distribution-line.html)

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adjustments to be made at a later stage, part of an approach called the 'Rochdale Envelope' (Wright, 2014). Therefore, the siting of a development and the impact assessment of a development are two processes that happen simultaneously so should be considered together.

EIA is mandatory in Scotland for offshore renewable energy projects generating more than 1MW (The Scottish Government, 2014). As well as that, it has to comply to a range of policy measures, including those set out in Scotland's National Marine Plan (Seagreen, 2018). For smaller projects, a screening opinion from the relevant regulatory authorities will determine whether an EIA is required (Fig. 4). If the authorities decided it is not mandatory, an assessment may still be done by the developer on a voluntary basis, in the form of an environmental appraisal (EA), environmental supporting information (ESI) and/or an environmental management plan (EMP). These non-statutory environmental studies are subject to different regulations than an environmental impact assessment. For the purpose of this study, 'assessments' will be the overarching term used to refer to EIAs, EAs, ESIs and EMPs.

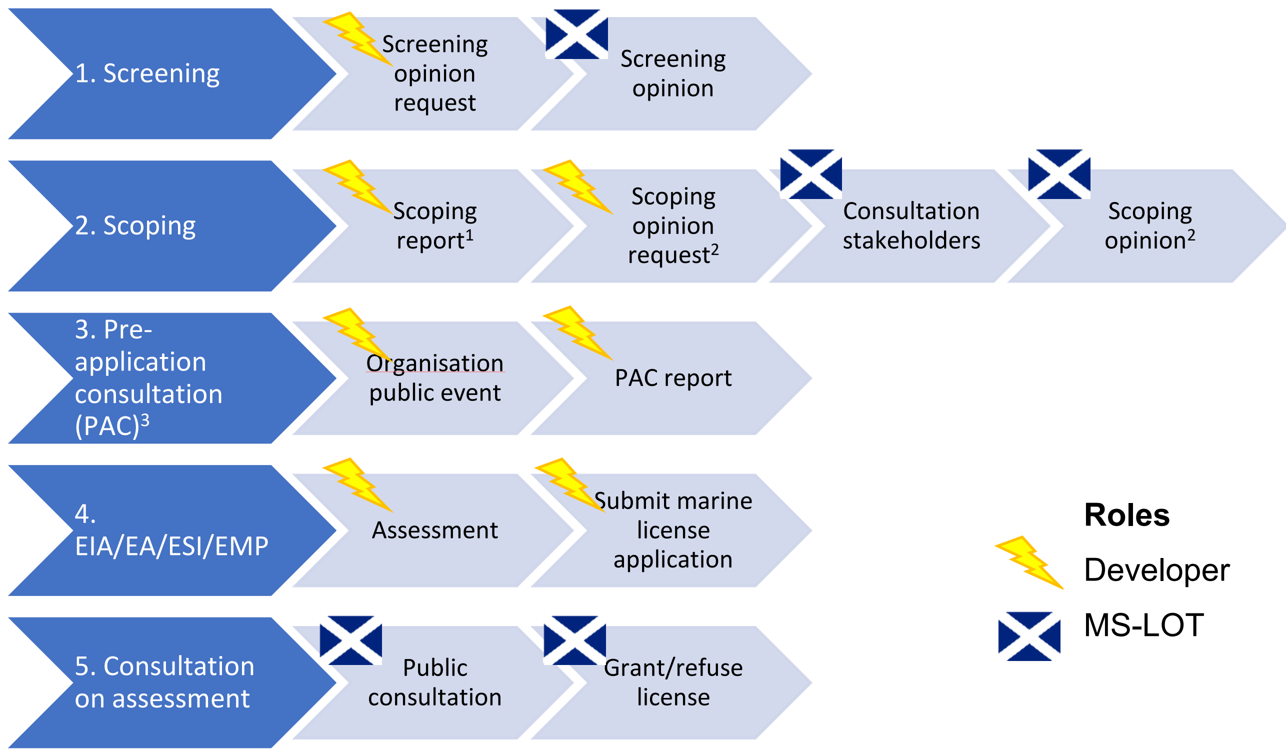

Figure 4 Overview of the consenting process for marine energy developments (EIA: environmental impact assessment. EA: environmental appraisal. ESI: environmental supporting information. EMP: environmental management plan)

[1] For studies not requiring an EIA, this may be called “Report identifying additional studies required”

[2] For studies not requiring an EIA, the equivalent of a scoping opinion may be called “Opinion on report identifying additional studies required”

[3] Not compulsory for smaller-scale projects (see text)

First, during the scoping stage, developers will investigate which impacts should be considered in the assessment, and how. Existing marine spatial plans and marine management measures implemented in the proposed area can help developers collect information on existing users of marine space whilst avoiding the cost of primary data collection (Kelly *et al.*, 2014; Crowther and Gray, 2016; Ryan *et al.*, 2019). Additionally, the fishing industry can provide knowledge and data as well as advice on impact assessment methodology (FLOWW, 2014). Potentially significant effects are identified by the developer in a scoping report. This report is examined by the MS-LOT, for which they also consult relevant stakeholders. Their feedback is published in a scoping opinion (The Scottish Government, 2018).

As well as a scoping report, a pre-application consultation (PAC) is mandatory in Scotland since 2014 for certain marine licensable activities. These include placing subsea cables longer than 1853 m and renewable energy installations that take up an area>10 000m^2. A pre-application consultation includes organizing at least one public event where local stakeholders can comment on the proposed development. A pre-application consultation report should summarize this public event and include any amendments to the design or location of the prospective development made based on the feedback received, or justify why some suggestions were not taken into account (MS-LOT, 2013).

After the scoping and PAC, developers can start the environmental impact assessment on the scoped in impacts, which can take between 2-5 years (Enablers Task Force, 2015). Once completed, MS-LOT and relevant stakeholders can give feedback on it. Objections can result in the cancellation or delay of a project.

Guidance documents such as those produced by the FLOWW (Fisheries Liaison with Offshore Wind and Wet Renewables Group) and FIS (Fisheries Innovation Scotland) assist developers with fisheries liaison before, after and during the impact assessment (FLOWW, 2014; Batts *et al.*, 2017a). For this, a fishing liaison officer is usually employed, who represents the developers on their interactions with fishers. They are the point of contact for the fishing industry if they want to contact the developer. They will be in touch with local fishers and fishing associations.

Moreover, UKFEN (UK Fisheries Economics Network) and Seafish provide guidance specifically for economic impacts (Seafish and UKFEN, 2012). As well as for EIAs, this guidance is used for purely economic assessments undertaken by public bodies e.g. for the implementation of an MPA (formal impact assessments or FIAs).

In contrast to FIAs, for assessments for offshore energy, there is a lack of guidance on how (and to what extent) economic impacts on a fleet or vessel basis should be quantified (Seafish and UKFEN, 2012; Copping, 2019). Currently, economic fisheries data is limited to the value of landings per port.

Without vessel-specific economic data, socio-economic indicators are also missing. This can lead to a risk of overlooking the human dimension of impact assessment (St. Martin and Hall-Arber, 2008). Socio-economic data refers to the relation between economic activity and social life, such as employment, infrastructure, services and health (Kruse *et al.*, 2009).

This study will investigate how socio-economic fisheries data is currently taken into consideration in marine energy projects, and whether it is possible to compare socio-economic impacts of fisheries displacement with employment opportunities the energy project will provide in an area. This will depend on whether vessel landings data is linked with fishing grounds and the home ports of crew members, which could allow employment parameters to be characterised. So, we will investigate at what scale economic fisheries data is made available and whether this allows a characterisation of socio-economic value of the local fishing industry to its hosting community.

Possible outputs of this research include best practice examples that could be applicable to other projects. For example, early consultation with the fishing community to inform the importance of fishing grounds to the local industry using valuation methods has been a success in a small island community with fishers in the Sound of Islay (Rodwell *et al.*, 2013).

Challenges to fisheries activity characterisation

In order to locate effects on the home ports and onshore communities of affected fishing fleets due to restricted access to a fishing ground, detailed information on fishing activity is needed first. Figure 5 gives an overview of the different types of fisheries data needed to characterise fishing activity.

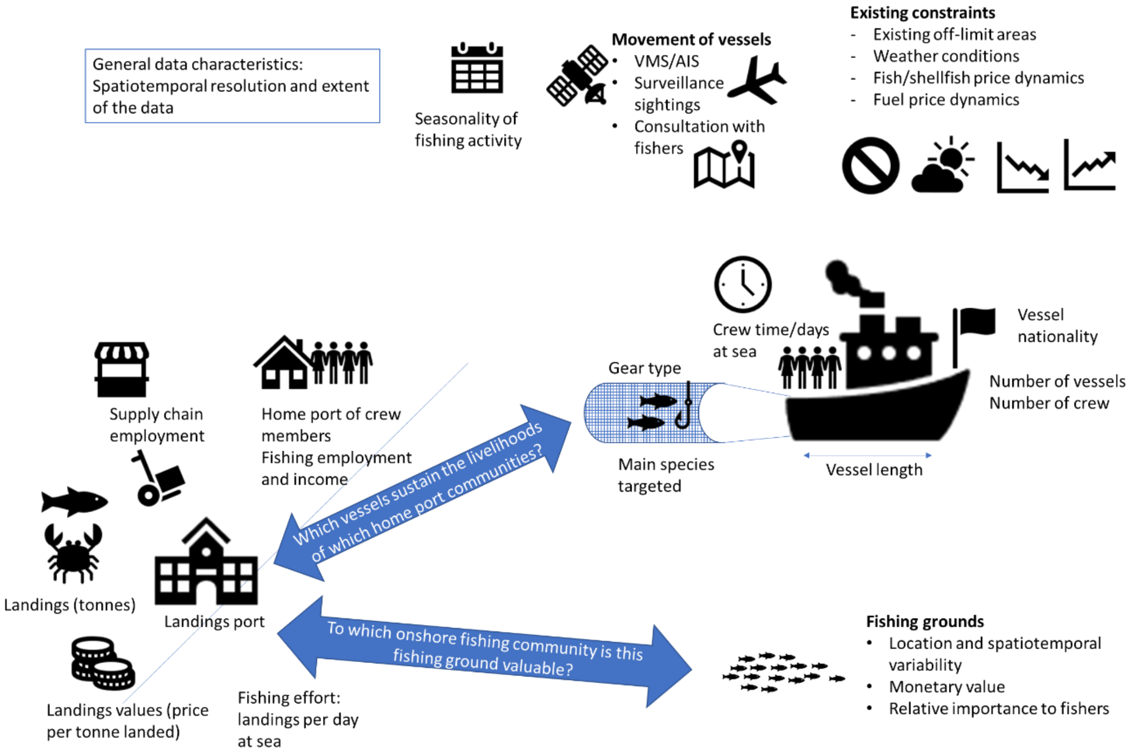

Figure 5 Overview of different types of data needed to characterise fishing activities. The blue arrows denote ‘missing links’ reported in the literature

Challenges to collecting fisheries data are plentiful. Accurate spatiotemporal data on fishing effort and catches is also one of the evidence requirements highlighted by the Scottish Marine Energy Research programme (ScotMER, 2018). Vessel Monitoring System or VMS data can be used for vessel tracking, but due to confidentiality concerns, access to details on the individual vessels is restricted (Natale *et al.*, 2015). As well as that, positioning information is only recorded every two hours (Natale *et al.*, 2015). This can lead to uncertainty when deriving the spatial distribution of fishing grounds using VMS (Jennings and Lee, 2012). Automatic Identification System (AIS) data on the other hand is publicly available and at a higher resolution, but requires more post-processing (Natale *et al.*, 2015; Trouillet *et al.*, 2019).

Another issue with collecting fisheries data is that only vessels larger than 12 m are equipped with a VMS, whilst most inshore fishing fleets are smaller than 12 m. The majority of the interactions between fisheries and energy developments occur inshore, for which characterisation of inshore fleet fishing activities is needed (Shelmerdine, Shucksmith and Mouat, 2017). As well as that, inshore fisheries is an important source of employment in Scotland, especially in the Highlands and

Islands region (Marine Scotland, 2019b). In Scotland, initiatives have been set in place to increase data availability on inshore fisheries. SIFIDS is a project focusing on the development of an integrated data system for the Scottish inshore fishing fleet (MASTS, 2016). One of their work packages focuses on developing low-cost alternatives to VMS for small-scale fisheries such as inshore fleets (Mendo *et al.*, 2019). Also, scientists from the Scotmap project have collected data on the spatial patterns of inshore fisheries by interviewing fishers and other stakeholders between 2007-2011 (Kafas *et al.*, 2014, 2017). Participatory data collection was also used to collect fisheries data for the Shetland marine spatial plan (Shucksmith *et al.*, 2014). In Shetland, the shellfish fishery within 6nm from the coast is managed by the Shetland Shellfish Management Organisation. Fishers have to become a member to get a license to fish, so the fishery are well represented by this organisation and they collect both logbook and VMS data (SSMO, 2018b, 2018a).

Spatial fisheries data is often presented in a gridded format aggregated into ICES rectangles (30’ latitude by 60’ longitude, which is approximately 30x30 nm) (ICES, 1977). This resolution overcomes confidentiality issues but is too coarse to facilitate the detection of potential user-user conflicts (Seafish and UKFEN, 2012; Janßen *et al.*, 2018; Trouillet *et al.*, 2019). User-user conflicts is a term used in marine spatial planning to describe conflicts between different human activities in marine space (Ehler and Douvere, 2007). Structures that represent fishers such as fisherman’s federations, associations, regional inshore fisheries groups or companies such as the SSMO can play a key role in aggregating enough fishing vessel data to prevent individual vessels from being identified, so that the data does not have to be gridded for confidentiality legislation (Shelmerdine, Shucksmith and Mouat, 2017).

Potential effects of offshore energy developments on fisheries

Along with existing regulations such as marine protected areas and quotas, fishers are increasingly having to share marine space with new developments such as subsea cables and offshore wind projects (Gray, Haggett and Bell, 2005; Jentoft and Knol, 2014; Yates, Schoeman and Klein, 2015; Kafas, Donohue and Davies, 2018). This can lead to adverse effects for fishing industries when the development area for renewable energy projects coincides with fishing grounds (Soerensen and Hansen, 2001; Slijkerman and Tamis, 2015). Economically, displacement of fishing fleets can lead to the loss of income or profit of the fishers, and increased steaming costs if they are forced to fish elsewhere (Kafas, Donohue and Davies, 2018). Secondary effects include potential loss of employment and supply chain effects, leading to socio-economic impacts on a fishing community (Tegelskär Greig, 1999; Alexander, Wilding and Heymans, 2013; de Groot *et al.*, 2014). As well as that, adjacent grounds to which impacted fishers are displaced will experience an increase in fishing pressure, indirectly affecting the profitability of pre-existing fisheries in that area (Kafas *et al.*, 2018). A case study investigating the combination of fisheries and offshore wind on the East Coast of Scotland recommends to account for indirect effects of fisheries displacement in EIA studies (Kafas, 2017).

On the other hand, marine energy developments can also provide benefits to the fishing community. Offshore wind farms can act as artificial reefs and sanctuaries devoid of fishing pressure, which could benefit the productivity of stocks (Petersen and Malm, 2006; Langhamer, 2012; Barbut *et al.*, 2019). This benefit was perceived as an important opportunity by some Scottish fishers, as well as alternative employment opportunities such as guarding duties and survey assistance (Alexander, Wilding and Heymans, 2013). Emerging industries such as offshore renewable energy can provide an alternative source of revenue and diversify local economies, providing socio-economic benefits (Blyth-Skyrme, 2010; Rodwell *et al.*, 2013; Kerr *et al.*, 2014; Schultz-Zehden *et al.*, 2018; Bocci *et al.*, 2019). Interviews conducted for a study to investigate community effects of a decrease in fishing opportunity in Scotland revealed that experience on inshore fishing vessels prepared young professionals for a career in the marine renewable sector (Jones, Caveen and Gray, 2014). However, barriers to alternative employment were also revealed through interviews with fishermen, including the lack of qualifications of fishermen and the unsuitability of fishing vessels for marine renewable energy work (Alexander, 2012).

Currently, it is difficult to compare effects on fishing grounds with employment opportunities, because spatial fisheries data on fishing grounds is rarely linked to onshore dependent communities at the homeports. Fisheries dependent communities can be defined as ‘a population in a specific territorial location which relies upon the fishing industry for its continued economic, social and cultural success’ (Brookfield, Gray and Hatchard, 2005). In the context of the implementation of the EU Common Fisheries Policy, dependency of communities on fishing employment in Europe has been quantified by disaggregating regional-scale datasets to the level of fishing ports (Natale *et al.*, 2013).

However, the concept of fisheries dependent communities has been challenged by a Scottish study that instead suggests the term “maritime-dependent communities” to encompass emerging non-fisheries employment opportunities in the offshore renewable and aquaculture sectors that can supplement income from fisheries (Jones, Caveen and Gray, 2014). These two studies have succeeded in portraying the onshore economic dependence of a community on fisheries/maritime-based incomes, but no link was made with the marine space this income relies on (illustrated on Fig. 5). This lack of integration between processes offshore and on land increases the risk to the developer (Kerr *et al.*, 2014).

One existing study has tried to map this ‘missing layer’. On the Northeast Coast of the US, ‘community resource areas’ were identified by combining information on gear type, principal port and trip location using vessel trip report data spanning over ten years, from 1994-2004 (St. Martin and Hall-Arber, 2008). This spatial data was complemented with interviews of fishermen to have insight into the relative value of different resource areas over time and the social and geographic boundaries of the specific communities. The study found that it was possible to distinguish distinct communities per port, gear type and fishing ground, and those different communities responded differently to regulations. Therefore, this missing link between different datasets is important for decision makers to consider.

To the author’s knowledge, even though the necessary data is available it might be at mismatching scales and anonymised, this layer has not been quantified before in Scottish waters, or in the context of fisheries impact assessment for offshore energy developments. If the main landing port can be linked with an affected fishing ground, impact on the community can be assessed in terms of the loss of direct and indirect employment, and the potential loss of heritage if there is a risk of fisheries closure (Brooker *et al.*, 2018).

This missing information on socio-economic impacts in environmental impact assessment could lead to unexpected objections to a development and is identified by the Scottish Government as a knowledge gap (MS-LOT, 2018; ScotMER, 2018). Several studies show that this lack of information has led to failures in siting developments or MPAs (St. Martin and Hall-Arber, 2008; Scholz *et al.*, 2011; de Groot *et al.*, 2014; MS-LOT, 2018). Missing data can lead to unequal stakeholder representation (Fox *et al.*, 2013; Lombard *et al.*, 2019). For an inshore fishing fleet that generally has a higher home port dependency, fishing grounds close to its home port will be more important in terms of reduced steaming costs, but will have the same economic value in terms of landings as for other fleets (Reed *et al.*, 2011; Batts *et al.*, 2017b). This might not be taken into account in the fisheries characterisation (St. Martin and Hall-Arber, 2008; Yates and Schoeman, 2013).

In Scotland, linking landings at a port with the fishing ground the landings were sourced from is not yet possible with publicly available data because the data is anonymised to the level that the principal port of fishing vessels is not identifiable. Additionally, for the inshore fleet, this data is largely unavailable, because VMS data for the inshore fishing fleet is scarce (Kafas *et al.*, 2017). This missing information has implications for the success of mitigation measures, as it may be difficult to know whether the mitigation measures benefit the impacted community (Blyth-Skyrme, 2010).

If impacts on fishery grounds can be linked with their home port, they can be compared with opportunities linked to the marine energy developments. Developers are known to only decide on the hosting port for their development at a later stage in the consenting process (de Groot *et al.*, 2014). Therefore, they could choose a hosting port based on which port hosts the most fishers likely to be impacted by the displacement, so that there is a spatial match between employment impacts and employment opportunities.

Stakeholder engagement

Active and early engagement with stakeholders is one of the key factors that may prevent delays and objections to a development (Kelly *et al.*, 2014; Shucksmith *et al.*, 2014; Tweddle *et al.*, 2014; Reilly, O'Hagan and Dalton, 2016; Batts *et al.*, 2017a, 2017b). During the impact assessment process, fisherman's federations, associations and inshore fishery groups are consulted at multiple stages. Table 2 is a table made for the MUSES project and it shows which fishing organisations responded to consultations on offshore energy developments on the East Coast of Scotland (Kafas, 2017).

Table 2 Consultation responses by fishery organisations to offshore wind developments on the East Coast of Scotland (Kafas, 2017)

	BOWL	MORL	SeaGreen	Inch Cape	NNG	Forthwind	KOWL	Hywind
SFF	■	■	■	■	■	■	■	■
IFGs	■			■	■	■		
Scallop Association	■	■	■	■				
Fife Fishermen Mutual Association			■	■	■			
10 Metre and Under Association			■		■			
IFA						■		
Arbroath and Montrose Static Gear Association				■				
Firth of Forth Lobster Hatchery					■			

The table shows that SFF formulated a consultation response for each project, while smaller fishery organisations responded more sporadically. Therefore, membership of a grouping organisation influences how fishers are represented towards developers. These structures are expected to represent the views of their members and share certain values and norms, which will determine how they will respond to a consultation on an energy development (Pascual-Fernández, Frangoudes and Williams, 2005; Alexander, Wilding and Heymans, 2013). An experimental study in France where fishers' representatives own and collect their data (similar to the SSMO) was found to be successful in sourcing reliable information and giving fishers a seat around the table where decisions can be made together with developers (Trouillet *et al.*, 2019). In general, there is a tendency for fisheries policy to encourage and enable fleets to collect their own data (FLOWW, 2014; Mangi *et al.*, 2018).

However, fishers' federations on a national scale, such as the Scottish Fisherman's Federation, may have different views and agendas than regional inshore fisheries groups (Batts *et al.*, 2017a). Also, within fishing organisations, some types of fisheries might be underrepresented. For example, not all shellfish boats are members of the Shetland Fisherman's Association (Shetland Fisherman's Association, 2019; SSMO, 2019). A report by COWRIE (Collaborative Offshore Wind Research Into the Environment) identified well-organised associations as a strength when looking for mitigation options, but organisations that represent different types of fisheries were more of a challenge because of conflicting needs (e.g. small-scale local fisheries compared with more mobile larger fleets) (Blyth-Skyrme, 2010).

As well as that, European fleets should be contacted because some have a historical right to fish between 6-12 nm, and all have access beyond 12 nm. Foreign vessel activity has been estimated to represent up to 27% of all fishing activity in the UK EEZ (Dunstone, 2009). European stakeholders to be contacted will include producer organisations and fisherman's associations (Seafish and UKFEN, 2012). To engage foreign fishing federations for developments out with 12 nm, there are also international regional advisory councils on a sea basin scale. For example, the North Sea (Regional) Advisory Council represents fishing members and NGOs and gives advice on renewable energy developments such as the proposed offshore wind projects on the Dogger Bank (North Sea Advisory Council, 2018).

Existing constraints

Finally, another factor that could play a role in the impact of an energy development on fisheries is the pre-existing influence of external factors (Seafish and UKFEN, 2012). This includes weather conditions, fuel prices, fish and shellfish prices and the state of the fish and shellfish stocks (St. Martin and Hall-Arber, 2008; Shucksmith and Kelly, 2014; Bartelings *et al.*, 2015). Whether or not this has been considered could also influence the acceptance of a proposed development.

In essence, this study will investigate to what extent the issues described above are reflected in existing assessment reports. This will include looking into the mitigation strategies imposed. For mitigation measures, an extensive guidance document has been published which is cited in EIA reports: Options and opportunities for marine fisheries mitigation associated with windfarms (Blyth-Skyrme, 2010). The results of a workshop highlight that barriers to implementing these proposed mitigation measures remain, such as an unsuccessful data gathering process during the site selection (Rodwell *et al.*, 2012, 2013). By reviewing existing assessments and conducting interviews in this study, it will be possible to evaluate if these barriers are relevant to the selected case studies.

Aim

The aims of this study are twofold. The first aim is to find out how fisheries data is incorporated in the site selection and impact assessment process for offshore energy developments, and to what extent socio-economic data is included. Barriers to obtaining any missing data will be explored. To the author's knowledge the way fisheries are represented by data and how this affects how they are being included in the decision-making process has not been investigated in this way before, even though fisheries data has been acknowledged as an evidence requirement by the Scottish Government (ScotMER, 2018).

The second aim is to assess whether the availability or lack of fisheries data influences the success in siting and consenting a development. A successful consent application could be defined as one against which there are little objections, and little or no delays take place. For evaluating the contribution of the use of fisheries data to a successful development, other determining factors will have to be considered (aside from the availability of data), such as the adapted approach to stakeholder engagement.

For conducting this study, a set of case studies has been chosen, including subsea cable projects as well as offshore energy developments. Investigating different types of energy developments allows for inter-sectoral comparison. A textual analysis will be complemented with semi-structured interviews with developers, stakeholders and government representatives to investigate their views on the fisheries impact assessments of the chosen case studies.

Link with PhD

This study is part of a larger-scale PhD for which a model will be developed to optimize the siting of marine energy developments by considering multiple objectives (socio-economic, environmental and technical) at an early stage in the development process.

The model will require spatial data inputs, and previous studies have highlighted that the human dimension of marine space is underrepresented, including the fishing industry (St. Martin and Hall-Arber, 2008; Trouillet *et al.*, 2019). Including more data on socio-economic indicators is expected to improve public acceptance of the model. By analysing case studies of the siting process and impact assessment of marine energy developments, it will be possible to have an insight into what information is necessary, at what scale, and how it is collected.

By combining a textual analysis with stakeholder interviews, outputs of this study should give a balanced picture of the current challenges. It will enable a comparison between empirical findings elicited with the evaluation framework and responses from fishers that may be more value-based.

This bottom-up approach of informing a model with stakeholder inputs is similar to the approach of the Aquaspace project, which designed a model to inform the siting of aquaculture sites, taking an ecosystem approach (Gimpel *et al.*, 2018).

Methodology

Case study protocol

Section removed; the reader is referred to Section 3.2

Chosen case studies

Section removed; the reader is referred to Section 3.2

Textual analysis – framework

Section removed; the reader is referred to App. 3.1

Interview methodology

Section is removed, the reader is referred to Section 3.2

Summary approaches to ethical and GDPR considerations

Issue	Approach
Data storage	Interview recordings, transcripts as well as identifiable information will be stored on a password protected drive from UHI
Signed consent forms	Hard copies of signed consent forms will be left with the interviewee and the researcher will only keep a digital copy where possible, to eliminate risk of consent forms being lost
Avoiding misunderstandings	Results from analysing the interviews will be e-mailed to the interviewees to ask them to make sure that their answers were interpreted correctly. This step of the process will be communicated with the interviewee beforehand so that they are aware they will need to make time for this. For interviewees that left their job since then, their successor was contacted to discuss results of the analysis.
Anonymising the interviewees	The interviewees will be referred to using codes according to stakeholder group, and only the researcher will have access to a key that can identify the persons representing the codes

Risk of a participant/organisation being identifiable if they are part of a small sample size within one stakeholder group	If there are less than three existing organisations within one stakeholder group, this will be communicated with the participant beforehand, so the participant can decide if they want their inputs to be able to be linked to their organisation/individual. If they do not consent to this, the stakeholder group will be joined up with another stakeholder group to ensure anonymity
Use of quotes in the published results of the study	Before using direct quotes from interviewees, permission from them will be sought after

Participant information sheet

Evaluating the current use of fisheries data in siting and impact assessment of marine energy developments

Participant Information Sheet

Invitation

As a professional with experience in fisheries interactions with offshore energy developments, you are invited to take part in this study through an interview. This participant information sheet will give you further information on the study and the interview process, to inform your decision on whether or not to take part.

Research rationale

The marine space that developers want to use for installing offshore renewable energy turbines or subsea cables may already be in use by fishers. This can lead to interaction and direct competition for space between the energy and fishing industries.

Fisheries data is important for developers to avoid fisheries impacts during the site selection process, and to characterise potentially affected fisheries in an impact assessment. There are many challenges to collecting fisheries data. For example, the Scottish Marine Energy Research programme (ScotMER) has highlighted the lack of knowledge on economic and social value of marine space from fisheries in Scotland as a current knowledge gap. This prevents a comparison between the potential socioeconomic value gained from an energy development with fisheries displacement.

This study aims to evaluate the extent to which fisheries data used in current site selection and impact assessments represent socio-economic impacts on fisheries. This includes examining which data is being used and which data is missing, and investigating what the barriers are to obtaining the missing data. Finally, the idea is to find out whether the availability/lack of data influences the success of a development and objections against it.

To do this, existing fisheries impact assessments for renewable energy developments and subsea cable projects in Scottish waters will be evaluated and scored. However, a textual analysis of publicly available documents does not give a full picture of how decisions were made during the impact assessment process. Interviewing relevant stakeholders involved will give further insight into how data was used in fisheries impact assessments and whether this was done successfully.

On this note, it would be greatly appreciated if you would consider taking part in this study.

This study forms part of a PhD project funded by the Bryden Centre, which supports research on marine renewable energy. The researcher is based at the NAFC Marine Centre in Shetland, a campus of the University of the Highlands and Islands (UHI).

What would taking part involve?

Participating in this research will involve an interview that will last for approximately 1 hour, to be arranged to suit your availability and at a venue suitable to you. The interviewer will use a list of open questions to frame the discussion and enable broader discussion as relevant. Questions will be sent to you beforehand. You will be asked to consider whether you are representing your personal views or that of your organisation.

After the results of the interviews have been analysed, you may be contacted at a later date for feedback on a follow-up study in the context of the PhD. Participation at a follow-up stage is voluntary.

What are the possible benefits of taking part?

Inform research on barriers to optimal use of fisheries data to characterise fisheries activities for site selection and impact assessment of marine energy developments

Provide insights into how improvements can be made to the current process

Contribute to research that can address current challenges in your work field

Privacy Notice

How will we process the interview?

The interview will be recorded, transcribed and then analysed using computer software (NVivo). Before being presented in academic research, the results will be shared with you to confirm everything was understood correctly. This will require making some time after the interview to go through the analysed results that will be e-mailed to you.

How will we ensure your inputs are confidential?

The interviews will be anonymised and referred to per stakeholder group using codes (e.g. “developer 1”, “fishing association member 2”). Only the researcher will have access to a key that can identify the persons represented by the codes. Therefore, the identities of the participants will not be revealed to anyone outside the study.

If there are less than three existing organisations within one stakeholder group, therefore making an organisation within this group more easily identifiable, this will be communicated with you beforehand, so that you can confirm that you consent to your organisation being identifiable.

How will the information be stored to make sure it stays confidential?

The raw data (transcribed interviews) will be held on secure, password-protected drives of UHI and accessed by the researcher (and if necessary, PhD Supervisory Team) and will be used for the purposes of the PhD research, including publication in an academic journal. The raw data will stay within the organisation and there will be no third-party access. The data, in its anonymised form, will be used as part of a PhD thesis and scientific publications.

The anonymised data (in the form of transcribed interviews) cannot be linked back to individuals so it will be kept indefinitely (the key linking it to individuals will be destroyed after the PhD has been submitted and examined or until the research has been published), as future studies can benefit from this work. The anonymised data will be stored on a password-protected UHI drive and will stay available for the researcher and the UHI. At any point, interviewees may withdraw consent to the use of their provided input with no need to justify. If someone withdraws consent, data collected with this interviewee will be permanently deleted. Please note this is only possible before the research is published in an academic journal, after which the results of analysing the anonymised data is already in the public domain.

Data protection

The legal reason for using the data you have provided is that it is necessary for the performance of a task carried out in the public interest or in the exercise of official authority vested in the controller. That being the delivery of a course of study or research undertaken at, or by, the university or its students.

The following are your rights in respect of this processing:

• The right to access your personal data
• The right to rectification if the personal data we hold about you is incorrect
• The right to restrict processing of your personal data
• The right to request erasure (deletion) of your personal data
• The right to data portability

You also have the right to lodge a complaint with the Information Commissioner's Office about our handling of your data.

Data controller

The data controller is the researcher, Inne Withouck.

For any data protection enquiries please contact UHIs Data Protection Officer at dataprotectionofficer@uhi.ac.uk

For any queries around the research please contact the doctoral researcher, the project supervisor or the head of department:

Inne Withouck, Doctoral Researcher: inne.withouck@uhi.ac.uk / 01595 772232

Rachel Shucksmith, Director of Studies: rachel.shucksmith@uhi.ac.uk / 01595 772492

Dr Beth Mouat, Head of Department: beth.mouat@uhi.ac.uk / 01595 772310

Research team

Doctoral Researcher:	Inne Withouck (PhD student at NAFC Marine Centre, UHI)
PhD Supervisory Team	Rachel Shucksmith (NAFC Marine Centre, UHI, Shetland), Dr Beth Mouat (NAFC Marine Centre, UHI, Shetland), Prof Paul Tett (Scottish Association for Marine Science, Oban, Scotland), Prof John Doran (Letterkenny Institute of Technology, Ireland)

Consent form

Evaluating the current use of fisheries data in siting and impact assessment of marine energy developments: Consent form

1. I confirm that I have read the participant information sheet dated................... (version............) for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason.

3. I consent to the interview being recorded (audio only) as part of the project.

4. I understand that any personal data will remain confidential and no information that identifies me will be made publicly available.

5. I understand that explicit consent from me will be sought after prior to the use of any data that will not be anonymised, for example if quotes will be used directly.

6. I consent to use of the data gathered through interview in research and publications as explained in the Participant Information Sheet.

I agree to take part in the above study.

Name of Participant Date Signature

Name of Researcher taking consent Date Signature

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App. 4.1 Interview guides

A4.1.1: Government stakeholders

Fisheries stakeholder engagement

Timing/Continuity

At what stage in a project are fisheries stakeholders usually consulted?

Are you happy with the communication with fisheries stakeholders from the onset of a project through to the post-consent construction and operational phase?

How do consent conditions including the setup of a commercial fisheries working group play a role in this?

Outreach

What is the role of (umbrella) fishing associations for reaching out to stakeholders?

What is the role of consultation events for reaching out to stakeholders?

Has it been possible to take all fisheries stakeholders’ views into consideration?

Assessment of impacts and benefits and proposed mitigation measures

Do you think there could be any improvements in the mitigation measures proposed that consider fishing communities dependent on fishing?

General questions

Do you think there might be better ways for the fishing industry and the renewables industry to engage?

Do you have any examples of fisheries interactions with offshore energy developments that went particularly well or were particularly unsuccessful?

A4.1.2: Fisheries stakeholders

Fisheries stakeholder engagement

At what stage did you first become involved as a fisheries stakeholder for a proposed offshore energy development?

Do you think impacts on fisheries can be avoided through early engagement with stakeholders? If yes/no, why?

Were you happy with the level of stakeholder involvement during the site selection process of energy projects?

Are you happy with the level of fisheries stakeholder engagement from the onset of energy projects through to the post-consent construction and operational phase?

How do consent conditions including the setup of a commercial fisheries working group play a role in this?

Assessment of impacts and benefits and proposed mitigation measures

Do you think there could be any improvements in the mitigation measures proposed that consider fishing communities dependent on fishing?

Are you happy with the proposed mitigation measures?

Is there an opportunity for employing fishers for guard work/FLOs as a form of mitigation?

What is (potentially) the role of fishing associations for coordinating this?

General questions

Do you think there might be better ways for the fishing industry and the renewables industry to engage?

Do you have any other examples of fisheries interactions with offshore energy developments that went particularly well or were particularly unsuccessful?

A4.1.3: Developers

Fisheries stakeholder engagement

Timing

At what stage in a project are fisheries stakeholders consulted?

How do you choose when to start involving fisheries stakeholders?

Do you think impacts can be avoided through early engagement with stakeholders?

Are you happy with the communication with fisheries stakeholders from the onset of a project through to the post-consent construction and operational phase?

How do consent conditions including the setup of a commercial fisheries working group play a role in this?

Outreach

Is it easy to find the relevant fisheries stakeholders to consult?

What is the role of (umbrella) fishing associations for reaching out to stakeholders?

What is the role of consultation events for reaching out to stakeholders?

Has it been possible to take all fisheries stakeholders’ views into consideration?

Impact assessment and mitigation

Do you think there could be any improvements in the mitigation measures proposed that consider fishing communities dependent on fishing?

Is there an opportunity for employing affected fishers for guard work/FLOs as a form of mitigation?

What is (potentially) the role of fishing associations for coordinating this?

General questions

Do you think there might be better ways for the fishing industry and the renewables industry to engage?

Do you have any examples of fisheries interactions with offshore energy developments that went particularly well or were particularly unsuccessful?

App. 4.2 Codebook interview analysis Chapter 4

This table includes all the codes (referred to as themes in the methods section) used to analyse both the interviews and the project documents. They include a combination of a priori defined themes, and themes that emerged during data collection and data analysis that appeared to be of significance (indicated with *). The emerging themes were either identified as a subcategory of a priori defined themes (e.g. 'burial' was deemed relevant for the 'primary mitigation' theme) or identified as themes independent of pre-defined themes (e.g. 'national importance' as a distinct theme).

Themes (*=emerging theme)	**Description**
positive impacts	Benefits of a project to the fishing industry, independent of compensatory measures
guardvessels	Reference to guard vessel work, a potential employment opportunity for fishing vessels
primary mitigation	Measures taken to avoid or reduce impacts on fishers
burial*	Degree of influence fisheries stakeholders have on the extent to which a cable is buried
overtrawlability*	Reference to overtrawlability which is where a fishing vessel can safely pass its fishing gear over a buried cable
rockdumping*	Situation where cables are protected with rock material when they cannot be buried deep enough
gradient*	Gradient of buried material over cable
surfacelay*	When a cable is laid directly on the seabed
secondary mitigation	Measures taken to avoid or reduce impacts on fishers
residual negative impacts	Remaining predicted negative impacts on the fishing industry after mitigation measures have been implemented
snagging	Reference to the situation where a fishing gear gets snagged with a cable
spacecompetition	This involves the element that soft bottom is where both cables and fishers want to go, and it also includes reference to moving a route because of high fishing activity
compensation	Monetary compensatory measures
EIA	Reference to the environmental impact assessment (EIA) process
installationphase	Project phase where the renewable energy development and/or cable gets constructed and installed on location
operationphase	Project phase where the renewable energy development and/or cable is in place and operational

Themes (*=emerging theme)	**Description**
compar_developments*	How different types of projects compare, e.g. comparing tidal projects with offshore wind farms
ESCA*	Reference to the European Subsea Cables Association (ESCA)
finance*	How projects get financed and how that plays a role in terms of taking into account potential impacts on fisheries
fishing_activity	This includes the characterisation of fishing activity and how it's done as well as references to the level of fishing activity that goes on in an area, and a reference to the dynamics of fisheries activities and how it depends also on tidal flows
landsea*	Comparisons with land-based equivalents, e.g. comparing farming to fishing
license conditions*	Binding conditions attached to a licence issued to developers
FLMAP*	Specific licence condition related to fisheries mitigation (also includes references to the equivalent for offshore wind farms, “FMMS”)
national_importance*	References made to the fact that renewable energy developments are classified as infrastructures of national importance, which makes the fishing industry feel they are on unequal footing
SMP_NMP*	Reference to the sectoral marine planning process or Scotland’s national marine plan
distributional justice	Reference to relative positive/negative impacts of proposed projects on the fishing industry
procedural justice	Reference to mechanisms that can foster procedural justice (engagement/involvement of fisheries in the process)
actor_involvement	Reference to the level of involvement of interested parties during the different project phases
objections	Objections raised by fisheries stakeholders in relation to proposed projects
fishing_association	Reference to a fisheries representative body such as a fishing association or an umbrella organisation
FLOWW	Reference to the Fishing Liaison with Offshore Wind and Wet Renewables Group (FLOWW)
communication	Reference to the communication between developers and members of the fishing industry
consultation	Reference to consultation events
FLO	Reference to the fishing liaison officer of projects
input_design	Degree of influence fishers/their representatives have on the design of a project
input_siting	Degree of influence fishers/their representatives have on the siting of a project

Themes (*=emerging theme)	Description
stage	At what stage do fishers become involved in the siting process. This includes both involvement as in they're represented by spatial data and involvement as in they get contacted.
resources*	Resources (time and money) available by fisheries (representatives) for engaging with proposed projects
transparency*	Transparency of the process as perceived by fisheries stakeholders
project_uncertainty*	Reference to the implications of project uncertainty on engagement with the fishing industry
localknowledge*	Input of local (fisheries) knowledge into the process
recognitional justice	Distinguishing between types of fisheries to understand if any fishing segments are underrepresented compared to others
fisheries_type	Type of fisheries and how that plays a role
geartype	Mention of gear type specificities
creel	Creel fishing
trawl	Trawling
independent	Fishers not affiliated with an association
inshore	Fisheries fishing close to the coast, usually within 3 nautical miles
large	Fishing vessels with a length larger than 10 m
small	Fishing vessels with a length smaller than 10 m
fulltime	Full time fishers
parttime	Part time fishers
non-UK	Foreign vessels
whitefish	Fishers targeting whitefish species
climatechange*	Reference to climate change, for example how it might affect fish stocks
corona*	Corona-related points made by interviewees

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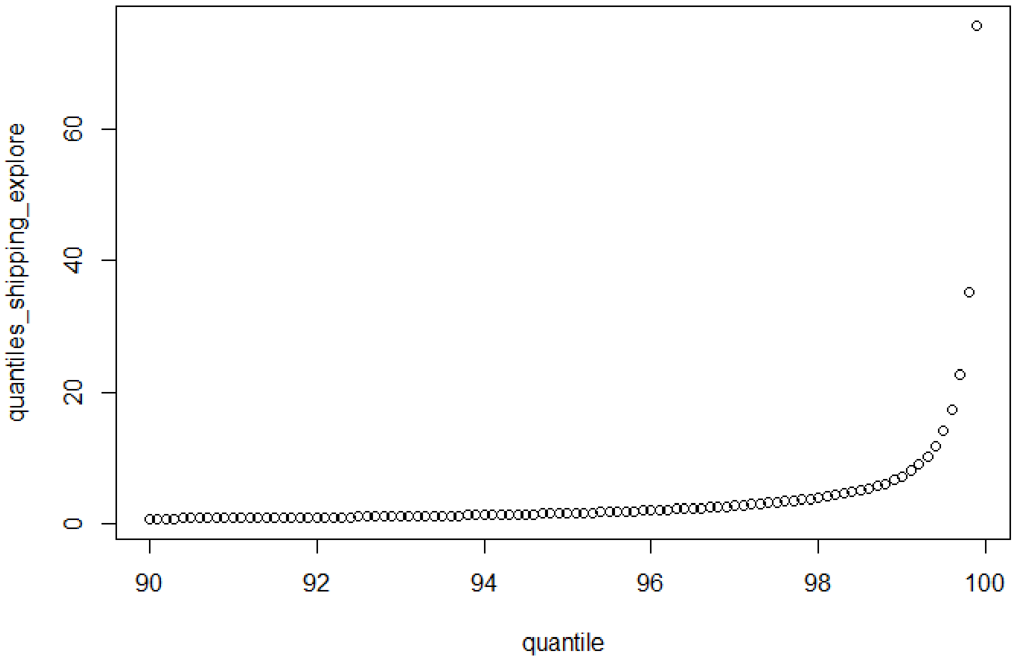
App. 5.1 Data preparation shipping layer

Figure A5.1.6 illustrates the number of grid cells in the 90-100% quantiles for a) the original dataset and b) the modified dataset where the top 1% of values was reclassified to the next highest value. The difference in curve shape between a) and b) reflects how smaller differences are masked by outlier values in the original dataset (a)).

a)



b)

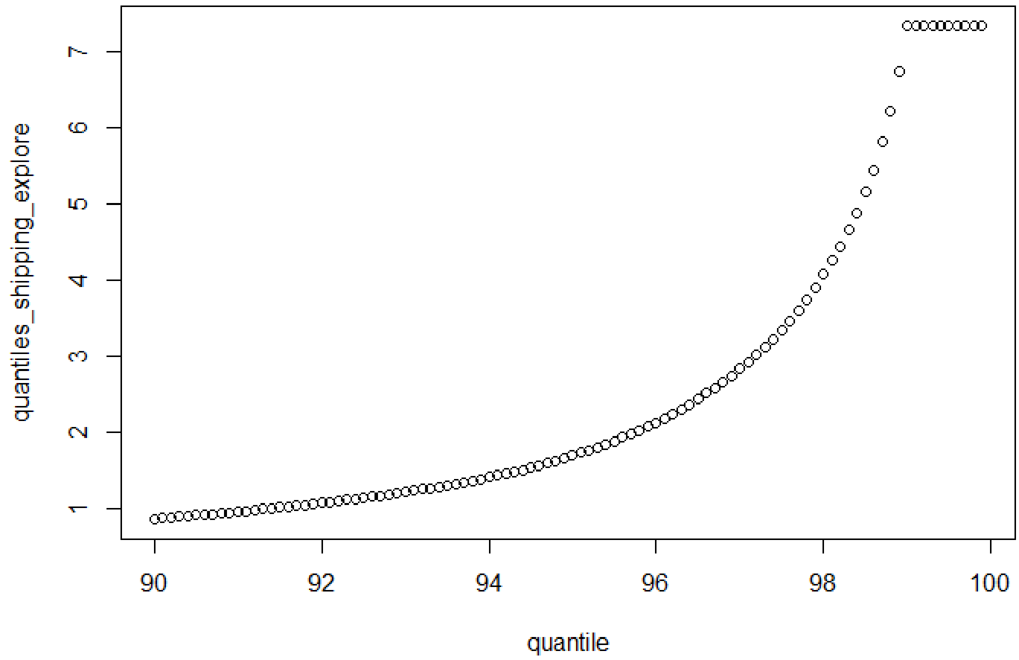


Figure A5.1.6 Distribution of grid cell values per quantile for the quantiles between 90-100, for a) original dataset b) dataset where the highest 1% of grid cells were reclassified to the next highest value

Reclassifying the top 1% reduced the maximum # hours per km^2 per month to 7.34 instead of 19 982.29 hours. The top 1% values were reclassified to 7.34 (the next highest value after the top 1%) rather than remove the outliers to prevent loss of spatial information within the study area.

This data processing step increases the number of grid cells that have the same (maximum) value, so there will be no distinction between these cells in levels of shipping density (see Figure A5.1.7).

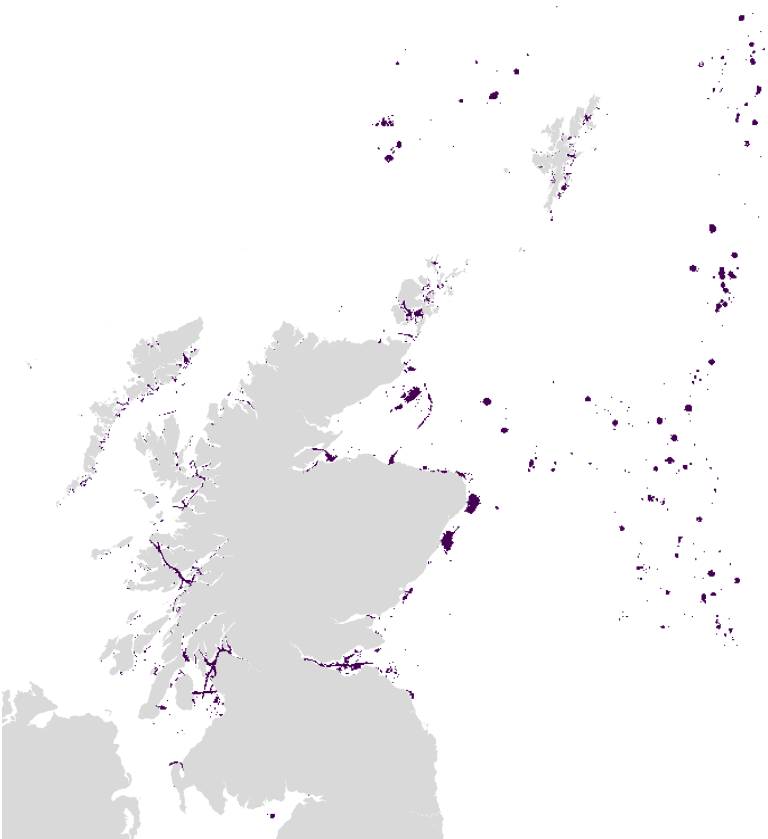


Figure A5.1.7 Grid cells with the same value for the shipping layer

Figure A5.1.7 illustrates where these grid cells are located. Figure A5.1.8 is the adjusted shipping data layer to account for the outliers.

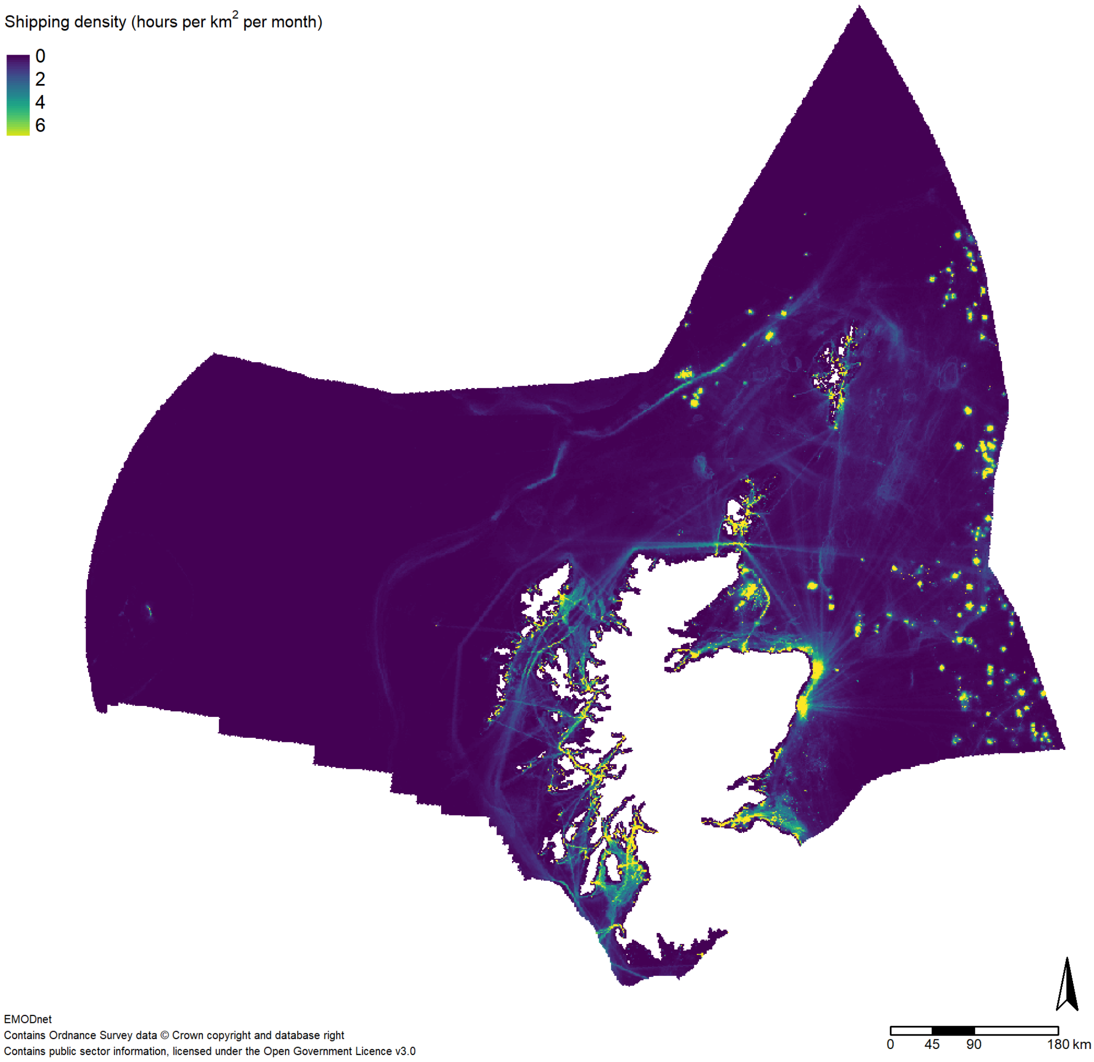


Figure A5.1.8 Shipping layer ready to be used for the analysis (#hours/km2/month)

App. 5.2 Class intervals data layers

A5.2.A: Class intervals used in the analysis for the five data layers

	a_{k0} (min)	a_{k1}	a_{k2}	a_{k3} (max)
Mobile fisheries	423.77	46325.01	140976.70	596621.23
Scotmap	0.00	12.73	58.82	304.68
Wind speed	4.48	9.00		11.91
Recreation	0.00	16.07	41.77	223.66
Shipping	0.00	0.20	0.88	7.34

A5.2.B: Local ranges per activity per marine region

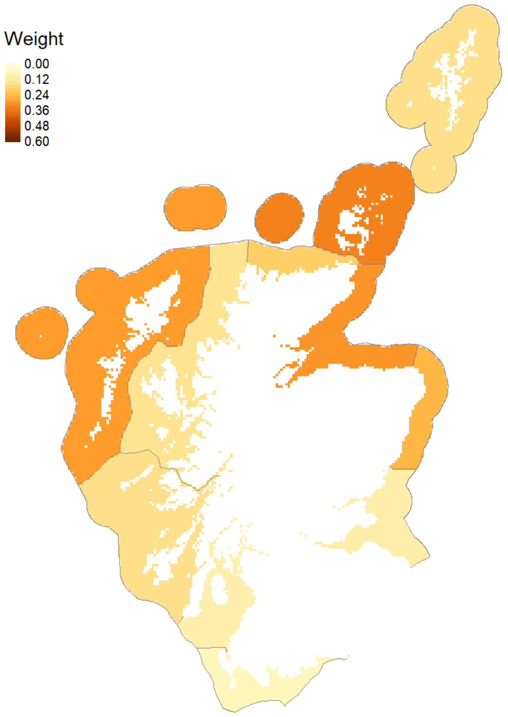
		Argyll	Clyde	Forth and Tay	Moray Firth	North Coast	Northeast	Orkney Islands	Outer Hebrides	Shetland Isles	Solway	West Highlands
Local max	Wildlife	32.6	21.8	16.3	26.8	11.9	14.9	9.1	14.8	5.0	5.7	28.2
	Surf	6.7	7.9	10.1	7.5	8.4	6.8	2.0	3.8	1.0	1.0	4.6
	Canoe	11.4	10.0	12.6	4.8	4.2	4.9	1.3	3.0	4.0	3.2	12.9
	Yacht_Racing	24.8	19.4	13.8	4.8	2.0	2.7	1.8	2.0	1.0	1.0	20.4
	Sailing_Cruising	57.5	38.6	10.2	10.2	2.9	2.9	4.3	6.9	2.5	3.8	57.4
	Motor_Cruising	5.2	7.2	3.3	1.6	0.7	0.7	0.9	1.0	0.6	1.1	4.2
	PowerBoat	10.8	14.9	8.0	2.1	1.0	1.0	1.0	2.1	2.0	3.8	9.9
	SeaAngling_Boat	8.7	10.7	6.9	4.0	2.1	2.7	2.0	3.1	4.0	19.4	7.4
Local min	Wildlife	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Surf	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Canoe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Yacht_Racing	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Sailing_Cruising	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Motor_Cruising	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	PowerBoat	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	SeaAngling_Boat	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Wildlife	31.6	20.8	15.3	25.8	10.9	13.9	8.1	13.8	4.0	4.7	27.2

Local range	Surf	5.7	6.9	9.1	6.5	7.4	5.8	1.0	2.8	0.0	0.0	3.6
	Canoe	11.4	10.0	12.6	4.8	4.2	4.9	1.3	3.0	4.0	3.2	12.9
	Yacht_Racing	23.8	18.4	12.8	3.8	1.0	1.7	0.8	1.0	0.0	0.0	19.4
	Sailing_Cruising	57.5	38.5	10.2	10.2	2.9	2.9	4.3	6.9	2.5	3.8	57.4
	Motor_Cruising	5.2	7.2	3.3	1.6	0.7	0.7	0.9	1.0	0.6	1.1	4.2
	PowerBoat	9.8	13.9	7.0	1.1	0.0	0.0	0.0	1.1	1.0	2.8	8.9
	SeaAngling_Boat	7.7	9.7	5.9	3.0	1.1	1.7	1.0	2.1	3.0	18.4	6.4

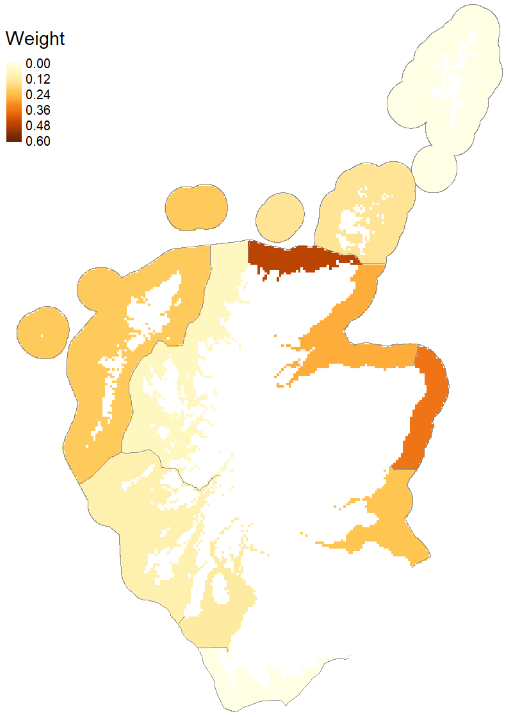
App. 5.3: Output maps local standardisation

A5.3.1 Spatial weights for all eight categories

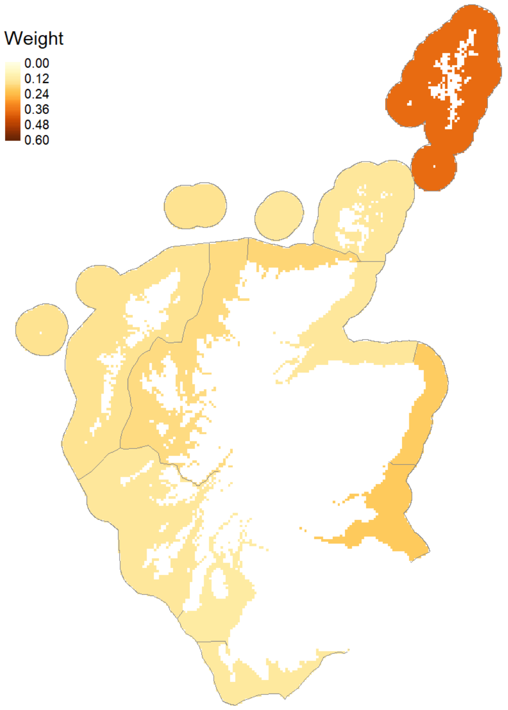
Wildlife



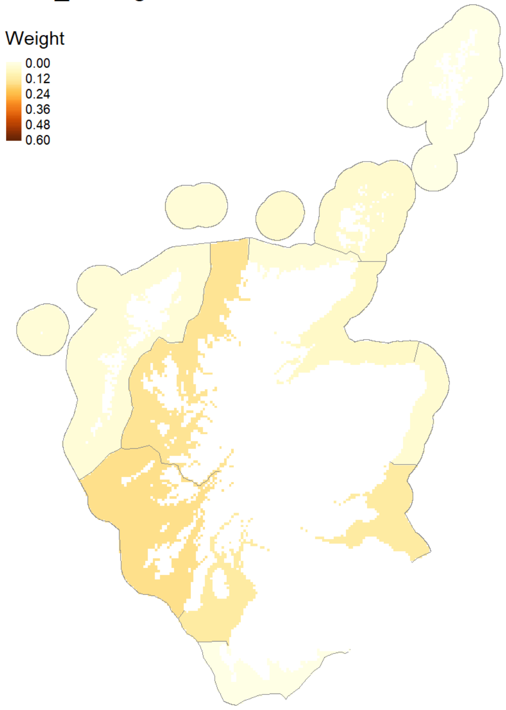
Surf



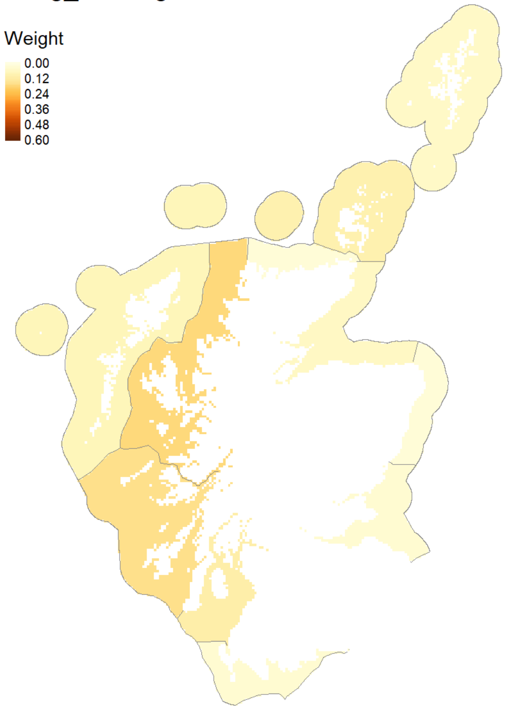
Canoe



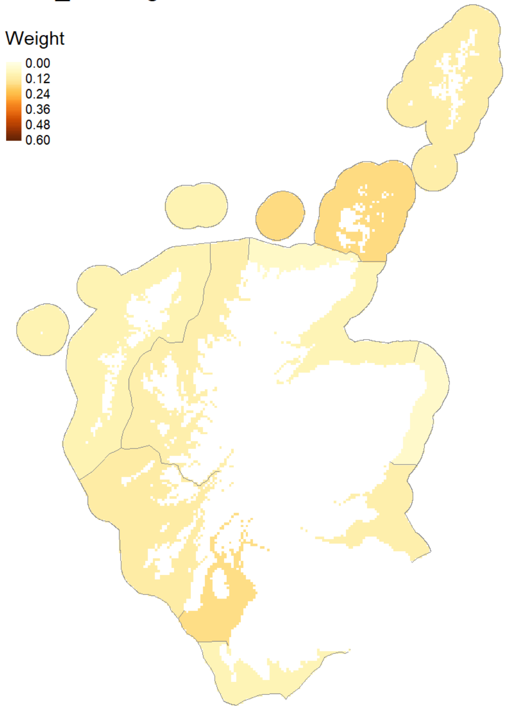
Yacht_Racing



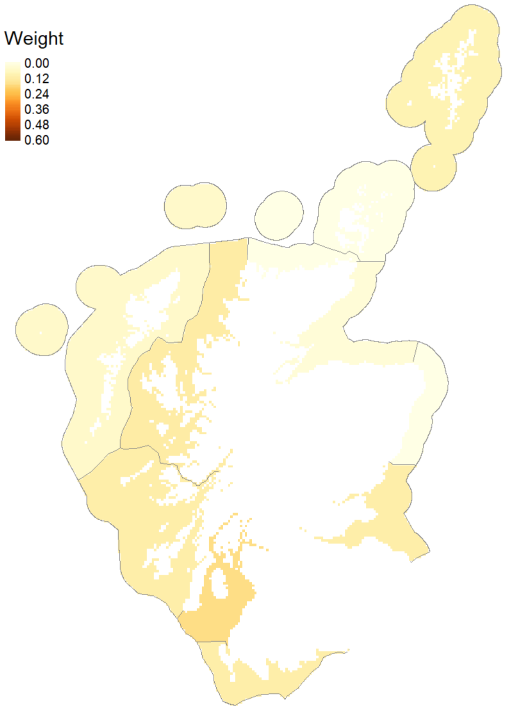
Sailing_Cruising



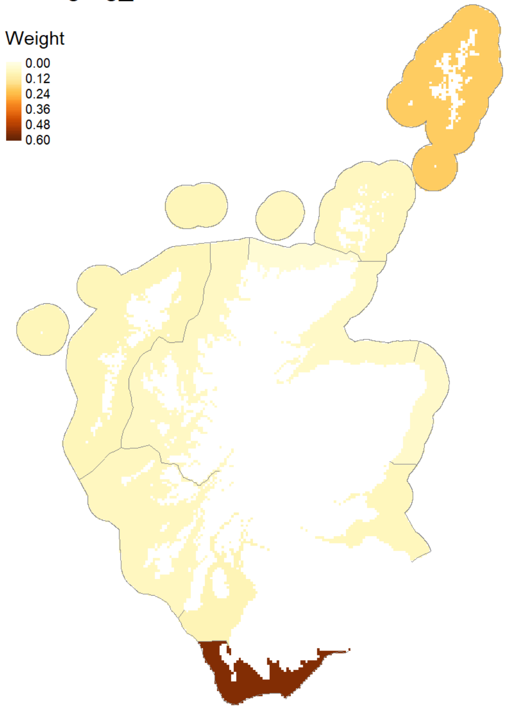
Motor_Cruising



PowerBoat

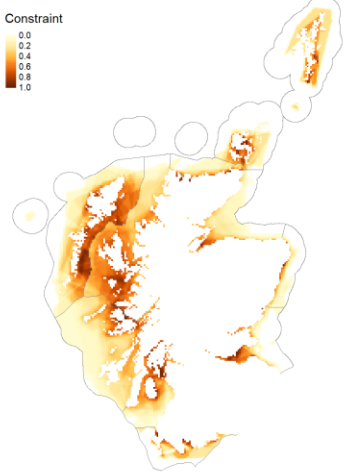


SeaAngling_Boat

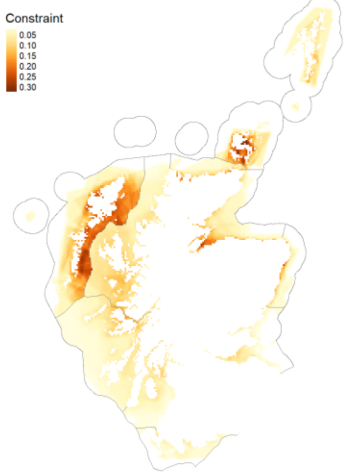


A5.3.2 Local fuzzy, Local weighted fuzzy and global fuzzy maps for the eight categories

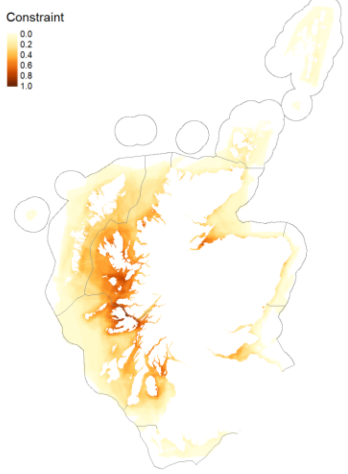
Wildlife -Local



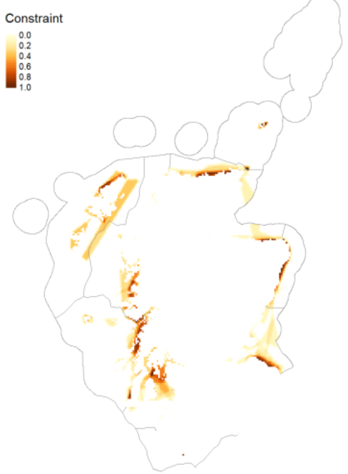
Wildlife -Weighted Local



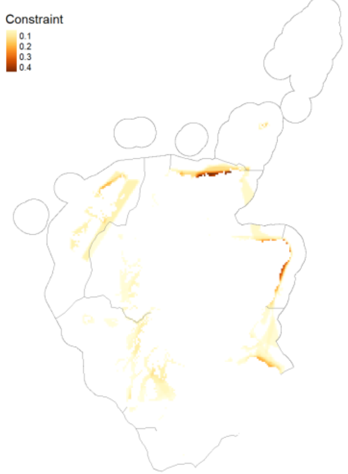
Wildlife -Global



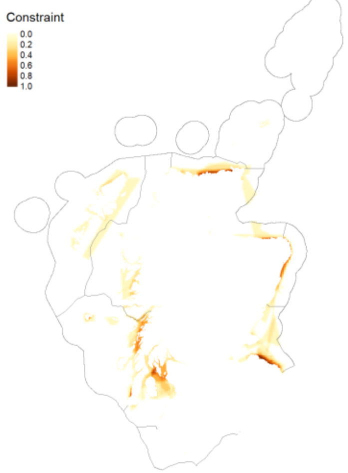
Surf -Local



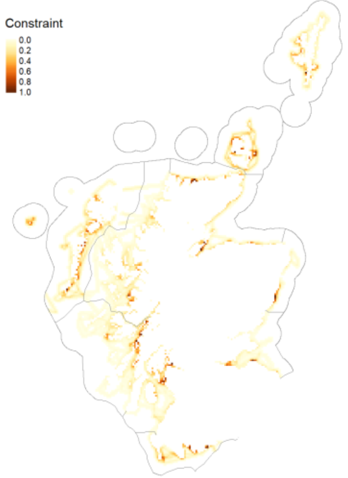
Surf -Weighted Local



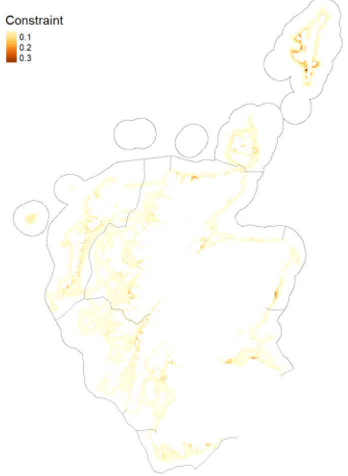
Surf -Global



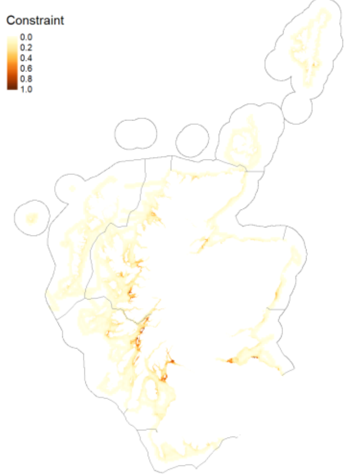
Canoe -Local

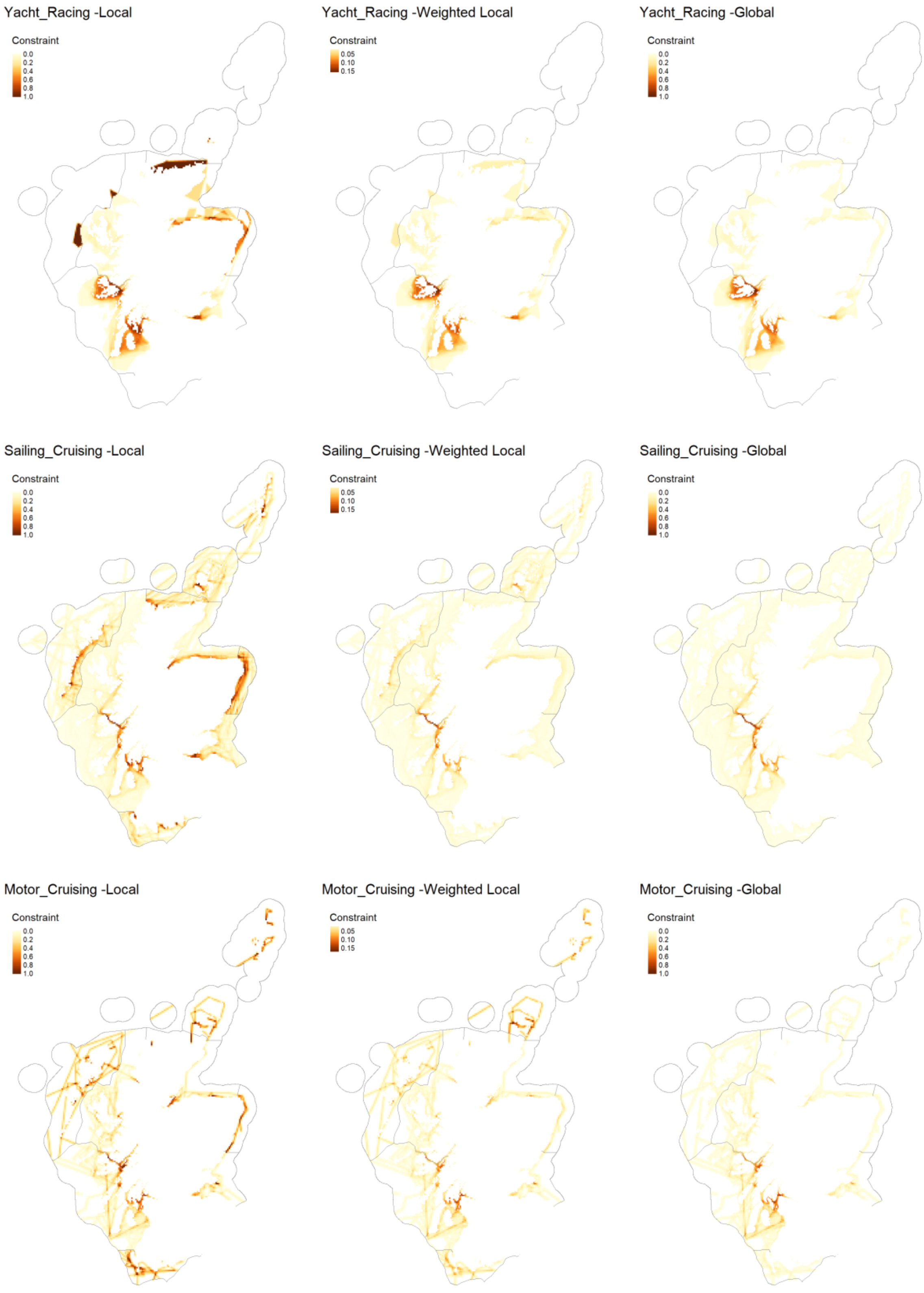


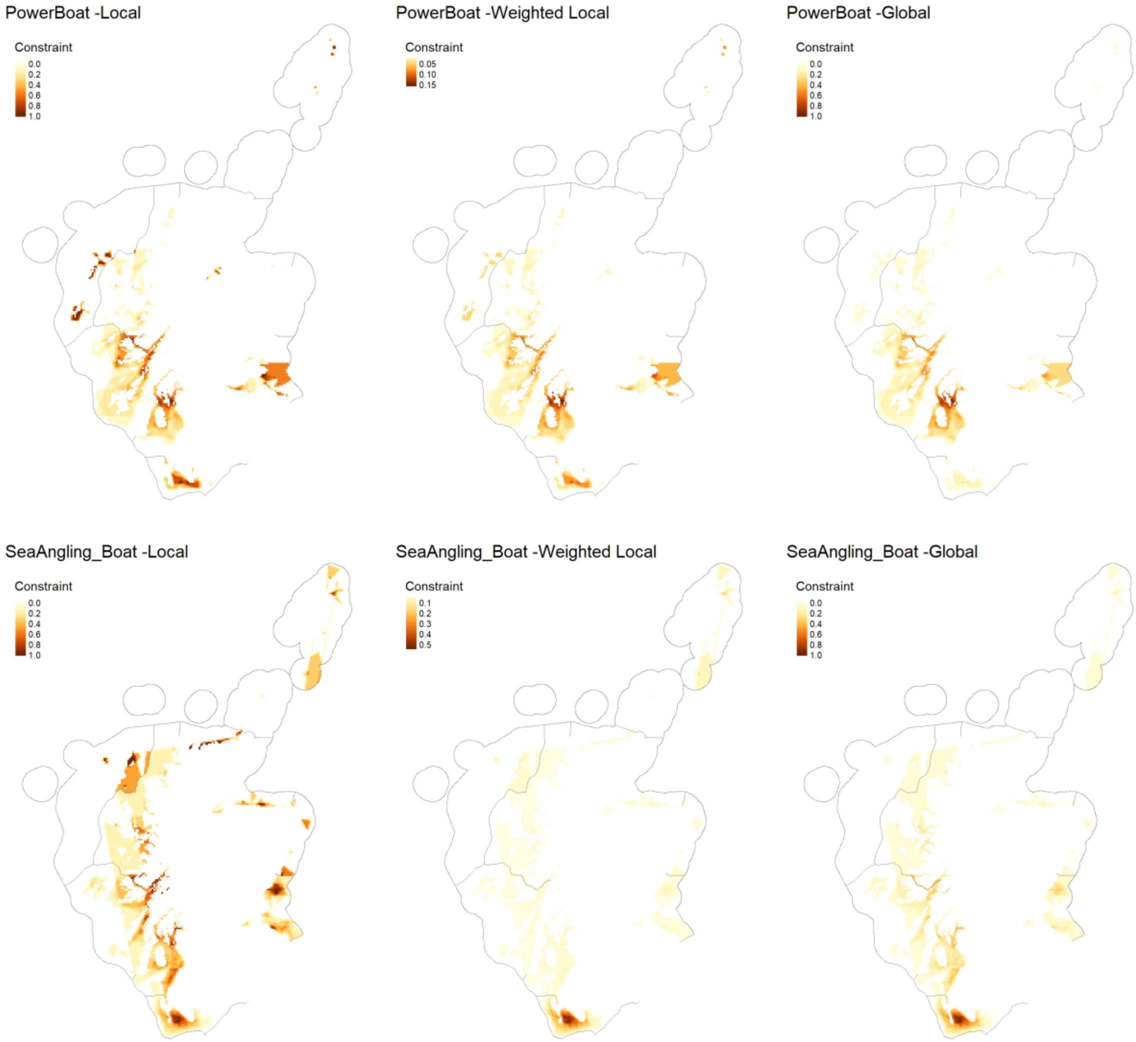
Canoe -Weighted Local



Canoe -Global




Yacht_Racing -Local
Constraint
0.0
0.2
0.4
0.6
0.8
1.0
Yacht_Racing -Weighted Local
Constraint
0.05
0.10
0.15
Yacht_Racing -Global
Constraint
0.0
0.2
0.4
0.6
0.8
1.0
Sailing_Cruising -Local
Constraint
0.0
0.2
0.4
0.6
0.8
1.0
Sailing_Cruising -Weighted Local
Constraint
0.05
0.10
0.15
Sailing_Cruising -Global
Constraint
0.0
0.2
0.4
0.6
0.8
1.0
Motor_Cruising -Local
Constraint
0.0
0.2
0.4
0.6
0.8
1.0
Motor_Cruising -Weighted Local
Constraint
0.05
0.10
0.15
Motor_Cruising -Global
Constraint
0.0
0.2
0.4
0.6
0.8
1.0


PowerBoat -Local
Constraint
0.0
0.2
0.4
0.6
0.8
1.0
PowerBoat -Weighted Local
Constraint
0.05
0.10
0.15
PowerBoat -Global
Constraint
0.0
0.2
0.4
0.6
0.8
1.0
SeaAngling_Boat -Local
Constraint
0.0
0.2
0.4
0.6
0.8
1.0
SeaAngling_Boat -Weighted Local
Constraint
0.1
0.2
0.3
0.4
0.5
SeaAngling_Boat -Global
Constraint
0.0
0.2
0.4
0.6
0.8
1.0