How is Offshore Wind Industry expansion transforming the UK North Sea?

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Developing a social-ecological systems approach to complement marine spatial planning and guide a sustainable blue economy

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Abstract

The industrial expansion of offshore wind energy in the UK North Sea is rapid, unprecedented and ongoing. It contributes to a global trend in the intensification of marine activity and forms a cornerstone of Europe's intended transformation to a sustainable blue economy. Increased research efforts are being made to understand the effects of this expansion on established social-ecological entities in the area, but these efforts have not been combined to form a whole-system perspective. In this thesis, the UK North Sea (UKNS) is perceived as a complex social-ecological system (SES), whose parts interact in dynamic and non-linear ways to produce emergent, system wide phenomena that affect the system's overall functioning and integrity.

Focus groups and marine expert interviews reveal the perceived ways that offshore wind expansion affects this complex adaptive system. These are analysed to qualitatively and semi-quantitively map UKNS interactions. Qualitative results mapped using the social-ecological action situations (SE-AS) framework depict complex and variable responses to offshore wind development across the UKNS: coastal communities both seek out and actively conflict with offshore wind developments, whilst fisheries are variously unaffected or threatened, reduced and displaced from traditional fishing grounds by them. Fish species are negatively impacted by offshore wind developments, but these impacts can be outweighed where the same developments prevent local trawling activity. Fuzzy cognitive mapping is used to combine qualitative and semi-quantitative results, which have then been modelled to reveal emergent UKNS system properties that could result from offshore wind expansion, such as fisheries reductions, pressure onto marine protected areas and shipping routes, and reductions in current strength and water quality. Marginal benefits to coastal communities and increased port investment are also anticipated.

Application of this social-ecological perspective can complement marine spatial planning (MSP) in several capacities. It illuminates trade-offs between marine plan policies and objectives in statutory marine planning, and could complement MSP tools such as The Crown Estate's resource

identification and optimisation tool through incorporation of feedbacks, cumulative effects, social value, and expert perceptions. Furthermore, a SES-based understanding solidifies geographical critiques of ‘blue growth:’ there are localised instances of ‘blue injustice’ for communities, fisheries and ecologies as a result offshore wind developments and addressing these will be important on the path to a sustainable blue economy.

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Glossary of Terms

Action Situation (**AS**) – a way to frame interactions. Consisting of multiple components including participants, their positions and potential outcomes, a function turning actions into outcomes, information about how the function is controlled, and information, costs and benefits related to the actions and outcomes (Ostrom, 2005).

Adaptive Capacity - the ability of systems, individuals, institutions, and other organisations to adjust to potential damage, to take advantage of opportunities, and to cope with the consequences (IPCC, 2014).

Adaptive Cycle - a metaphor that describes the patterns of stability and instability in systems (Gunderson & Holling, 2002).

Blue Growth – a call for sustainable development and holistic management of complex marine social-ecological systems (Burgess et al., 2018).

Blue Fix – made up of three sub-fixes: conservation, protein, and energy. Broadly, reconfigurations of ocean space to resolve capitalism's inner crisis tendencies and ensure continued reproduction of capital (Brent et al., 2020).

Blue Justice – a commitment to achieving a more just ocean economy, based on past evidence of social injustices that can result from ocean-based development (Bennett et al., 2020)

Complex Adaptive System (CAS) – a system which exhibits nonlinear behaviour emerging from the interactions of its different parts, and which has the capacity to adapt, evolve, and learn (Levin, 2002).

Connectedness – a measure of the number of connections and by extension rigidity of a system (Gunderson & Holling, 2002).

Ecosystem Based Approach (EBA) - The comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity (HELCOM-OSPAR, 2003).

Ecosystem Based Management - an integrated approach to management that considers the entire ecosystem, including humans. The goal of EBM is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need. EBM differs from current approaches that usually focus on a single species, sector or activity or concern; it considers the cumulative impacts of different sectors. (Macleod et al., 2005)

Ecosystem Approach - a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. Thus, the application of the ecosystem approach will help to reach a balance of the three objectives of the Convention: conservation; sustainable use; and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources (Convention on Biological Diversity, 2010).

Emergence - the generation of novel properties or functionalities that cannot be explained by their constituting elements alone, e.g., outcomes that are more than the sum of their parts (Schlüter et al., 2019).

Green Growth – "fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies." (OECD, 2011)

Marine Spatial Planning (MSP) - a public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives that have been specified through a political process (Ehler, 2021).

Ocean Grabbing - where ocean-based developments cause displacement of local users, or dispossession from their local resources (Bennett et al., 2020).

Panarchy: a nested set of adaptive cycles operating at a discrete range of scales (Gunderson & Holling, 2002).

Potential – a measure of accumulated resources in a system (Gunderson and Holling, 2002).

Resilience - the capacity of a system to adapt to change, persist disturbance, learn, self-organize, and transform while sustaining its main processes, functions, and structure (Folke et al., 2016).

Social-ecological action situations framework (SE-AS)– A framework to map the emergence of social-ecological phenomena. It begins with a network of interactions between entities. Key interactions, which are identified by their theoretical or empirical relevance, are abstracted into action situations (AS, see above), which capture relations and interactions between human and nonhuman entities that are core causes of social-ecological phenomena. Each AS has emergent outcomes which can affect other ASs, and each AS can be either social, social-ecological, or ecological. Linked action situations are hypothesised to produce system-wide emergent phenomena of interest (Schlüter et al. 2019).

Social-ecological System (SES) - a system of people, communities, economies, society, and culture embedded in the biosphere (Folke et al., 2016).

Sustainable Blue Economy - Based on the European green deal and the recovery plan for Europe, the European Commission now advocates for a shift from blue growth to a *sustainable* blue economy, because "The outdated notion that environmental protection conflicts with the economy is giving way to the realisation that, especially in the maritime industry, the environment and the economy are intrinsically linked" (European Commission, 2021, p.2).

Tipping Points - thresholds of localised effects, including ecological, socio-cultural or economic system properties. They occur when small changes in pressures induce large, abrupt changes in system properties, whether in single species or populations, entire ecosystems, climate or human society (Lauerburg et al., 2020).

Abbreviations Used in the Text

AS	Action situation
Aura CDT	Aura Centre for Doctoral Training
CO_2	Carbon Dioxide
CAS	Complex adaptive system
DEFRA	Department for Environment, Food and Rural Affairs
DESNZ	Department for Energy Security and Net Zero
EBA	Ecosystem-based approach
EEZ	Exclusive Economic Zone
EU	European Union
FCM	Fuzzy cognitive mapping, or Fuzzy Cognitive Map in Chapter 6
GDP	Gross Domestic Product
L	Number of connections (links in a fuzzy cognitive map)

MMO	Marine Management Organisation
MPA	Marine Protected Area
MSP	Marine spatial planning
N	Number of components (nodes in a fuzzy cognitive map)
NS	North Sea
NorthSEE	North Sea Shipping, Energy, Environment project
OEUK	Offshore Energy United Kingdom
RIO tool	Resource Identification and Optimisation tool
RO	Research Objective
RQ	Research Question
SDG	Sustainable Development Goal
SE-AS	Social-ecological action situation
SES	Social-ecological system
SMMR	Sustainable Management of Marine Resources
TCE	The Crown Estate
TS	Territorial Sea
UKNS	United Kingdom North Sea

Statement of Copyright

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To Bill and Bo, who've walked beside me

Chapter 1: Introduction

The expansion of the offshore wind industry in the UK North Sea (UKNS) is one of the most significant transformations in the UK marine space in recent decades. The UK is a global leader in offshore wind development, and after only recently being supplanted by China, boasts the second largest offshore wind energy capacity in the world (World Population Review, 2025). Together with onshore wind, this industry now produces 30% of the UKs electricity supply (Offshore Wind Growth Partnership, 2025). Further expansions are planned, with capacity predicted to increase from 14.7GW as of 2024, to 41.5GW by 2030 (EnergyPulse, 2025). Such rapid and unprecedented transformation of marine use raises questions over how the established marine social-ecological system this industry is being built within is being affected. The evolving interactions between the offshore wind industry and other marine users contribute to emergent, system-wide phenomena across the UKNS. Discerning what these changing characteristics are and could be is a key problem for social and natural scientists who seek to sustainably manage a complex and adaptive marine environment.

In this first chapter, I introduce the aims and objectives of the thesis and the geographical context of the UK North Sea in which it is set. I also introduce the physical, theoretical and conceptual units it seeks to draw together. After briefly laying out the evolving physical characteristics of the UK North Sea, I focus on one of the most significant forces affecting its transformation: the expanding offshore wind industry. A relevant and holistic way to analyse the effects of offshore wind expansion is through an interdisciplinary set of frameworks called social-ecological systems (SES), which offer an approach focussed on understanding the complex and evolving interactions between different marine entities. SES constitutes the theoretical grounding of this thesis, and it will explore the potential of SES for understanding the emergent outcomes of offshore wind expansion. Here, after outlining SES, I establish how it could make significant contributions to marine spatial planning (MSP) and the transformation to a sustainable blue economy. By exploring the connections between marine SES, MSP and blue economy, I lay out the aims of this thesis, alongside sets of associated research objectives and questions.

1.1 Background and Context

1.1.1 Geographical introduction to the UK North Sea

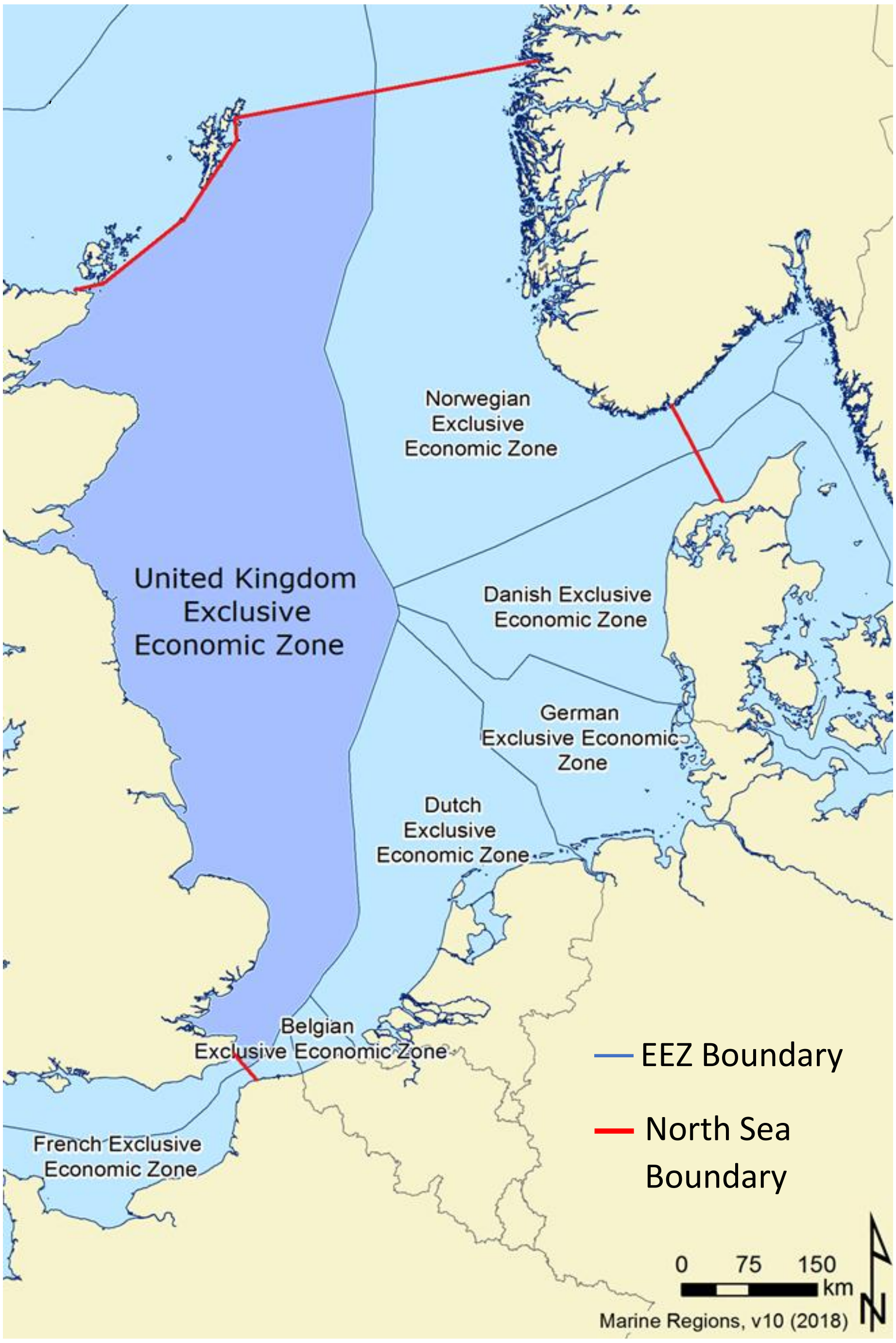

Figure 1.1 Exclusive Economic Zones in the North Sea alongside sea and ocean boundaries – adapted from (De Hauwere, 2018) Marine Regions photogallery. North Sea boundary is as defined by the International Hydrographic Organisation (Marine Regions, n.d.)

The UK North Sea (UKNS) occupies a 215,000km^2 section of the North Sea (NS, Figure 1.1), which is a productive, shallow, epicontinental sea (Misachi, 2021)[1]. It covers approximately 38% of the 570,000km^2 North Sea, bounded to the West by the East coast of the United Kingdom, and to the East by the Exclusive Economic Zones (EEZ) of Norway, Denmark, Germany, The Netherlands, Belgium and France (Misachi, 2021). To the North lies the North-Eastern Atlantic Ocean, and to the South-West, The English Channel (Figure 1.1). Politically, the UKNS is composed of parts of the UKs territorial sea (TS) - up to 12 nautical miles from the coastline, and EEZ – up to 200nm from the coastline. This national division of ocean space is a result of the United Nations Convention on the Law of the Sea, which has been ratified by 168 national signatories since it was solidified in 1982 (UNCLOS, 1994). The Law of the Sea has become the backbone of a complex international legislative framework that helps to organise and account for human uses of ocean space.

The primary human uses of ocean space around the world are fishing, maritime transport and trade, aggregate extraction, oil and gas exploration, tourism and recreation, and increasingly since around the turn of the 21st century, offshore renewable energy and marine protected areas (MPA). An ongoing international intensification of these uses - collectively referred to as the 'blue economy' - has been dubbed the blue acceleration (Jouffrey et al., 2020). This phenomenon looks set to continue through the first half of the 21st century, as many countries and international organisations develop ambitious strategies under the banner of blue growth or sustainable blue economy (Fenichel et al., 2020; European Commission, 2012). In the UK, the oil and gas industry is still the largest blue economy sector, though its output is declining whilst the offshore wind sector continues to grow due to the UK's low carbon energy strategy (Stebbings et al., 2020). Offshore waters are likely to be the focus of blue economy expansion over the coming decade, with floating offshore wind, seafood production by aquaculture, and mineral extraction anticipating particularly strong growth globally (Novaglio et al., 2022).

1.1.2 Offshore wind in the North Sea

The increasing concentration of human activity in the ecologically productive NS has led to it being ranked amongst the most anthropogenically impacted marine ecosystems in the world (Halpern et al., 2008), yet anthropogenic activity in this area looks set to continue intensifying and diversifying. For example, the North Seas Energy Cooperation - an EU initiative which links together the nine

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[1] Productive: able to host photosynthetic organisms which form the basis of marine food webs (Sigman & Hain, 2012). Shallow: The North Sea has an average depth of 95m, being at its shallowest in the south and broadly deeper towards the North (BHS, n.d.). The deepest part is the Norwegian trench in the north-east, which extends to a depth of 725m. Epicontinental: a sea which overlays a continental shelf (Merriam-Webster, n.d.). In this case the continental plate in question is The Eurasian plate (Brilliant Maps, 2024).

North Sea Countries to support and facilitate offshore grid development and large renewable energy potential in the region - have recently set a new aggregate offshore wind energy target of 260GW of offshore wind energy by 2050 (Directorate-General for Energy, 2022). This target dwarfs the current capacities of offshore wind in the NS, which sat around 19.8GW in 2020 (WindEurope, 2021). The scale and rate of the ongoing and proposed expansion of offshore wind energy in this sea is unprecedented, and is accompanied increasingly by knowledge of its environmental and social effects (e.g. Kaldellis et al., 2016; Haraldsson et al., 2020). Efforts have recently been made to, for example, combine grey and primary literatures to better understand the ecosystem service outcomes of offshore wind farm developments on the marine environment (Szostek et al., 2024). However, there is still a lack of research that considers holistic, long term and cumulative effects of offshore wind expansion, especially when considered in tandem with other human effects (Bergström et al., 2014).

Offshore wind development is needed in the North Sea to tackle grander scale existential threats such as energy security and climate change mitigation, which align with Sustainable Development Goals (SDGs) 7 (ensuring access to sustainable energy) and 13 (managing climate change) (United Nations, 2015). It is also relevant to SDG 14 (life below water), as offshore wind energy structures are built within the marine environment. As an industry, offshore wind exemplifies how the varying goals for sustainability in the ocean zone can be at odds with one another. Constructing renewable infrastructure can aid in mitigating the effects of climate change and the production of more sustainable energy. However, this could hinder several targets of SDG 14 – such as protecting and restoring ecosystems, supporting small-scale fishers, and conservation of marine areas (The Global Goals, n.d.). Novel disciplinary perspectives, tools, models and methods are needed to capture which objectives are met, and which are left at the wayside as industrial developments transform the seascape. Recent work mapping the institutional apparatus for global offshore renewable energy governance reveals the objectives of offshore renewable developments to be very broad, including for example “energy security, promotion of renewable energy (namely wind and ocean energy), economic development and international cooperation, climate change mitigation, environmental protection, and ocean conservation” (Guerra, 2018, p.26). The wide range of these offshore renewable energy governance objectives suggests the industry may be receptive to research fields that offer interdisciplinary, whole system perspectives: one such field is the study of social-ecological systems.

1.2 Social-Ecological Systems

Social-ecological Systems (SES) are systems of people, communities, economies, society, and culture embedded in the biosphere (Folke et al., 2016). Their study emerged in the mid-1990s through collaboration between scholars from the interdisciplinary fields of ecological economics and common pool resource systems (Biggs et al., 2021). SES falls within the domain of sustainability science and has a key aim of helping to solve the environmental and social sustainability issues societies face in the 21st century, by examining human-nature interactions and trade-offs. Two qualities separate SES from other sustainability science sub-disciplines, such as human-environment interactions (Dearing et al., 2006) or coupled human natural systems (Liu et al., 2007). Firstly, SES are complex adaptive systems (CAS) – they exhibit non-linear behaviours which emerge from the interactions of their different parts, and have the capacity to adapt, evolve and learn (Levin, 2002). Secondly, to better understand how a system works, SES research prioritises the interactions of components in a system, over the functioning of components themselves (Preiser et al., 2018). These qualities of SES research are based on real-world observations of social-ecological phenomena, which repeat at scales from the individual organism to the global system. Combined, they imply that understanding the interactions taking place between different social (economic, political, cultural and technological) and ecological (biotic and abiotic) components of a system can provide insights about its emergent properties when subject to change. As the UKNS undergoes transformation due to the expansion of the offshore wind industry, these emergent, social-ecological changes should be of keen interest to marine users who inhabit and/or work within this marine space, especially where they could be beneficially or detrimentally affected by offshore wind expansion. It could also be of importance to those who manage the marine environment - statutory marine planners such as the Marine Management Organisation (MMO), or owners of the seabed like The Crown Estate (TCE) - to proactively (rather than reactively) plan how the blue economy evolves.

1.3 Marine Spatial Planning Towards a Sustainable Blue Economy

As anthropogenic pressures on the UKNS ecosystem continue to mount, management choices for this region become ever more important. Perceived failings in the dominant method for marine management in the late 20th century, known as single species fisheries management (Domínguez-Tejo et al., 2016; Smith & Jaleel 2019), led to the discussion and promotion of an ecosystem-based approach (EBA) to marine management from the turn of the 21st century. National and regional governments have developed their own processes to best achieve the variably prioritised principles and objectives of EBA, and these processes have become collectively known as MSP. By 2017, over 75 countries were known to be exploring and developing their own marine spatial plans (Ehler, 2021) in pursuit of the goals of an EBA.

Today, MSP is an eclectic toolset designed to balance the three aims of marine management: conservation and enhancement of the marine ecosystem; economic development; and retaining or improving the social value of the ocean to people (Ehler, 2021). Its principal drivers are: human use conflicts, the need for a more integrated approach, conservation concerns, new and emerging human uses of ocean space, conflicts between human use and conservation, economic growth concerns and the effects of climate change (Ehler, 2021). Like SES, MSP arises as a response to the need for an informed interdisciplinary perspective when tackling complex management problems. However, its primary means of doing this is through multi-layered sectoral mapping and spatial optimisation tools, which fulfil some planning objectives but arguably can circumvent the primary aim of balancing social-ecological activity in marine systems (Trouillet, 2020). By incorporating social-ecological interactions and outcomes into spatial planning decisions, SES research can potentially help draw MSP closer towards its primary aims.

Across the NS, marine plans have been developed by national and subnational governmental organisations within their respective EEZs and occasionally TSs (Lukic et al., 2020; Marine Management Organisation, 2014). There are nine marine spatial plans in the NS: Germany, Belgium, and The Netherlands first generated national marine plans in 2005 (Ehler, 2021) and are now on their 2nd, 3rd, and 4th cycles respectively (Lukic et al., 2020)[2]. Denmark and Sweden do not yet have marine spatial plans (Lukic et al., 2020), Norway has three regional marine plans, but only one which concerns the NS (Ehler and Douvere, 2010). Finally, England has marine plans for the South East, East and North East parts of its North Sea EEZ, with each of these areas further subdivided into inshore (TS, up to 12nm from the coast) and offshore (Marine Management Organisation, 2014b; Table 1.1). Scotland has a national plan as well as several regional marine plans on its East coast. Most NS MSPs are revised every 5-10 years to assure they maintain or enhance their adaptive capacities in the face of an increasingly changeable environment. The thesis study area was chosen considering the ecological boundaries of the Greater North Sea ecoregion (ICES, n.d.), the areas in which wind energy development is taking place (and is projected to do so), as well as the geo-political boundaries of the UK's EEZ (Figure 1.1). This means that the thesis study area intersects with several marine plans and does not perfectly overlap with any single one. MSPs for England and Scotland that correspond with the thesis study area are outlined in Table 1.1.

[2] A cycle here refers to how many times an MSP has been revised.

Table 1.1 Names of marine plan areas that overlap partially or fully with the UKNS thesis study area, as well as associated legislative powers

Plan Name	**Overlap with thesis study area**	**Legislative power**
Scotland: The National Marine Plan	Partial (Scottish East Coast)	UK Parliament (offshore), Scottish Parliament (inshore)
Scotland: Shetland Isles Inshore Region	Partial (Shetland East Coast)	Scottish Parliament
Scotland: Orkney Islands Inshore Region	Partial (Orkney East Coast)	Scottish Parliament
Scotland: Moray Firth Inshore Region	Fully within	Scottish Parliament
Scotland: North East Inshore Region	Fully within	Scottish Parliament
Scotland: Forth and Tay Inshore Region	Fully within	Scottish Parliament
England: North East Inshore	Fully within	UK Parliament
England: North East Offshore	Fully within	UK Parliament
England: East Inshore	Fully within	UK Parliament
England: East Offshore	Fully within	UK Parliament
England: South East Inshore	Fully within	UK Parliament

The marine plans in Table 1.1 have been created- and influenced by several key plan forming acts and initiatives. The Marine and Coastal Access Act 2009 established a framework for marine spatial planning in England, Wales and Scottish Offshore Areas, and created the Marine Management Organisation (UK Parliament, 2009). The Marine (Scotland) Act 2010 is in turn responsible for establishment of Scottish inshore marine regions and creation of Scotland’s marine planning system (Scottish Parliament, 2010). Both pieces of legislation are guided by the UK Marine Policy Statement 2011, which provides a shared vision and policy direction for sustainable use of UK seas (Defra et al., 2011). Finally, the EU Directive 2014/89/EU – establishing a framework for marine spatial planning, sits above national marine legislation and required EU member states to create marine planning systems, apply an ecosystem-based approach, and coordinate across borders (The European Parliament & The Council of the European Union, 2014). The broadest aim for the marine spatial plans relevant to the study area (Table 1.1), which have been formed through this legislation, is to achieve a desired collective vision across a parcel of marine space. Visions of blue growth and the blue economy came to dominate marine discourse through the 2010s. They were often used interchangeably, aided by their conceptual ambiguity which enabled them to be deployed by a range of marine users to confer variable visions for the marine environment (Eikeset et al., 2018). Broadly speaking, these blue imaginaries are split between purely development driven interests, and interests in pursuit of more holistic management goals i.e., incorporating economic development whilst also seeking to prevent ecological degradation (Eikeset et al., 2018). More recently, the European Commission (2021) has advocated a shift from blue growth to a sustainable blue economy, reflecting contemporary understanding of the intrinsic links between the environment and the economy, and attempting to more firmly assert sustainability into the marine agenda. Once more, SES representations are well placed to explore to which extent a sustainable blue economy is emerging in the UKNS, providing evidence on how a range of marine users affect and are affected by a core industry of a sustainable blue economy transformation: offshore wind. A social-ecological perspective on the sustainability of the UKNS's blue economy can help to challenge the concept and/or corroborate a range of critiques and reconceptualisations emanating from systems-based and geographical research. These include blue degrowth, the blue fix, and blue justice (terms that are expanded upon in Chapter 2's Literature Review). Overall, a more holistic view of the UKNS via SES can help reveal progress, tensions and tradeoffs in the transformation to a sustainable blue economy, and what could be done to go further.

1.4 Research Aims and Objectives

The primary aim of the thesis is to analyse the effects of the current and future expansion of offshore wind energy in the UKNS. The secondary aim is to explore how the results of these analyses can complement marine management processes such MSP, and outline the emergent forms of a sustainable blue economy in the region. To achieve these overall project aims, the thesis has the following four research objectives (RO):

RO1: Generate data describing the linkages between offshore wind energy and other social, economic, and ecological components that act within the UKNS.

RO2: Based on knowledge gained through RO1, generate a unitless, relational network map of the intertwined UKNS social-ecological system.

RO3: Using the map generated via RO2 as a semi-quantitative model, model a scenario to show the effects of offshore wind expansion on the UKNS SES.

RO4: Use the results from RO3 to explore how SES can complement marine management and contribute to the academic discourse on the transformation to a sustainable blue economy.

To address these objectives, the thesis draws on relevant literature on marine SES, offshore wind energy, marine governance (especially MSP) and geographical critiques and reconceptualisations of blue growth (see Chapter 2). It deploys frameworks and methods from social science and SES – focus groups, fuzzy cognitive mapping, power-interest matrices, expert interviews, the social-ecological action situations framework and scenario modelling. It generates original data through primary research using qualitative methods to develop semi-quantitative and qualitative results, and analyses these using qualitative and modelling approaches. The research on the effects of wind expansion in the UKNS is guided by four RQs and these are outlined in the following section.

1.5 Research Questions

The setting, research aims and objectives, and academic context have informed the development of a set of research questions, which in turn inform the methods selected for each stage of the thesis in Chapter 3. These research questions (RQ) are:

> RQ1: What are the linkages between different components of the UK North Sea social-ecological system, especially with relation to the offshore wind industry?
>
> RQ2: How might these linkages interact together to generate emergent properties of the UK North Sea system due to the expansion of the offshore wind industry?
>
> RQ3: How could social-ecological perspectives complement the marine spatial planning process in the UK North Sea?
>
> RQ4: What can social-ecological systems research reveal about how the offshore wind industry affects a transformation towards a sustainable blue economy in the UK North Sea?

The thesis addresses these RQs over a sequence of six further chapters. Chapter 2 outlines the theoretical and conceptual underpinnings of the thesis through a literature review on SES, marine governance and blue growth. Chapter 3 details the methods and frameworks used in the thesis' three empirical chapters. In Chapter 4, a focus group-based scoping exercise reveals the perceived relational layout of the UKNS social-ecological system, with a skew towards the offshore wind industry. Chapter 5 involves in-depth analysis of complex and nuanced interactions taking place between the offshore wind industry and other marine and coastal social-ecological entities, using expert interviews and the social-ecological action situations framework. In Chapter 6, the empirical data is combined into a fuzzy cognitive map, which models system change under different offshore wind energy expansion scenarios. Chapter 7 draws on the results of the empirical chapters to explore how social-ecological analyses are complementary to the MSP process, and lend weight to geographical critiques of blue growth that must be considered in the transformation to a sustainable blue economy. A diagram showing how the research aims, ROs, RQs, methods and chapters are aligned in this thesis can be found in Figure 1.1.

Chapter 2: Literature Review

Much of the conceptual toolkit for this thesis comes from work on complex adaptive systems (CAS) and the field of social-ecological systems (SES). In this chapter, I outline the concept of a CAS, review work on SES and meld it onto the UK North Sea (UKNS) as a case study. Throughout the rest of the review, the emergence of modern marine governance (including marine spatial plans), and debates on blue growth are explored and linked with the SES toolkit. By doing this, the chapter introduces the primary conceptual ideas used in the thesis for thinking about the relationship between the offshore wind industry and other interacting entities of the UKNS.

2.1 Social-Ecological Systems

The core notion of this broad research area is that the delineation between social and natural systems is artificial and arbitrary (Berkes and Folke, 2000), and the concept that people and nature are intertwined is prevalent throughout its literature. This interconnected, whole system view could better frame issues relating to marine conflict in MSP by providing a more widely inclusive and balanced approach to management. A key distinction of SESs from other human-nature approaches such as human-environment systems, coupled human natural systems, and socio-natural systems is the emphasis of SESs as CAS (Biggs et al., 2021). A CAS exhibits nonlinear behaviour which emerges from the interactions of its different parts. It also has the capacity to adapt, evolve, and learn (Levin, 2002). CAS contain adaptive components, which allow systems to change and evolve over time in response to changes in the system context as well as feedbacks (Preiser et al., 2018). These features exist throughout real world systems but were first incorporated into systems theory by ecosystem scientists (Hartvigsen et al., 1998). Their inclusion into human-nature approaches helps bring researchers closer to understanding how systems behave and evolve over time.

2.1.1 The UK North Sea as a social-ecological system

Within the set of interdisciplinary frameworks known as SES (Biggs et al., 2021), the UKNS can be viewed as a CAS, which processes through the adaptive cycle at multiple scales (Figure 2.1). The area itself constitutes a dynamic ecological environment, bounded by coastal communities that utilise its resources for themselves and the societies they support. As with any CAS, the UKNS is subjected to patterns of stability and instability that constitute adaptive cycles (Figure 2.1A; Gunderson and Holling, 2002). The UKNS consists of a nested set of these adaptive cycles, which operate at discrete scales in what is termed a Panarchy (Figure 2.1B). At its largest scale, we might consider the UKNS to be entering or within the ***conservation*** stage of the adaptive cycle, which is characterised by high and slowly increasing connectedness, high potential and decreasing resilience. However, within the greater UKNS, sub-systemic, regional and local adaptive cycles are variously processing through all phases at varying rates. Examples of this come with the ***collapse*** of North Sea (NS) cod stocks in the late 1980s (Beaugrand et al., 2022), and the rapid ***growth*** of the Offshore Wind Energy sector since the early 2000's (IRENA, 2019). Both examples demonstrate the social-ecological concept of emergence, as they were novel properties and functionalities of the UKNS SES that could not be explained by their constituting elements alone (Schlüter et al., 2019). They were both the result of complex system interactions and have changed the context of human actions and ecosystem functioning in the UKNS.

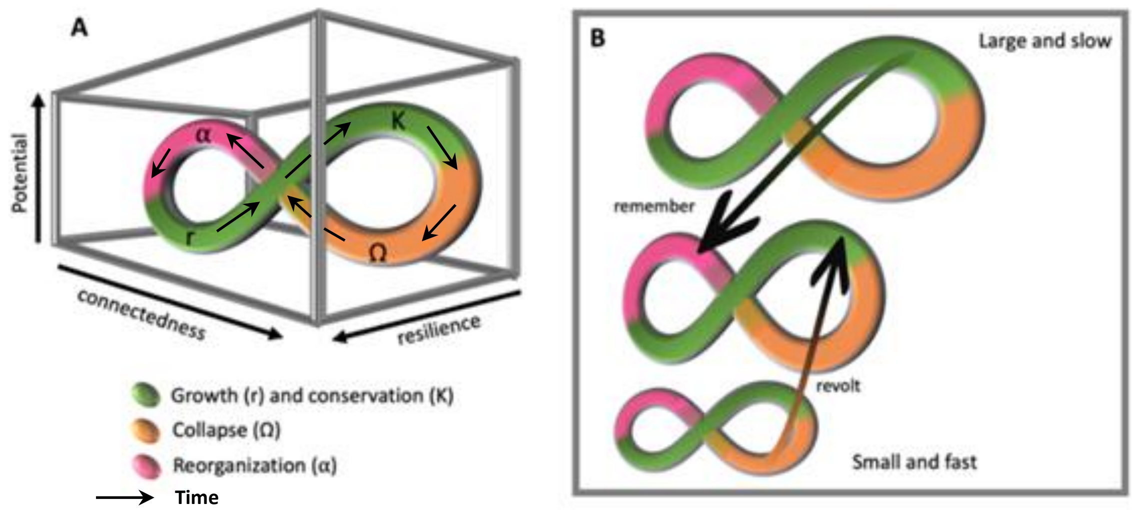

Figure 2.1 The Adaptive Cycle. ***A*** *– shows how potential, connectedness and resilience of CASs vary through time, in the repeated cycle of rapid growth or exploitation (r); to slow growth and conservation (K); collapse or release (Ω); and reorganization (α). Potential determines the number of alternative options for the future. Connectedness exhibits the rigidity of internal control over external forces. Resilience determines how vulnerable a system is to external surprises or disturbances that can exceed or break that control.* ***B*** *– shows a nested set of adaptive cycles affecting one another at a range of scales – "The Panarchy", which is how SES can be viewed. Revolt and remember processes connect scales of the adaptive cycle within a Panarchy. Revolt describes how a faster, smaller scale collapse can cascade up to larger scale, lower resilience stage adaptive cycles to create novelty. Remember describes how lower level reorganisation draws on the potential and context from the system memory at larger and slower scales. Graphic and some theory obtained from Ammar (2021), core theory from Gunderson and Holling (2002).*

The collapse of the NS cod stocks also shows that this area, like any other CAS, exhibits tipping points. In the literature, when tipping points are passed regime shifts are induced. These abrupt changes of steady state (often towards a state of lower productivity) have often been associated with the ***collapse*** stage of the adaptive cycle (Gunderson and Holling, 2002; Figure 2.1). A return to what is often the more desired, higher productivity steady state (in this example, higher cod stocks) is often not possible. Tipping points have often been most clearly catalogued through changes in ecosystem composition, despite their prevalence through many scientific fields, from SESs to ice flow dynamics and societal transformations (Milkoreit et al., 2018). Such changes have already been seen in the NS with the collapse of cod stocks (Beaugrand et al., 2022; ICES, 2023), and regime shift dynamics have also been shown to exist in five other highly valued fish stocks in European waters, where despite fisheries management that explicitly aimed to recover stocks, some fish species have been unable to recover (Blöcker et al., 2023).

The expansion of offshore wind in the NS could potentially cause social-ecological tipping points to be reached. For example, Daewel et al. (2022) have recently used numerical modelling to confirm that increased wind wakes caused by offshore wind turbines would produce large scale changes in primary production, reduce ocean currents, and decrease dissolved oxygen levels in the southern NS. Fundamental biophysical changes such as these could push the UKNS SES towards a tipping point. Regime shifts could also lead to "positive" outcomes for the UKNS: Hooper et al.'s (2017) review of a mixture of effects of offshore wind farms on ecosystem services found that their negative effects do not dominate. In fact, offshore wind farms can support commercial fisheries by providing nursery habitats for key species, whilst also helping with waste remediation and carbon sequestration by the blue mussels that grow on turbine foundations (Hooper et al., 2017). In addition, Li et al. (2023) found that artificial reefs created by offshore wind farms could lead to a doubling of benthic species richness and a two-order-of-magnitude increase in species abundance. In these latter studies, it is suggested that offshore wind energy installations have beneficial, stabilising effects as opposed to destabilising effects that could push the ecosystem closer towards a detrimental tipping point.

Processes in the UKNS Region are strongly connected, despite occurring at differing rates and scales. Every action and interaction contributes to the overall functioning and phasing of this CAS, and yet due to increasing complexities at grander scales, the largest and slowest cycles (Figure 2.1B) – i.e. the scales which marine management practitioners should be most concerned about - have rarely been the focus of investigations (Lauerburg et al., 2020; Figure 2.2).

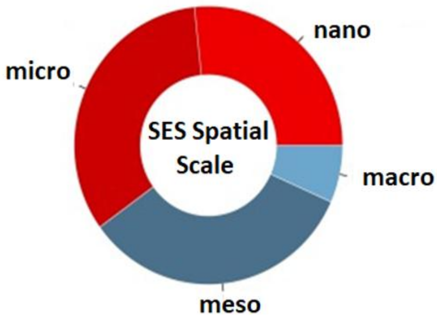

Figure 2.2 The proportions of various marine SES study spatial scales, with macro scale studies being the least well explored scale (Lauerburg et al., 2020). Total reviewed studies: 38.

2.2 Modern Marine Governance Frameworks

Where SESs provide theories, frameworks and methods to develop a holistic perspective of how complex systems function, marine governance concerns “the myriad ways in which groups of people attempt to solve collective action problems, deal with externalities, and ensure the provision of public goods” (Florini, 2008, p.1). SES can contribute to marine governance by making clear the effects of management decisions in complex and rapidly evolving environments. Emerging industries, such as the offshore wind industry, challenge existing marine governance frameworks, which are evolving from single sector management to more integrated and holistic models (Wright, 2015). The core aspects of modern marine governance frameworks are management of ocean space, resource management, environmental impacts, and rights and ownership – which are all challenged by offshore renewable energy developments (Wright, 2015). These core aspects will be incorporated through this review, through SES as a complementary research field, and blue growth as a vision for marine governance. The following section explores the management of ocean space, which is dominated by the eclectic toolset known as MSP.

2.2.1 Marine spatial planning: origins and global context

MSP was borne from a convergence of interests from different fields onto the challenge of managing the balance between conservation and development of three-dimensional marine space over time (Ehler, 2021). This convergence has made MSP inherently multidisciplinary, which increased the variety of available methods and processes. As a result, there is a wide variety of forms of MSP worldwide, with no single best method evident (Trouillet, 2020). Principles of SES have tended to only overlap with MSP design on the broadest of conceptual scales: acknowledgment of the interconnected nature of systems, seeing humans as a part of the ecosystem, and adaptive management forming the backbone of both (Kirkfeldt, 2019; Biggs et al., 2021). The research field and set of methods and processes also share the broad goal of achieving sustainable use of the marine environment.

One goal of MSP across the globe is to act as a set of processes that aid in the execution of an ecosystem-based approach (EBA) to marine management (The European Parliament & The Council of the European Union, 2014; Smith & Jaleel, 2019). This goal has been discussed and promoted by coastal managers since the early 2000's (Domínguez-Tejo et al., 2016), and at least 75 countries are exploring MSP across the world (Ehler, 2021). The complex concept of EBA itself, which is formed by a set of principles and objectives, contributes to the variety of MSP methods and processes used. This has resulted in the infrequent inclusion of several EBA principles into MSP (Domínguez-Tejo et al., 2016). Increasing complications arise as EBA is often interchanged with Ecosystem Based Management and an Ecosystem Approach by different groups who also adapt the concept's meanings to suit their own agendas. Overall, these terms have similar sets of principles and objectives to EBA, but with key additional inclusions, such as the principle to consider ecosystem services (Kirkfeldt, 2019). However, like the blue growth and blue economy terms discussed later in this chapter, their definitions are melded to suit the needs of different marine users, meaning there is no single, universally accepted definition.

The primary focus of MSP tends to either be marine ecosystem conservation or enabling development of economic activities (Trouillet, 2020), perhaps due to the direct limit each objective places upon the other. An example of MSP that tended towards the former goal is The Great Barrier Reef Park Act of 1975 – now known as one of the earliest examples of MSP – which focussed on conserving socio-cultural heritage and enhancing tourism through conserving the phenomenal biodiversity of the Australian Great Barrier Reef (Hassan and Alam, 2019). An example of tending to the latter objective is MSP off the coast of Massachusetts, which prioritised increasing the area's overall economic value. An ecosystem service-based trade-off analysis here highlighted that MSP benefitted the local economy by billions of dollars (White et al., 2012).

Such far flung locations across the world understandably have very different MSP objectives, but unbalancing of the MSP process towards economic development or (less frequently) ecological conservation (Ehler, 2021) is not cohesive with the holistic EBA aim of the MSP process. Furthermore, though there is some focus on trying to balance ecological and economic objectives, Domínguez-Tejo et al. (2016) found that most marine spatial plans do not effectively integrate social sciences approaches and the development of social objectives. Such integration could improve understanding of non-market and cultural heritage values.

A perfect world of intersubjective rationality where planning processes such as MSP are unbiased does not and cannot exist. Real world planning is subjected to power dynamics, differences in value, and resultant conflicts of interest (McGuirk, 2001). As such, planning is disproportionately influenced by those in higher stations of power, which often correlates with economic influence in society. Given this situation, it may be more beneficial for research to be aimed at developing methods and processes for MSP that can more effectively convey the value of ecological and sociological inclusion in planning for the UKNS system.

2.2.2 Marine spatial planning in the North Sea

Marine Spatial Plans of the NS tend to prioritise economic development above other system necessities (Ehler, 2021), although creators of the UK plans – MMO and Defra, would argue that they strive to make environmental concerns central to the Marine plans of England at least (for example, Defra, 2021). NS plans also share more similarities with each other than many other global Marine Spatial Plans, due to the legal frameworks used to develop them (Casimiro & Guerreiro, 2019) and the relative physical and ecological homogeneity of the region. Despite this, different approaches are used by NS countries regarding management decisions within MSP. This is because systems that appear objectively can have differing context dependencies, which change the nature, intensity and probability of social-ecological interactions (Klinger et al., 2018), and therefore the way MSP has developed.

Some interactions between the same sectors may be similar across different parts of the NS, and therefore data collected for one planning area may be useful for understanding another (Burgess et al., 2018). Thus social-ecological data gathered in this project to complement UK North Sea MSP may be of use in understanding how other regional North Sea or UK-based marine systems are organised.

The fragmented nature of nine separate Marine Spatial Plans in one relatively small epicontinental basin has caused issues in inter-regional cohesion and work to connect NS MSP processes together has been ongoing since 2016. The NorthSEE (Shipping, Energy, Environment) project, for example, ran until 2021 and aimed to increase MSP coherence in key incompatibility areas (Lukic et al., 2020). It was funded by the EU regional development fund along with a host of national and academic partners from the North Sea bounded EU countries (European MSP Platform, N.D.). Shipping routes needed to be connected, energy infrastructure such as pipelines and electricity cables would often cross EEZ boundaries, and marine life pays them no heed. These transboundary issues hint strongly of a need to view the NS as a whole system, and the NorthSEE project does make moves in this direction by endeavouring to connect marine spatial plans in the region. Yet despite clear intentions of inclusivity, the NorthSEE project did not incorporate partners from England and Norway (as they are not part of the EU) or France (perhaps due to the diminutive size of its North Sea EEZ), and so these countries' MSP processes were included only by mention in the NorthSEE project (Lukic et al., 2020). This may set some limits on the utility of project results, especially given that England and Norway's EEZs are two of the largest in the North Sea.

As has happened before with inter-regional projects (see the Balt-Coast Project (2006), for example), the NorthSEE project partners broke their work into three more digestible sectoral packages. However, in contrast to other cross-border MSP projects, NorthSEE brought the completed work back together into a computer simulation game and board game known as the MSP Challenge (NorthSEE, 2021). This game is used to educate decision makers, stakeholders and students on management of the maritime economy and the marine environment.

Simulating the marine system, say the creators of the MSP Challenge, helps to critically engage the human agents of a marine space, by enhancing data visibility and demonstrating future consequences of planning decisions on other agents within the system (MSP Challenge, 2023). If executed correctly, this kind of stakeholder engagement could be a useful tool in answering the call from Domínguez-Tejo et al. (2016) for greater inclusion of social values in MSP decision making.

Where ideally this thesis would follow on with initiatives which link the different NS EEZs together, this direction cannot be taken for two reasons. First, including perspectives from a range of users across nine NS countries is beyond the scope of a doctoral dissertation. Second, an aim of this project is to produce SES results that are complementary to MSP, but MSP across the NS is at variable stages of development (Lukic et al., 2020). The decision has therefore been made to have the study boundaries of this SES as the jurisdictional boundary, despite the social-ecological connectedness of the UKNS to the rest of the NS. Future work could consider the NS as a whole system, taking into account issues that arise at transnational boundaries.

2.2.3 Statutory MSP in the UK North Sea

The overlap of the UKNS study area with established MSP areas is outlined in Chapter 1. In English waters, the Marine Management Organisation (MMO) are responsible for preparing marine plans in each marine plan area, which aim to be monitored and reviewed on a regular basis (MMO, 2014b). These regional plans set out visions and objectives for social benefit, economic growth and environmentally sustainable development (Slater & Claydon, 2020), alongside plan policies which give effect to and conform with national policies (MMO & Defra, 2014). In Scottish waters, Marine Scotland are responsible for the production and implementation of Scotland's national marine plan.

Through devolution, inshore areas are directly legislated through Scottish parliament, whilst the offshore is legislated through UK Parliament, which follows a system of marine management laid out in UK's marine and coastal access act (Slater & Claydon, 2020; UK Parliament, 2009).

Of the 11 regional marine plans in English waters, the East Inshore and East Offshore plans were the first UK plans to be adopted in 2014 (MMO & Defra, 2014), a year before Scotland's national marine plan was adopted (Slater and Claydon, 2020). The structure and contents of these plans were mimicked by plans for other English marine regions, which were published in 2021 (e.g. MMO & Defra, 2021). The plans are designed to "inform and guide regulation, management, use and protection of the marine plan areas" (MMO & Defra, 2014, p.8), and have been developed over a number of stages, which include: developing a stakeholder participation strategy, evidence collation and analysis, generation of plan options and options analysis, habitats regulations assessment, and sustainability appraisals (MMO & Defra, 2014). Evidence is internally quality assured and comes from a range of sources - from spatial data, to policy documents, third-party research reports and specifically commissioned research. Planning is defined by a vision of the marine environment in 20 years time, which leads to definition of a set of objectives for the marine area. A set of plan policies (which conform with national policy) in turn inform how decisions should be made to reach the objectives and vision of the marine plan (MMO & Defra, 2014). Each objective has at least one directly associated policy and a raft of contributing (indirect) policies. Finally, it is the responsibility of public authorities to ensure that decisions take account of plan policies (MMO & Defra, 2014).

2.2.4 Social-ecological systems to aid UK North Sea marine spatial plans

SES could be an important research field when it comes to balancing MSP's three aims of economic development, social values and ecological conservation in the UKNS, as there is increasingly a call for MSP to incorporate different disciplinary perspectives to resolve its own internal debates[3] (Trouillet, 2020). SES itself is designed to aid in the understanding of human-nature relations, or perhaps more accurately, the trade-offs between biophysical and socio-economic resilience within a system (Young et al., 2006). Such an approach, which shifts focus towards component interactions as opposed to components themselves, would suit the process of MSP, which looks to meet ecological, social, and economic objectives synchronously by understanding how to best fit everything together.

However, integration of SES and MSP can encounter difficulties. Where SES and CAS are radically open systems, with energy, information and matter exchanged between the system and its

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[3] Trouillet (2020) finds that MSP theoretically appears to be a process benefitting all marine use. However, when practically applied MSP tends to be unbalanced towards either sectoral economic logics, or from conservationist objectives.

environment (Preiser et al., 2018), marine spatial plans are specifically designed for bounded spaces and have practical and applicable objectives and limits. In the related field of landscape planning, Martín-López et al. (2017) have delineated social-ecological systems boundaries at the local scale through a process of mapping ecological units and biophysical variables, then mapping municipalities based on socio-economic variables, before integrating these map layers. In this thesis, the regional scale biophysical and socio-economic units do not directly overlap. The biophysical unit is the Greater North Sea ecoregion (ICES, n.d.), whilst the socio-economic unit is exclusive economic zone and coastlines of the United Kingdom. The overlapping area, outlined in Figure 1.1, becomes the study area.

As SES studies have trended from theoretical to being applied in real-world scenarios, and MSP is increasingly accepting of new interdisciplinary perspectives (Trouillet, 2020), there has been a boundary-based conceptual convergence between them which hints at the importance and necessity of reaching balance between a radically open and practically closed system. As discussed in section 2.2.2, there are increasing efforts for MSP to be more accepting of the cross-boundary nature of ocean activities. The NorthSEE project is a good example of this – endeavouring to tackle issues beyond the scale of an individual EEZ (Lukic et al., 2020). Equally, SES research is evolving to aid in the achievement of bounded, practical objectives. Smith et al. (2025) highlight how a range of SES frameworks have been practically applied in marine management contexts. They emphasise that a Simple SES approach - maintaining the minimum complexity necessary to understand marine management situations – is crucial to ensure an adaptive marine management process that can be applied in multiple contexts.

The broader framing of SES incorporates several underlying research areas, such as adaptive governance, resilience frameworks, and transformations towards sustainability. Frameworks have been developed within and between these research areas which specify ways to conceptualise a SES. Through interrogation of *The Routledge Handbook of Research Methods for Social-ecological Systems* (Biggs et al., 2021) and other resources, I identified the most suitable social-ecological frameworks and associated methods to understand the NS more deeply within the context of the aims of this thesis.

A smaller scale example of the potential of an SES approach to advance marine sustainability is presented by Haraldsson et al. (2020), who modelled a CAS of a local community and ecosystem to see how it may be affected by a future offshore windfarm development. They demonstrated that relationships between social and ecological factors within the local system could be illustrated through use of qualitative mathematical models, and that it became possible to predict indirect and sometimes counterintuitive effects of offshore wind farm development even with relatively simple models. As it has on this smaller scale, a deeper understanding of the complex interactions between the components of a system could foster more informed and robust decision making for marine management which could ultimately bring MSP further towards its goal of an EBA.

Simulations such as the MSP Challenge and other models have continued to increase our understanding of the complex, non-linear relationships at play throughout the marine SESs such as the NS over the past couple of decades. Of the three SES subsystems (social, ecological, and economic), ecological modelling, which at larger scales becomes ecosystem modelling, has been developed furthest. By 2015 in the UK – a world leading nation for modelling - there were 14 active marine ecosystem models which analysed a vast range of ecological and physical characteristics (Hyder et al., 2015). Unfortunately, the few models that were being used to support decision making were only applicable to specific issues, such as harmful algal bacterial blooms. This was due to the difficulties of integrating economic and social factors into these models, which meant that instead of realistic, complex and ever-changing socio-economic conditions, models could only work with an array of set-in-stone anthropogenic influences (Hyder et al., 2015).

Through their review, Hyder et al. (2015) showed that the Atlantis (Audzijonyte et al., 2019) and Ecopath with Ecosim (EwE) (Colleter et al., 2015) modelling approaches had the most potential for integration of social and economic factors. Eight years later, the Ecopath organisation is squaring up to the transboundary coordination and connectivity issues that MSP is currently facing. Their MarinePlan (2023) project, which is running between 2022 and 2025 and coordinated through Thunen University, is aiming to co-develop a decision support system with marine stakeholders to create an ecosystem-based marine spatial plan for European seas. It remains to be seen how much SES thinking will be incorporated into this project, but that their plan is to apply their tools in "differing social-ecological" settings is encouraging language. Whilst it is not within the scope of this thesis to couple any qualitative model findings with EwE modelling, it is a promising direction for future research, as suggested by Giabbanelli et al. (2017).

2.3 Achieving Blue Growth: A Blurred Vision for Marine Management

MSP carries the underlying assumption that through balance, its triple aims - economic development, environmental protection and social value - can be achieved. Whilst one goal of MSP has been to achieve an EBA for marine management, the broader vision for this set of tools is to help in the achievement of the blue growth concept – which broadly calls for sustainable development and holistic management of complex marine social-ecological systems (Burgess et al., 2018).

Blue growth is an oceanic extension of the green growth concept, and both terms share a contested history due to their conceptual vagueness. Green growth took centre stage at The Rio + 20 conference, a lead-up event to the 4th conference on Sustainable Development (Eikeset et al., 2018). Months later, the first notable use of the term blue growth occurred in February 2012 at the World Oceans Summit when Robert Zoellick, then President of the World Bank, announced the World Bank's Global Partnership for the Oceans. Within this speech, he said:

"At a time when the world is looking for sources of growth, there is huge potential for "blue growth"—wisely preserving and investing in the value of ocean ecosystems to fight poverty and improve lives" (Zoellick, 2012).

Since that time, the term has become a buzzword within the marine management discourse (Hadjimichael, 2018), used by politicians, scientists, and stakeholders alike to further interests in the ocean space (Eikeset et al., 2018). Eclectic use of the term has caused divisions in its agreed upon goal – either to maximise economic growth, or to maximise inclusive economic growth whilst preventing degradation of blue natural capital. As such, blue growth carries conceptual ambiguity. It means different things to people from different disciplines, who themselves can lack the ability to see things from other disciplinary perspectives (Eikeset et al., 2018). This ambiguity is further increased with the interchangeable use of blue growth with other emergent terms in ocean management discourse, such as blue economy, the ocean economy, and the marine economy. Martínez-Vázquez et al. (2021) review similarities and differences in these terms, highlighting that blue growth and blue economy share common elements of the economy and protection of marine ecosystems to ensure sustainability. However, as both terms are rooted in sustainable development, they exclude industries which conform to economic exploitation without a focus on a sustainable maritime environment – such as the oil and gas and deep sea mining industries (Voyer et al., 2018). These industries are captured instead by marine economy and ocean economy terms.

Blue growth and the blue economy are interrelated terms; blue growth being predicated on the idea that the blue economy could continue to expand without impacting planetary sustainability (Ertör & Hadjimichael, 2020). Like blue growth, the blue economy also gained institutional recognition at the Rio +20 conference in 2012 (Silver et al., 2015), and is still subjected to a range of interpretations and uses as part of country-level political agendas and intergovernmental policy tools (Ceglia, 2024). Silver et al. (2015) identified four porously bounded discourses in blue economy from an ethnographic analysis with the Rio +20 conference attendees: oceans as natural capital, as good business, as integral to Pacific small island developing states and as small scale fisheries. Three years later, Voyer et al. (2018) highlighted four lenses of the blue economy – corroborating Silver et al.'s

(2015) oceans as good business and natural capital, whilst adding oceans as livelihoods (aligned with the Silver et al. (2015) themes of oceans as integral to pacific small island developing states and oceans as small scale fisheries livelihoods) and as a driver of innovation. Both studies highlight the malleability of the blue economy term, whose sub-themes are not exclusive to a particular lens.

Blue growth shares these malleable qualities, and can therefore be considered a boundary object (Star, 1989) in the sense that varied interpretations have contributed to its broadness and plasticity, with a lack of consensus drawing many groups to it (Brent et al., 2020). Consequently, there is a call for more interdisciplinary research rooted around blue growth, as well as into some of the tensions concealed within the term. This can be well met by research into marine SES which takes a whole-system perspective. However, studies of this nature may reveal dynamics that undercut some blue growth assumptions. For example, arguments for blue degrowth suggest 'sustainability' and capitalist 'development' are fundamentally opposing forces, thus offering a critique of the blue growth agenda (Hadjimichael, 2018). The following section explores some of the key debates around blue growth, starting with whether two of the core aspects of modern marine governance - resource use and environmental management (Wright, 2015) - are reconcilable. It then covers some critiques of blue growth, which mostly concern the remaining core aspect of marine governance – rights and ownership. Blue growth is first reframed as a series of 'blue fixes' to the problems of capitalist development (Brent et al., 2020) and then critiqued for leading to blue injustices (Bennet et al., 2020).

2.3.1 Blue growth, resource use and environmental management

Proponents of blue growth and economically focussed MSP argue that the economy can continue to expand without negatively impacting planetary sustainability (Ertor & Hadjimichael, 2020), as new technology helps to decouple GDP from resource use and CO_2 emissions. In response to the promise of exciting new frontiers for growth, governmental entities have released strategies for blue growth in recent years, including the EU Blue Growth Strategy, which focusses on five main growth sectors: marine aquaculture, coastal tourism, marine biotechnology, ocean energy and seabed mining (European Commission, 2012). In the UK context, blue growth is used synonymously with the more frequently used but slightly older term blue economy. These terms share common core elements - economic growth and the protection of marine ecosystems to ensure sustainability. Their differences are that blue growth champions holistic management – making it more suitable for social-ecological methods - whereas blue economy has added focus onto social systems and commercial development (Martinez-Vasquez et al., 2021).

Blue growth that incorporates holistic management is considered advantageous because of the proven folly of separate management of interacting components, leading to sub-optimal outcomes at the system level (Burgess et al., 2018). Furthermore, ocean management models and projections become biased when they fail to account for interactions of the other components of a system. Therefore, one blue growth imperative should be to develop a multi-sector approach to ocean management: working out how different marine sectors interact, and how those interactions could be optimised (Klinger et al., 2018). There is often a lack of information on such interactions, and on how changes in one sector affect the incentives and interactions of others. As a set of theories, frameworks and methods which seek to incorporate varied attributes in the search for emerging system properties, and one which focusses more on the interactions between components of a system than on the components themselves (Preiser et al., 2018), SES research is suited to contribute to the study of this part of the blue growth discourse.

The original 'state of the art' practice of the blue growth concept - The EU's Blue Growth Strategy (European Commission, 2012) and Maritime Fisheries Policies (e.g. European Union, 2013) - have been critiqued as being predominantly economically focussed, with job creation as the only social component (Hadjimichael, 2018). As the blue growth concept has been adapted into the mainstream, and in many cases has become a national economic imperative, a blue degrowth counter-narrative is evolving from critiques of the infinite growth paradigm (Ertor & Hadjimichael, 2020) that would suggest that increasing resource use cannot be achieved whilst retaining or improving the quality of environmental management . Degrowth is defined as an equitable down-scaling of production and consumption that increases human well-being and enhances ecological conditions at the local and global level, short and long term (Schneider et al., 2010). It is a call to de-link sustainability and growth, based on perceptions that environmental sustainability is not compatible with economic growth (Hadjimichael, 2018).

2.3.2 Reframing blue growth

In one critique, blue growth is reframed as a series of blue fixes by Brent et al. (2020), based on work by Harvey (2001), who championed the geographical concept of the spatial fix. The spatial fix refers to capitalism's insatiable drive to resolve inner crisis tendencies by geographical expansion and restructuring. Through this lens, blue growth can be seen as a geographical expansion of production to the ocean, to temporarily overcome land-based limits and ensure continued reproduction of capital. The UNCLOS conventions have been conceptualised as a spatial fix by Steinberg (2001), as expanding fisheries and offshore mineral extraction resulted in state territorialisation of coastal waters through these conventions. Claiming sovereignty of coastal waters constituted a geographical restructuring of the ocean, which paved the way for industrial expansions. Another step towards the blue fix concept is the socio-ecological fix. This concept expands on the spatial fix to incorporate how landscapes, processes, human and non-human organisms and socio-natural relationships are transformed, as well as how labour processes are restructured, in order to address or offset the social and environmental crises of capitalism (Ekers & Prudham, 2015). The trend from spatial to socio-ecological fixes, and more recently blue fixing reflects increasing consideration for the plethora of interactions that industrial expansion and restructuring has on the systems within which it occurs. Reconceptualisation of blue growth as a selection of blue fixes can uncover re-workings of the use and control of ocean space (Brent et al., 2020), which in their capital-focussed wake could have significant social-ecological consequences.

Of the blue fixes identified by Brent et al., (2020), the 'energy fix' is most relevant to this project. The energy fix is often framed as a response to climate change concerns; by expanding energy production into the ocean, it should be possible to decouple it from greenhouse gas emissions to help address or offset the environmental crises of climate change. Blue growth discourse related to this energy fix tends to focus on new and emerging renewable energy industries as a response to this threat – with the UK North Sea's offshore wind energy expansion being a prime example. This discourse pulls focus from the goliath of the oil and gas industry, which represents one of the largest forces in the ocean and the global economy (Brent et al., 2020). It is not possible to match the sustainable vision that many hold of the blue growth concept with the expansive consumption of the oil and gas industry, given its widely known local ecological and global climatological impacts. Whilst offshore wind promises fewer global climatological impacts (Allan et al., 2020), there are questions concerning its local and regional social-ecological effects. Reconceptualised as a blue energy fix, the expansion of offshore wind energy has required further allocation of marine space for the purpose of energy generation and capital accumulation, which is in turn increasing the spatial squeeze onto marine spaces such as the UK North Sea. The development of MSP to manage new sessile spatial demands of offshore wind energy (alongside marine protected areas) from the turn of the 21st century (Jouffrey et al., 2020) can be construed as further geographical restructuring of marine space, paving the way for renewables, but limiting access to and use of ocean resources for other users.

2.3.3 Seabed rights and ownership: fixes and injustices

Reframing blue growth as a series of blue fixes helps to join it with a core aspect of the modern marine governance discourse: seabed rights and ownership. It highlights that economic growth in the blue is currently dependant on a geographic restructuring of ocean space that typically involves the privatisation of ocean use. In UK waters, The Crown Estate – a publicly owned property business (McHarg, 2016) – is responsible for identifying and leasing suitable seabed sites for offshore wind developments (The Crown Estate (a), n.d.). Leases of marine space for offshore wind developments last for approximately 30 years, though some of the latest leasing rounds allow for 60 years of continued retrofitting and operation (The Crown Estate (b), n.d.). Exclusive rights to the seabed lie with the wind developers over this time, and though public rights for fishing and navigation are still enforceable, the government can limit these rights when granting consents for offshore wind developers (Todd, 2012). Offshore wind developments are privatising a use right, which has the potential to create conflicts with public rights such as fishing and navigation, other private rights, and perceived rights of communities and existing marine users (Wright, 2015).

Privatisation of ocean space has also been referred to as 'ocean grabbing,' and is one of ten themes of social injustice that ocean-based economic developments have produced (Bennett et al., 2020). These blue injustices depict the struggles of communities against blue growth projects, and collectively fall under the blue degrowth banner. Four additional themes identified by Bennett et al. (2020) are considered of high relevance to this thesis:

- undermining livelihoods of small-scale fishers,
- inequitable distribution of economic benefits,
- social and cultural impacts of ocean development, and
- exclusion from decision making and governance

To not repeat past injustices, Bennett et al., (2020) claim that blue justice should be at the centre of the blue growth agenda, but that this may require a complete rethinking or transformation of blue growth itself.

SES methods which help to illuminate the relationships between the offshore wind industry and other ocean users, such as coastal communities and small-scale fishers, could be used to explore the realities of what blue growth in the UKNS looks like now, and how it could look in the future. They can help to paint a picture of the complex social-ecological transformations that are currently unfolding - a result of the need to 'fix' our energy system by decoupling it from greenhouse gas emissions. In future work, they could also reveal pathways to more just and inclusive blue growth for marine spatial planning authorities. A deeper understanding of how parts of the UKNS are interconnected could help in understanding the complex adaptive feedback processes that are happening in the area, which could in turn hint at emergent crises that the current socio-ecological energy fix may be unwittingly producing.

2.4 Conclusion

This chapter has reviewed relevant literature on social-ecological systems conceived as complex adaptive systems. It has enabled me to characterise the UK North Sea as a complex social-ecological system, within which dynamic, non-linear, and multi-scalar interactions have the potential to generate emergent phenomena. The effects of the continued and projected expansion of offshore wind energy are not well understood in this system, which poses challenges for the core aspects of modern marine governance: management of ocean space, resource use, environmental management, and rights and ownership.

These core aspects have been explored through the rest of the review, beginning with the management of ocean space. This is spearheaded by the regionally varied marine spatial planning (MSP) toolset, which tends to prioritise economic over ecological and social objectives in the North Sea. An interconnected, whole system, social-ecological perspective could complement UK North Sea MSP, by helping to incorporate the complex relationships between different entities.

Drawing on more geographical themes, this review then discussed how marine spatial plans are enacted to achieve the vision of the blue growth concept, which broadly seeks to balance resource use with environmental management. Proponents of blue growth argue the economy can continue to expand whilst marine ecosystems are protected and flourish. Critiques are centred around the economic focus of blue growth strategies: blue degrowth is a direct rejection of the infinite growth paradigm, and a call to downscale production and consumption thereby increasing human wellbeing and enhancing ecological conditions. The blue fix is a reframing of blue growth as a geographical expansion and restructuring of ocean space to temporarily resolve capitalism's inner crisis tendencies. A final critique - blue justice, which falls under the umbrella of blue degrowth, is a call to break free from past patterns of marine social injustice that haunt ocean developments, by transforming and rethinking blue growth itself. Both blue fixes and injustices speak to the rights and ownership aspects of marine governance.

Social-ecological systems research provides a way to examine across disciplines which visions of blue growth are currently being enacted in the UK North Sea. It will further allow us to explore how offshore wind developments are and will increasingly affect other marine entities and so could be complementary to the development process of MSP, helping it to incorporate interactions between different UK North Sea entities, and uncovering complex and non-linear relationships that characterise the area. SES research could also contribute to uncovering the feasibility of various interpretations of the blue growth concept itself and reveal the robustness of its various critiques. A fuller understanding of the expansion of offshore wind in the UKNS could help reconfigure prevailing visions of blue growth by, for example, pivoting it towards blue degrowth, a greater inclusion of blue justice, or a reframing of blue growth as a blue fix.

Chapter 3: Research Design and Methods

My research design follows on from the research questions (RQ), objectives (RO) and overall aims outlined in Introduction, with the overall layout displayed in Figure 3.1. Answering these questions requires a research design that allows for interrogation of the complex relationships between different entities of a system, from a range of experts with differing backgrounds and disciplinary perspectives. Development of a central, semi-quantitative and unitless relational model that all participants can contribute their knowledge to, and that can be eventually ran to better understand how offshore wind as an agent of blue growth could affect the UK North Sea system is crucial. To make this model as robust as possible, the most complex, nuanced and uncertain relationships will require deeper analysis, the results of which should be re-applicable to the central model. Given these design requirements, this research has been split into three phases, the methods for which are detailed in this chapter. The first is a system scoping exercise, to build a skeleton model which shows how different entities of the system are linked. The second phase fleshes out the most complex, nuanced or uncertain relationships identified in the first to validate the relationships and bring the model closer to what it is aiming to replicate. It uses the social-ecological action situation (SE-AS) framework to achieve this. Results of the first two phases are combined to answer RQ1. The third phase seeks to answer RQ2, 3 and 4, by running several offshore wind expansion scenarios through a network model which are developed through the first two phases and analysing the results.

This chapter starts by outlining the need for - and selection of - an established SES framework for the thesis. It then delves into the process for method selection in social-ecological systems studies, which involves defining the characteristics of the research problem and pinpointing the most appropriate methods to use for this thesis. Methods forPhase 1: Scopingaid with system scoping, which involves facilitating focus groups to generate fuzzy cognitive maps (FCMs) and qualify the power and interest different stakeholder groups have in the expanding offshore wind industry. Methods forPhase 2: Divingdescribe the process of preparing and running expert interviews designed to explore the complex relationships between offshore wind and other UK North Sea entities. The methodological process for Phase 3: Modelling describes how results from the first two phases are combined, as well as the process of running a scenario showing how an expanding offshore wind industry could affect other entities in the UK North Sea.

Figure 3.1 Chart to show the various links between research aims, objectives (RO), questions (RQ), methods and chapters for this thesis. Aim 1 and associated must be complete in order to tackle Aim 2. Research aims, objectives, and questions are in Chapter 1. Method phases are found in this chapter. Relevant abbreviations: MSP: Marine Spatial Planning, SES: Social-Ecological System, SE-AS: Social-Ecological Action Situation, UKNS: United Kingdom North Sea

3.1 Social-Ecological Systems Framework Selection

One or several established SES frameworks are often used to direct conceptualisation of the system. A method used throughout this thesis, Fuzzy Cognitive Mapping (FCM), creates a basic relational framework to aid in the conceptualisation of the relationships between different entities of the system. This was considered robust enough for methodological Phases 1 and 3 (pertaining to results Chapters 4 and 6 of the thesis). However, for Phase 2 which dives into the complexities of important but variably perceived social-ecological relationships, a distinct SES framework was required to help conceptualise and visualise these interactions to a finer degree than the FCM framework could. Through a preliminary exploration of SES frameworks, I deduced that Ostrom's (2009) Social-Ecological Systems Framework was limited in its capacity to aid in this project, as it only focussed on and analysed one resource system (typically not related to energy), as opposed to a distinct set of resources in a system. Similarly, I found that the Social-Ecological Robustness Framework of Anderies et al. (2004) had strong capabilities for analysing institutional arrangements such as those present in the offshore wind industry. However, the framework depicted biophysical disturbances as externalities rather than as interwoven parts of a system, which did not align with the project's aim for a holistic approach. The social-ecological action situations (SE-AS) framework, developed by Schlüter et al. (2019) but originally based upon Ostrom's (1990) institutional analysis and development (IAD) framework, provides a means to segment complex social-ecological interactions into linked action situations. This framework of linked action situations displays the interactions that have jointly and dynamically generated a social-ecological phenomenon of interest and helps to draw focus towards the interplay between social-ecological interactions and the outcomes they produce. A strength of this approach for this thesis is that it presents a clear way to abstract and focus on interactions of interest within a given system, which is the goal for the second empirical chapter of this thesis (Chapter 5). It also considers the multi-scalar nature of systems, which is a weakness of the FCM approach. A downside of the SE-AS framework for this thesis is that it is designed to explain social-ecological phenomena that have already emerged, which is misaligned with this thesis' descriptive and exploratory aims. Overall, however, Schlüter et al.'s (2019) framework represents the best fit for this project, especially as a conceptual framework to incorporate complex interactions between specific entities (Phase 2: Diving). There is novelty also in the use of this framework in an exploratory capacity (without yet knowing the social-ecological phenomena of interest that the expansion of offshore wind in the UKNSR could produce).

3.2 Unpicking the Social-Ecological Action Situations Framework

The SE-AS framework (predominantly used in Chapter 5) uses the concept of the action situation (AS) which describes “events, venues, or physically interdependent instances of decision-making" (Kimmich et al. 2023, p.1). The AS is increasingly used “in bridging the social and the biophysical or ecological side of interdependent decisions” (Kimmich et al. 2023, p.1), but was initially introduced in relation to the management of common pool resources via Ostrom’s (1990) institutional analysis and development (IAD) framework (Kimmich et al. 2023). According to Ostrom (2005), an AS consists of multiple components that include: participants; their positions and potential outcomes; a function turning actions into outcomes; information about how the function is controlled; and information, costs and benefits related to the actions and outcomes. It generalises a game (drawing on game theory) in which participants have a range of available actions that can generate alternative potential outcomes (McGinnis, 2011). This generalisation allows participants internal to an AS to alter their own actions and thus incur a change to the rules of an AS. However, participants have difficulty in viewing how their interactions are intertwined with other AS within a complex, non-linear system and are considered to be boundedly rational – i.e., they are constrained by their ability to process information, as well as by norms and cultural values (McGinnis, 2011).

The language around AS – participants, actions, outcomes - reflects the original design of the AS, as a tool for analysis of social dynamics and institutions, with ecological variables considered as exogenous to the system under examination (Ostrom, 1990). Evolution of the AS to include ecological entities and pay equal heed to the social and the ecological came with the SE-AS framework (Schlüter et al., 2019). Within this framework, linked AS are identified as either social, ecological, or social-ecological depending on the entities involved in the interaction. When the outcomes of one AS affects the rules of another (i.e., the conditions under which an interaction is occurring) they can be considered adjacent action situations that constitute a network (McGinnis 2011) Where McGinnis’ (2011) saw AS within polycentric governance systems being ‘adjacent’, Schlüter et al. (2019) understand them as being linked when their outcomes affect the rules governing other action situations. In the SE-AS framework, a network of linked AS generate an emergent phenomenon – an empirical observation one wants to understand or explain (Herzog et al., 2022).

Non-exhaustive sets of social, ecological and social-ecological AS have been developed in the works of Schlüter et al. (2019), Pahl-Wostl et al. (2020) for water governance, and recently Herzog et al. (2022), who gathered the SE-AS described by the other authors into an appendix, as well as identifying more SE-AS themselves. It is likely that the structure of many of the SE-AS identified by these authors match the dynamics I find through the course of my research, and so I will attempt to align my own SE-AS with the terminology used by these authors. Herzog et al. (2022) also helpfully explain some potential limitations of use of the SE-AS framework, such as the subjectivity of converting causal links identified at interview and through causal link diagrams (such as FCM in my study) into ASs, and how the distinction between AS and their outcomes can be unclear. For more on the methods through which I will operationalise the SE-AS framework, refer to section 3.6.1.

3.3 Method Selection in Social-Ecological Systems

Due to the interdisciplinary nature of studies in social-ecological systems (SES), the range of methods available to researchers in this sub-field of sustainability science is broad, and highly diverse. Strict protocols for method selection do not feature in SES, as many different approaches could be used to generate a deeper understanding of system properties and dynamics (de Vos et al., 2021). There is no 'one size fits all' or universal approach due to context dependence, so method selection is instead principally guided by (de Vos et al., 2021):

- **The identification of the research problem** – in this case to explore the unknown effects of the expansion of offshore wind in the UK North Sea Region.
- **The purpose of the research** - to complement marine spatial planning processes, and contribute to understanding the consequences of a blue growth vision, by improving understanding of the complex interactions between marine entities in this area.
- **The research area that the researcher is embedded within** – this most frequently relates to the area of SES research - such as Adaptive Governance or Resilience Assessment – that the researcher's institution specialises in. However, because I am currently not embedded within any SES specific research institutions, my methods selection and justification will be influenced by the recently released *Routledge Handbook of Research Methods for Social-Ecological Systems* (Biggs et al., 2021b), as well as by my supervisors' research specialities – Resource and Economic Geography, and Marine Macroecology. In addition to this I expect to be influenced by Durham University's Department of Geography that I research from, which situates itself across both the physical and social sciences, as well as by my studentship within Aura CDT. Finally, my own beliefs, judgements, perceptions, skillset and worldview also form part of the area I am embedded within. This latter, more personal set of influences is an important set of considerations within SES and many adjacent fields, termed reflexivity.

This thesis will endeavour to use a pluralistic methodological approach to better understand social – ecological interactions in the UKNS. This means that the current and predicted expansion of offshore wind in this area will be examined using a range of methods from differing academic and non-academic perspectives. Commonly used SES methods have been collated and described by Biggs et al. (2021b), and digestibly differentiated from one another by their key characteristics to aid SES researchers in narrowing down the options when selecting methods for individual projects (Table 3.1).

Table 3.1 Key Characteristics of project specific methods as described in the Routledge Handbook for Research Methods in Social-ecological systems (Biggs et al., 2021a, p.75). To note, some methods here refer to a single method, whereas some titles refer to a group of methods clustered under one distinct banner. Yellow outlines denote preferred characteristics, blue boxes tell us if a method fulfils a certain criterion, red boxes show where certain methods lack a required characteristic.

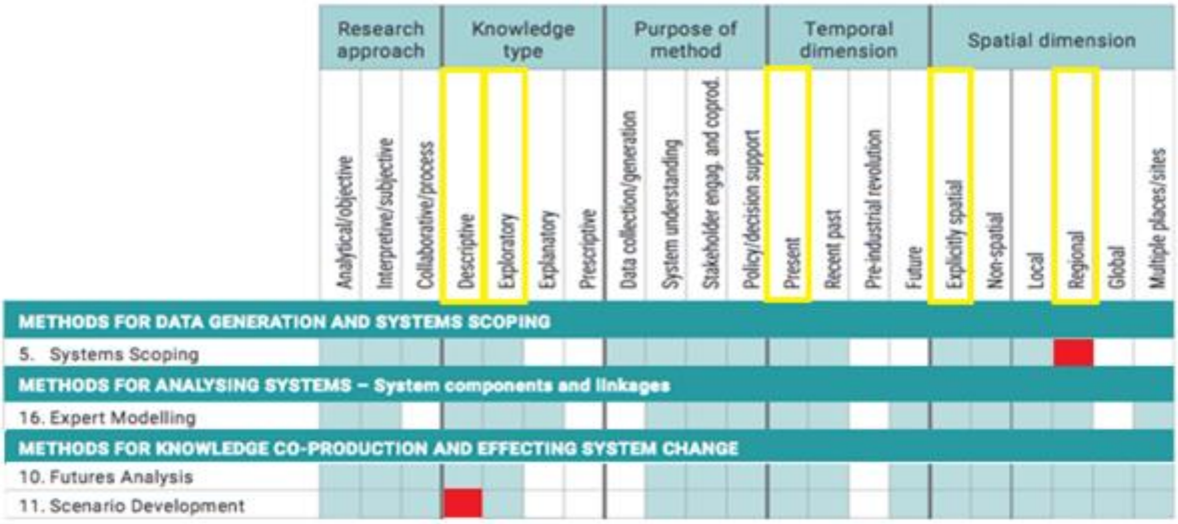


Table 3.1 displays how these differentiations were used to identify key methods to research further for use in the thesis. For this project, the key characteristics that helped narrow down the choices of method were:

- Knowledge type: **Descriptive** whilst gathering data and building up a picture of the system, and **Exploratory** to help predict the effects of the expansion of offshore wind.
- Temporal Dimension: **Present** – which is classified here as occurring within the last 5-10 years.
- Spatial Dimension 1: **Explicitly Spatial**[4] was considered important since these methods are being designed to inform MSP, which itself only uses explicitly spatial methods.
- Spatial Dimension 2: **Regional (provincial/state to continental)** as the focus area for this project is The North Sea.

Based on these project requirements, the following methods were highlighted for further research:

- Systems Scoping (despite lacking regional dimension)

[4] It was considered that not all methods used need to be explicitly spatial, but that certain methods could aid in adding a spatial dimension where others were lacking.

- Expert modelling
- Futures analysis
- Scenario Development

3.4 Methods Used for Each Thesis Phase

The methodological structure of the thesis (found fully in Figure 3.1) has been broken into three phases, loosely designed around the previously mentioned handbook (Biggs et al. 2021b), but named by me. An overview of the methodological layout can be seen in Table 3.2.

Phase 1 – Scoping, has been used to answer RQ1. It seeks to describe and constrain the UK North Sea System using stakeholder analysis (focus groups) composed of AURA Centre for Doctoral Training (CDT) students to identify and categorise social-ecological entities of the UK North Sea, then map their linkages using FCM. Focus Groups also build power-interest matrices to inform how to approach marine experts in Phase 2. Transcript analysis of the focus groups is also used to ratify and confirm the linkage weightings between different UKNS entities.

The results of Phase 1 are used to identify some of the most complex social-ecological action situations for investigation in Phase 2 – Diving. This phase, which also contributes to answering RQ1, uses semi-structured interviews with marine experts to unpick the complex relationships between the offshore wind industry and other significant entities in the UKNS, namely Coastal Communities, Fisheries, and the UKNS Ecosystem. The interview transcripts are analysed and their data displayed and combined using the SE-AS framework.

Many other structures and methods could be used for data gathering in these first two phases. For example, marine experts could share their knowledge through focus groups instead of semi-structured interviews in phase two. This would facilitate the development of a group consensus on which social-ecological action situations and outcomes are occurring in the UKNS (Reed et al., 2009). Furthermore, discussion of complex interactions by experts could aid how they come to be understood. However, focus groups would not be as likely to generate in-depth and detailed responses in the same way as semi-structured interviews can (Reed et al., 2009), and aggregating expert perceptions can be done outside of data gathering to uncover bias.

Additionally, other streams of data could have been used to gather the data. Another method in system scoping for phase 1 could be to conduct a literature review of published materials – both grey literature and peer-reviewed literature – on the topic of the UKNS system (Sitas et al., 2021).

Whilst this may have resulted in a more complete and exhaustive range of UKNS system interactions which portray actual interactions as opposed to socially perceived interactions, this approach has two difficulties. The first is the breadth of the area of interest in this topic - a literature review on interactions between entities of a regional marine social-ecological system would be an immense undertaking beyond the scope of a thesis - instead being more suitable for mapping interactions within a more specific and constrained topic of interest. The second difficulty is the heavy reliance on the ability of the researcher to accurately convert literature review data into relational fuzzy cognitive mapping form. Incorporating subject experts into data gathering (as with through the focus group and interview processes) outsources the expertise required to accurately summarise complexity on in fuzzy cognitive mapping.

Phase 3 – Modelling, has two sub-phases, and will be used as a methodological basis to answer RQ2, 3 and 4. The first is Combining, which brings together results from the Scoping and Diving phases to create a master FCM. The second, Executing, runs the final FCM under several offshore wind expansion scenarios to predict the emergent effects of its expansion in the area.

Table 3.2 shows research methods employed for different stages of the thesis, and which RQs each set of methods is used to answer.

Phase	Sub-phase	Methods	Purpose	Contributes to RQ
Framework Selection		Social-Ecological Action Situations (SE-AS)	SE-AS – provide a framework to follow for Phase 2	RQ1.What are the linkages between different components of the UK North Sea social-ecological system, especially with relation to the offshore wind industry?
1. Scoping		Focus Groups Fuzzy Cognitive Mapping (FCM) Power-Interest Matrices	Focus Groups - data generation FCM – expert modelling, combining data Power Interest Matrices – inform approach to interviews	

		Transcript Analysis	Transcript Analysis – adding complex detail to FCM	
2. Diving	a) Offshore Wind x Coastal Communities	SE-AS Semi-structured Interviews Literature review	SE-AS – framework Semi-Structured Interview – complex data use Literature Review – complex data collection	
	b) Offshore Wind x Fisheries			
	c) Offshore Wind x Ecosystem			
3. Modelling	Combining	Fuzzy Cognitive Mapping	FCM – combining	RQ2 How might these linkages interact together to generate emergent properties of the UK North Sea system due to the expansion of the offshore wind industry? RQ3. How could social-ecological perspectives complement the marine spatial planning process in the UK North Sea?
	Executing	Scenario Development FCM	Scenario Development – adjust system variables to a scenario of an expanding offshore wind industry FCM – semi-quantitative modelling	

			RQ4. What can social-ecological systems research reveal about how the offshore wind industry affects a transformation towards a sustainable blue economy in the UK North Sea?

This thesis uses a predominantly inductive approach – gathering data to build (and then test) a model, as opposed to working deductively from the literature to pose and test a hypothesis. An inductive approach aligns with the exploratory approach the thesis takes - the social-ecological phenomena that are emerging as a result of offshore wind expansion in the UKNS are variably understood, but can be drawn together through modelled marine expert perspectives. These experts can guide the research through their perceptions of which interactions are important to consider when exploring this CAS.

This approach has both benefits and drawbacks. It is a useful mechanism to flexibly focus the attention of the research towards social-ecological phenomena of interest, and also allows for deeper interrogation of complex phenomena. However, what experts perceive to be the most important interactions within a system may not align with what actually are (Herzog et al. 2022), which can lead to bias and incompleteness within inductively gathered data. It could therefore be tempting to gather data through a literature review on UKNS social-ecological interactions to gain a more accurate representation of the known interactions. However, literature reviews of such a magnitude are highly time-consuming, data for such an interdisciplinary study for which data surely exists across multiple databases would be difficult for a researcher to synthesize (Carver et al., 2013), and quality literature resources may be lacking across some parts of the UKNS system.

Overall, there is value in both an inductive, expert-led approach, and a more deductive, literature led approach. A different study, seeking to explain more specific and known social-ecological phenomena, would be more suited to the latter. This study, which explores which social-ecological phenomena are emerging, is more suited to the inductive approach.

3.5 Phase 1: Scoping the UK North Sea System

3.5.1 Method selection

Methods for systems scoping have been developed to help set boundaries and identify key components and linkages of a system (Sitas et al., 2021). The purpose of the scoping process is to describe a system from a variety of perspectives before establishing a key set of issues. In this thesis, scoping refers to the earliest stage of the overall research process. Important considerations for this scoping exercise are to strive to conduct it within an inclusive ethical framework, acknowledging the role of power in determining who or what should be included and considered through the system framing process (Sitas et al., 2021). Another consideration is that aspects of systems scoping more closely linked to describing the social subsystem are often constrained by scale, favouring the local over the regional (Table 3.1). Attempting to utilise systems scoping methods at institutional scales (and reliance of individual stakeholder knowledge at such scales) will likely result in some loss of dynamic accuracy and realism, which is an acknowledged limit of larger scale social studies.

To gather social-ecological data – that is data relating to the social (economic, political, cultural and technological), and ecological (biotic and abiotic) entities and interactions of a system (Folke et al., 2016) - I organised and facilitated a series of focus groups. To map and organise this social-ecological data provided by the participants, FCM was employed. To help prepare with who to and how to approach interviewees from differing backgrounds in Phase 2, power-interest matrices, a method which falls under the stakeholder analysis umbrella alongside focus groups, was also used. Descriptions of and explanations for the choice of each method follow:

Stakeholder Analysis

This broad term encompasses a range of methods and approaches that seek to identify, categorise, and understand the relationships between stakeholders (Reed et al., 2009). It developed from the burgeoning understanding in business circles that stakeholders have a significant effect on the success of a firm. Stakeholders, in the SES context, are best defined through a broader and more normative view as 'any naturally occurring entity that is affected by organisational performance' (Reed et al., 2009, p. 1934). In this thesis, methods for stakeholder analysis are being used in both Phase 1: Scoping (where component and linkage identification is the priority) and Phase 2: Diving (where understanding the complexity of linkages of interest is the priority). Therefore, the set of methods that I intend to follow within stakeholder analysis in Phase 1 are focus groups and power-interest matrices. The rationale for their selection follows:

Focus groups –are thought to be particularly useful for generating data on complex issues that need discussion to develop understanding (Reed et al., 2009). They comprise of small groups of participants, in this case Aura CDT students, who are bought together to brainstorm the range of stakeholders, alongside their relations, power, influences, and any other attributes of the UK North Sea System. Aura CDT students are good scoping participants as they have pertinent knowledge of a range of issues relating to offshore wind energy and the marine environment and are an accessible group for this research. Having gone through the same training centre, they also have social connections and familiarity meaning that there would likely be positive group dynamics and synergistic relationships amongst participants, which are hallmarks of productive discussion (Nyumba et al., 2019). However, having Aura CDT students as participants also carries some unique challenges concerning positionality and group dynamics. Firstly, many of the participants know and are familiar with me and each other, and they all share a key characteristic with me: being Aura CDT students. This gives me a partial insider perspective on who my participants are (Chavez, 2008), which could suggest I have a firmer grasp of their suitability for this research (Ansley et al., 2023), yet could also reduce my own objective sense of their value as participants. This could also either enhance or weaken my ability to observe and interpret the focus group data. This is not necessarily a limit, but this setup does create avenues through which my own biases could come to alter the way that this research unfolds.

Secondly, my positionality could have adverse effects on my ability to keep each group focussed on tasks and approaching them with professionalism during the focus group (Berkovic, 2020). To counteract this challenge, it will be important to cultivate a serious and professional atmosphere for focus groups, distancing myself as a session facilitator as pose to a friendly colleague. Finally, several participants are likely to have some pre-conceived notion of what the focus group session would entail, because they will have seen me present my project ideas in seminars before at our shared doctoral training centre. This could mean that some participants are at different levels of readiness to contribute data than others, which could in turn affect group dynamics and results. It will therefore be important to make sure all participants are aware of the session structure, and have an equal level of methodological background, by providing a short introductory presentation at the start of each focus group.

Whilst utilising AURA CDT students as participants for this scoping phase comes with some benefits, their limited expertise also introduces limitations that bring into question the accuracy and validity of the data. Other populations could be used for this data gathering exercise. For example, system scoping participants could be purposively sampled from a broader population of marine experts – such as attendees to a marine science and policy conference. This could help to produce richer and more accurate data in the scoping phase. However, due to time constraints for this thesis, a more accessible but less expert group of AURA CDT participants has been selected.

Power-interest matrices – which are an analytical (top down) tool for making power dynamics in the system explicit (Reed et al., 2009). In this method, stakeholders are placed within a matrix according to their influence (power) and interest in relation to a given phenomenon.

Power-interest matrices are a useful way for researchers to gain familiarity with a new field of stakeholders and consider ways of approaching them. This was considered an important preparatory step for Phase 2 of the methodology for this thesis, which would involve approaching a range of marine users with variable stakes in the expansion of the offshore wind industry. Figure 3.2 depicts how those involved in a system can be split depending on their power and interest within a given context. According to Reed et al. (2009), Key Players should be actively groomed, Context Setters should be monitored and managed, Subjects are often the marginal stakeholders that projects such as this thesis may seek to empower, and the Crowd need not be considered or engaged with in as much detail.

Using this method could help to manage power imbalances between distinct stakeholder groups, but are more likely to be of greatest use through distinguishing how to approach different stakeholder groups in Phase 2 of the project.

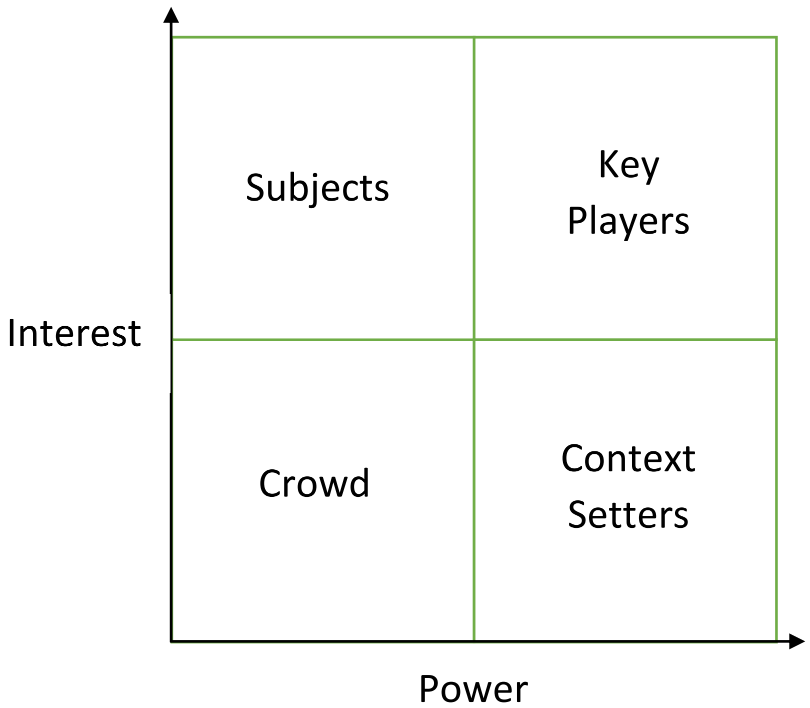


Figure 3.2 A standard power-interest matrix template, based originally on Mendelow's (1981) Power Dynamism Matrix for environmental scanning, before adaptation by Eden & Ackerman (1998)

*Expert modelling - fuzzy cognitive maps***:** Methods are required for mapping the components and linkages that are discerned through the system scoping process. Kininmonth et al., (2021) present Bayesian belief networks and FCM as two routinely used expert modelling methods that allow researchers to understand the structure and dynamics of complex systems through formalisation of stakeholder generated knowledge. Both methods begin through formation of semi-quantitative cognitive maps, (Kininmonth et al., 2021) which visually and transparently represent the interacting elements of a system, often in the form of signed digraphs (Axelrod, 1976) as seen in (Harraldsson et al., 2020).

Bayesian networks are rooted in mathematics, and explore how change in one parameter relates to change in another (Kininmonth et al., 2021). The calculated probabilities propagate across a constructed network to predict the probability of one event based on another. A weakness of this method within the context of this project is that it relates components to each other through probability functions that map onto a directed acyclic graph (Liu, 2001; Gray et al., 2015), which is not conducive to the dynamic cyclical social-ecological feedback processes that this thesis is endeavouring to incorporate. By contrast, FCMs accept the unquantifiability of some relationships and apply a fuzzy or uncertain description of the causal link between two events (Kininmonth et al., 2021). They are comprised of concepts which represent key system drivers, which are joined by connections which represent causal relationships between concepts (Kok, 2009). Connections are assigned weights which quantify the strength of causal relationships between concepts. These weightings tend to be unitless to enable description of a range of linkages (e.g. energy, economics, values). An example of an FCM from an environmental management context is shown in Figure 3.3.

Some of the key issues with FCM are that the semi-quantification of relationships through use of unitless weightings is not very structured, and the weightings in our case will be reliant on expert opinion (Kok, 2009), which could be subject to biases due to the impossibility of including all stakeholders and the likelihood that certain stakeholders will provide incomplete or perhaps purposefully biased information. In addition, the outputs of FCM only accurately provide a snapshot of a certain time, and at best could output semi-dynamic results (Kok, 2009). This suggests that to make this modelling method more predictive, it could be used in combination with more quantitative explorative methods, such as agent based modelling or dynamic systems modelling. Whilst this is a tantalising prospect, it falls beyond the scope of the thesis due to time and resource constraints. As a relatively simple way to graphically display complex and system properties such as feedbacks to a variety of stakeholders (Kok, 2009), and integrate multiple knowledge types, FCMs are highly suitable for this thesis.

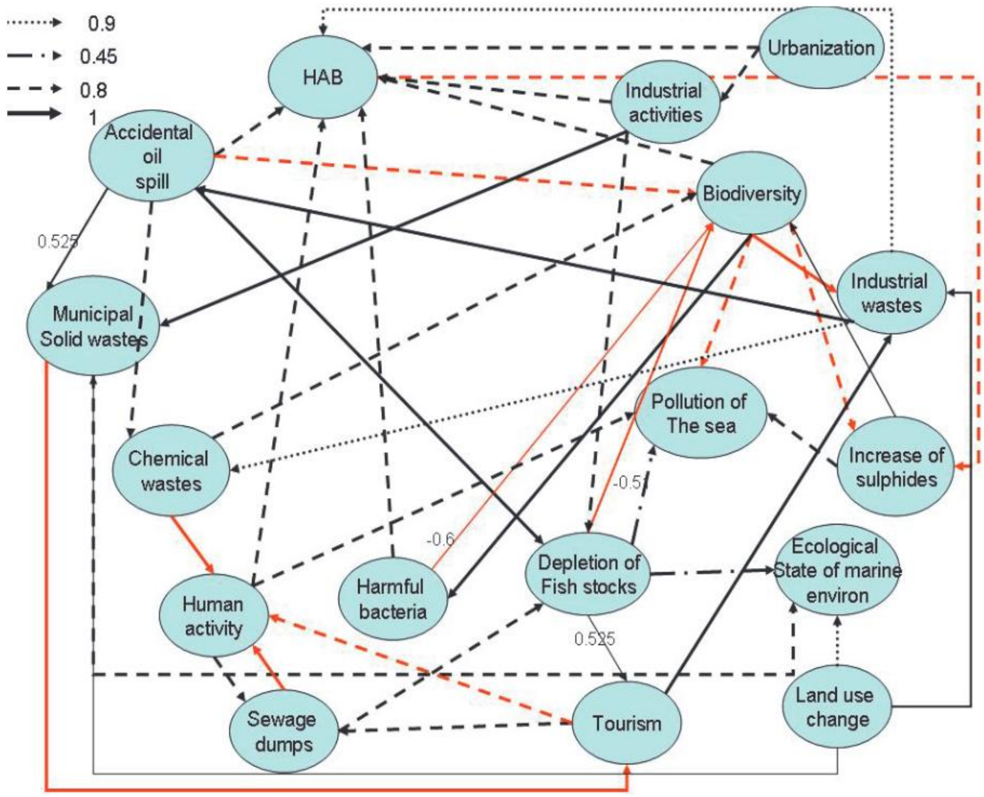


Figure 3.3 A fuzzy cognitive map to show and weight linkages between human and natural components within the Northern Black Sea. Black lines are positive effects; red lines are negative effects. Obtained from Papageorgiou,and Kontogianni, (2012).

3.5.2 Methods process: focus groups, fuzzy cognitive maps & power-interest matrices

Focus Group Outline

24 participants, split over 5 Focus Groups, which each were conducted over 2.5 hours including a tea break, occurred across the months of July and August 2023. Each focus group had between 4 and 7 participants. The first took place at Durham University's Institute for Hazard, Risk and Resilience on July 20th. Three took place in The University of Hull's Energy and Environment Institute on the 10th, 17th and 24th August, and one more took place at The University of Sheffield's Alfred Denny Building on 18th August. Participants were recruited via emails with attached participant information sheets (Appendix II) that were sent through Aura CDT's admin email, and further advertisement for the project was done through the Aura Students WhatsApp Channel. Participation in the focus groups was completely voluntary, and participant comfort and safety was assured by sticking to Durham University's ethical research guidelines by completing an ethics review and a data management plan ahead of the commencement of the research.

The primary goals of each focus group were to (a) produce a FCM to describe the relationships between different UK North Sea entities, and (b) to compare the power and interest of different entities within the context of the current expansion of the offshore wind industry. A copy of the instruction sheet for the facilitator (primary researcher) to follow whilst running focus groups can be found in Appendix I. The instruction sheet was honed (altering timings, adjusting questions for easier comprehension etc.) after each focus group. Appendix II, Appendix III and Appendix IV contain the participant information sheet, the consent form and the eight minute introductory powerpoint that was used to inform participants about what would be happening through the course of a focus group. What follows from here is a catalogue of the analysis methods used once the focus group data had been collected.

Introduction

In the wake of the focus group sessions, I digitised the physical products of the component identification, categorisation, and linkage stages using the MentalModeler software (Gray et al., 2013). The power and interest matrices were digitised using scatterplots on Microsoft Excel, and the transcripts were fed into Otter AI, a transcription software. Otter's transcription was imperfect due to challenging audio quality and Speakers often talking over one another. Consequently, I edited the transcripts myself to make sure they were as accurate as possible before the audio files were deleted. Whilst combing through these audio files, I highlighted and commented on key quotes and ideas, and incorporated data that had been spoken in the session but not added to the FCM or power-interest matrix to the visual products of each session. What follows is a more in-depth account of the processing of the social-ecological data generated in these focus group sessions.

Sample Adequacy

Several factors involved in the processing of the FCM data combined to make the process more time consuming than initially anticipated. These were the limited quality of audio recording, multi-voiced audio tracks limiting OtterAI's ability for accurate transcription, and the time-consuming process of attaching time-stamped notes to MentalModeler FCMs based on transcripts. As such, I was already behind schedule by the time I approached Focus Group 5.

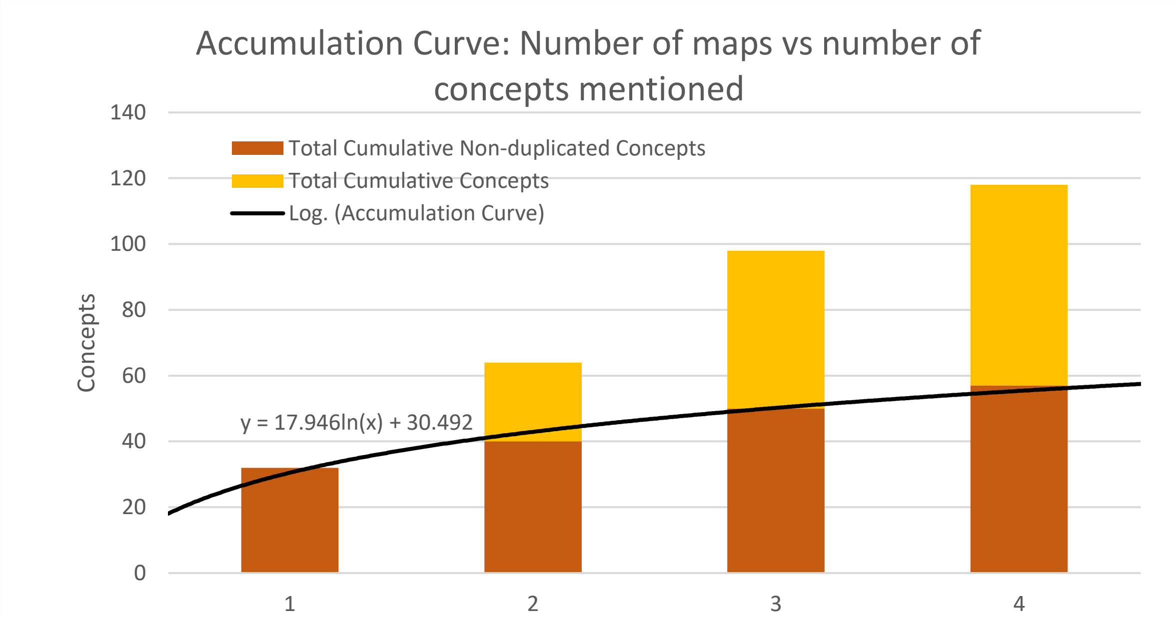


Figure 3.4 Accumulation graph to show the number of total cumulative concepts (yellow) and total number of non-duplicated concepts (orange) for each additional FCM.

As a potential time-saving measure, Özesmi & Özesmi's (2004) accumulation curve method was employed to predict the likely number of new concepts to be included by Focus Group 5. In this method, the number of new concepts introduced is plotted against the map number (Figure 3.4). The logarithmic line of best fit predicted an addition of two new concepts with the processing focus group 5's data, which was not considered a valuable enough amount of data given the time constraints. Therefore, analysis of Focus Group 5's data was not undertaken.

Fuzzy Cognitive Mapping

Analysis I: Identifying and Categorising UK North Sea Components

The categorised components were digitised using the MentalModeler software. Colours were applied for larger scale categorisations, and any extra notes (for example, component distinctions are smaller categorisations were incorporated into the notes area for each relevant component (Figure 3.5A/B). Capitalised components acted as headers for each category.

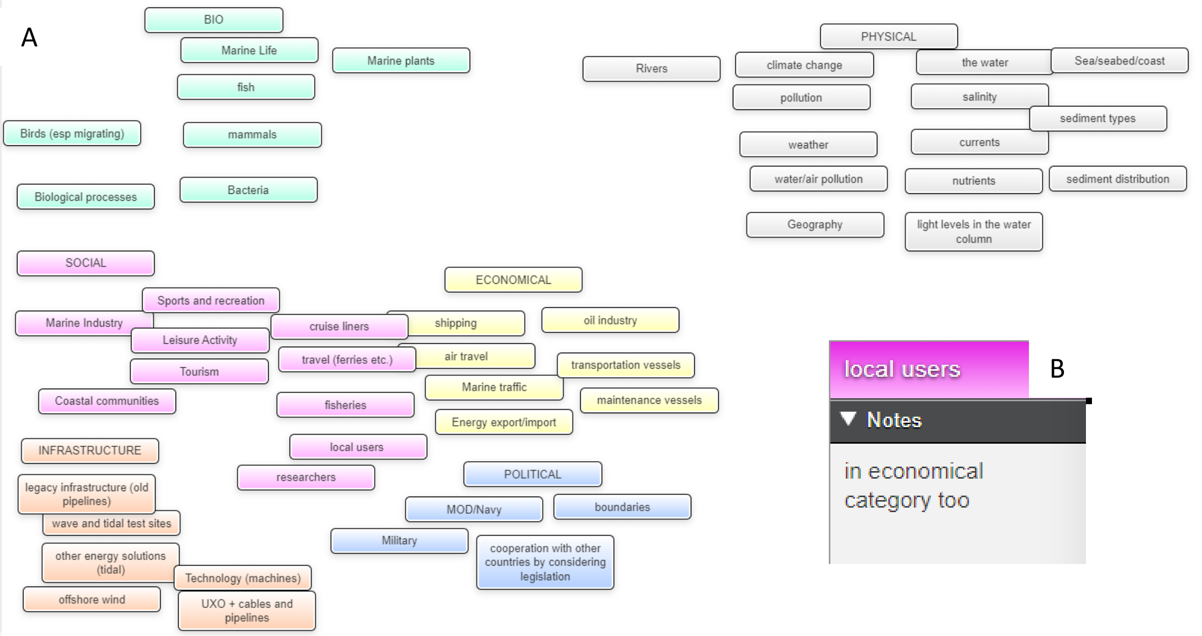


Figure 3.5 (A) Digitisation of Focus Group 1 identification and categorisation exercise. (B) An example use of the notes function on the Mentalmodeler software.

Analysis II: Linking UK North Sea Components

Figure 3.6 displays a digital copy of the FCM produced by Focus Group 2. During this important stage of each focus group, participants were asked to discuss the interactions between the social-ecological components they had already identified and categorised. First, they were asked more broadly to describe in which direction the effects were occurring (is X affecting Y, or is Y affecting X?) and whether the effect was positive or negative. Then they were instructed to debate and then assign a qualitative weighting to describe the strength of the effect, based off the scale in Table 3.3.

Table 3.3 Shows the Likert style scaled weightings for the strength of effect between two components of a system.

Strength of Effect	**Strong Negative**	**Moderate Negative**	**Weak Negative**	**No Net Effect**	**Weak Positive**	**Moderate Positive**	**Strong Positive**
Corresponding Weighting Range	-1 to -0.7	-0.7 to -0.3	-0.3 to 0	0	0 to 0.3	0.3 to 0.7	0.7 to 1
Weighting Average	-0.85	-0.50	-0.15	0	0.15	0.50	0.85

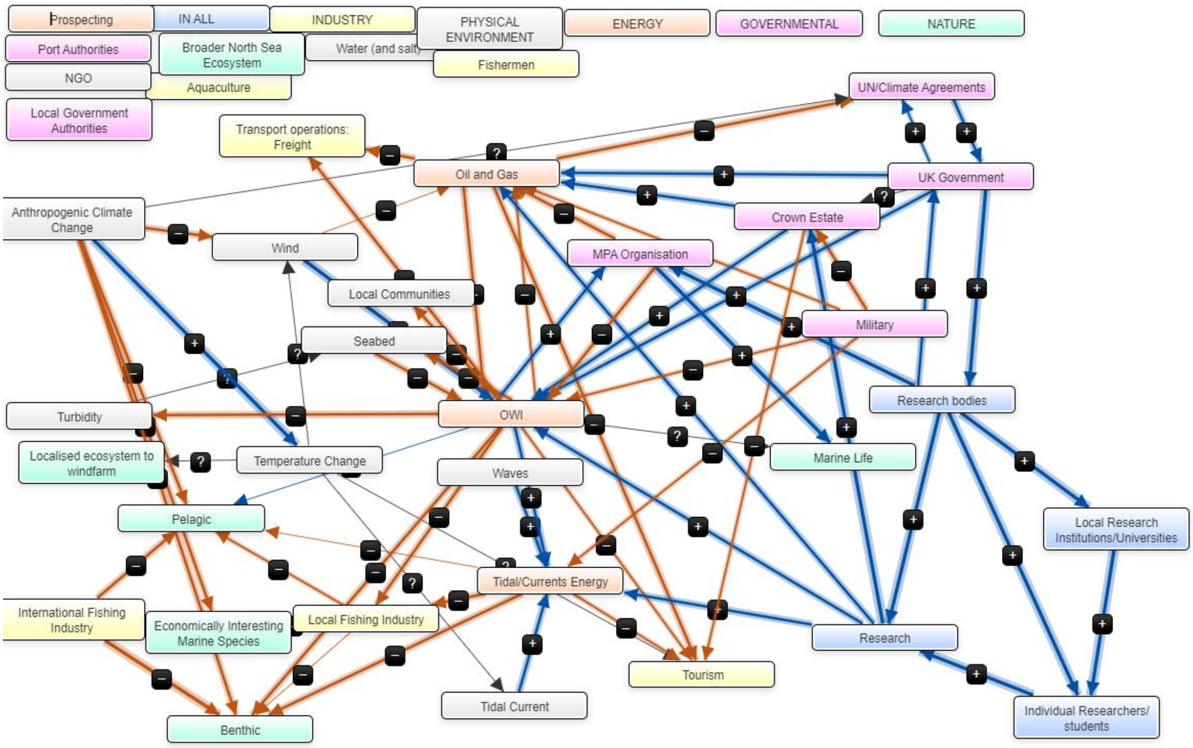


Figure 3.6 Focus Group 2 FCM, digitised using MentalModeler. Blue arrows = positive effects, Orange arrows = negative effects, Black arrows = uncertain effects. Connected Boxes = Components, Box colour = primary component category. Disconnected boxes = Category if capitalised, unconnected component if lower case and without arrows.

Analysis III: Transcript Analysis

Transcript analysis for the focus groups was undertaken to enrich the social-ecological data that had already been produced through each group's creation of the FCM and power- interest matrix. As per the session structure (Appendix I), this meant that in-depth analysis could be trimmed down to one important stage: exercise 2, which was the discussion of the linkages between different UKNS components. Within this exercise, the primary goal was to produce a FCM displaying the complex interactions between different entities of the area. Consequently, coding of the transcripts mostly revolved around adding depth to the FCM that had been produced during the focus group. For exercise 2, the key points to code of the discussion were:

- The disclosure of linkages between different components of the system
- the assignment of weights (from -1 for a strong negative effect to +1 for a strong positive effect) to linkages between different components of the system
- The reasoning behind these given weightings

- The confidence with which a participant would disclose their weighting and reasoning (Table 3.4)
- Disagreements between participants and uncertainties related to linkages
- Setting of rules

The entire transcript was also analysed by coding to highlight:

- How components were distinguished and defined (both well and poorly).
- Points of interest related to the components
- Critiques based around the facilitation of the focus group itself, as well as the overall structure, instructions and methodological process
- Difficulties in the categorisation of components
- Abbreviations for terms adopted by each group (e.g. Eco = Economic)
- Perspectives on the power relations between different representatives of each component in relation to the expansion of the offshore wind industry, mostly discussed during exercise 4.

Data from the transcripts was incorporated into each focus groups FCM by transferring it onto the digitised FCM itself through the MentalModeler software (Gray et al., 2013). The transcript data, when attached to relevant linkages and components through the “notes” facility of MentalModeler (Figure 3.3B), acts as a reference to the linkages.

The goal of these transcript analyses was to clarify as many details related to the complex and dynamic relationships between different entities of the UKNS as possible, and to make sure that intricacies that were discussed but not written onto the visual products of the focus groups were not lost.

Analysis IV: Homogenisation of Fuzzy Cognitive Maps

A final, aggregated map of the components of the UK North Sea System was required, to display the combined knowledge of all four analysed focus groups. To maintain transparency and reproducibility of the results for future studies, Olazbel et al.’s (2018) good practice measures for aggregating focus group data FCM were followed, especially at the homogenisation and aggregation stages.

In the homogenisation stage, which was carried out using the spreadsheet found in Appendix V, the components of the social-ecological system were manipulated to the point where they matched across FCMs and were therefore ready to be combined. This process was broken down into two parts; identification of common terms and choice of a common scale of detail to unite the data.

To identify common terms, all components identified by the Focus Groups were incorporated into one spreadsheet (Appendix V), before the data was scoured to find terms which carried the same meaning. To give an example: where Focus Group 1 used "Offshore Wind" and Focus Group 2 used "OWI" (Offshore Wind Industry) to describe the same component, a suitable common term was selected that best described the component. In this example, "Offshore Wind Industry" was selected as the common term. The same process occurred at the category level, where for example "Economical", "Commerce" and "Industry" were given the common term "Industrial".

Selecting a common scale of detail for the data meant expressing the degree of generalisation versus specialisation that the final aggregated map would convey (Olazbel et al., 2018). This project has been designed for the regional scale of the UK North Sea and is being worked on to inform macro-scale decisions for marine spatial planners. Manipulating the components towards this scale would often err towards generalising over specialising detail provided by the focus groups[5]. For example, Focus Group 2's internal structure of the "Research" component, and Focus Group 4's division of the Offshore Wind Industry workforce were considered too finer detail to include in the final aggregated map.

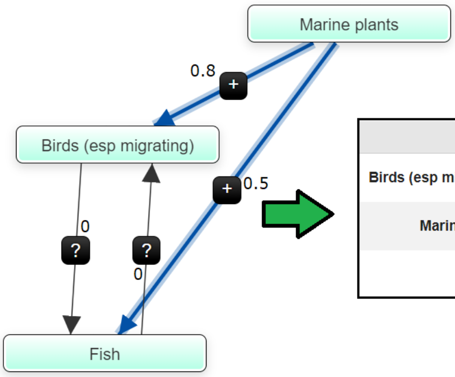
Adjusting components at this stage involved: grouping some together and adding their connections into a grouped term, ungrouping others and duplicating their connections, and removing others whose scale was deemed to be too small or broad within the context of the UK North Sea System.

To ensure transparency in the process of homogenising each focus group's component terms, Appendix V also includes a comments column, to describe and justify how components were manipulated in preparation of aggregation. There were occurrences where the adjustment of terms caused the signs (positive or negative) of their connections to become questionable or incorrect. This would commonly occur when a named component would not have a defined, measurable flux. Such an example was in adjustment of the Focus Group 2 term "Seabed"; an important component of the UK North Sea System which in this case had no distinct alterable value (increasing/decreasing the value of "Seabed" did not have a tangible meaning), which is an important qualifier for inclusion into a FCM (such as in Figure 3.3). The term was altered to "Suitable Marine Geology/Sediment", a Focus Group 4 term which denotes how suitable an area of seabed is for the placement of offshore wind turbine structures. A final glossary of terms from the homogenisation stage can be found in Appendix V.

[5]Generalising to larger scales in this way goes against some social-ecological theory, which is based on observations that faster, smaller scale interactions within any system give rise to emergent slower and large-scale phenomena (Levin et al., 2013). In this way, the need to homogenise FCM data is not particularly cohesive with systems thinking.

Analysis V: Aggregation of Fuzzy Cognitive Maps

Aggregation of the FCMs produced by Focus Groups 1-4 broadly followed the technique from Olazbel et al,. (2018), with some exceptions. The data from each FCM was automatically reconfigured from a mind map to a matrix form using the MentalModeler interface (Figure 3.7). From that point, a process was followed that involved collapsing each individual matrix, building an augmented matrix, and finally collapsing the augmented matrix.



	Birds (esp migrating)	Marine plants	Fish
Birds (esp migrating)			0
Marine plants	0.8		0.5
Fish	0		

Figure 3.7 Shows how Focus Group's Fuzzy Cognitive Map data is converted into Matrix format on MentalModeler

To collapse each individual matrix: confidence ratings (Table 3.4) from the transcript analysis were applied as a colour code to each given linkage within each focus group's individual matrix. Where no confidence rating was captured through the transcript, a neutral score of 4 was given.

Then each matrix was treated to the same manipulations as the component names had been previously subject to during the homogenisation phase; being variously duplicated, grouped, ungrouped, removed, or having their sign reversed. In incidences where these manipulations led to several components from one focus group being grouped together under one common term, rules were applied to come to a final value for the strength of a given effect:

- If the assigned confidence rating for linkages to be grouped is the same, average the strength of effect values when grouping
- If the linkages to be grouped together have differing confidence ratings, use the highest confidence rating to determine the overall strength of effect

Table 3.4 Table to show colour coding for focus group confidence rating for a given linkage.

Confidence Rating Key	
1	Completely unconfident
2	Very unconfident
3	Somewhat unconfident
4	Moderately confident / no confidence score given
5	Somewhat Confident
6	Very confident
7	Completely confident
	Query cells and connections

In circumstances where the investigator is not familiar with focus group participants, qualitative metrics such as confidence ratings are easily subject to misinterpretation, and so should not be used to help determine strength of effect values. In this specific case, because of my familiarity with the focus group participants and our shared experience as post-graduate group, I deemed it appropriate to include this qualitative scaling.

Once the matrix data from each focus group had been homogenised, an R code developed by Olazbel et al. (2018) and altered here for compatibility with the latest R updates (Appendix VII), was used to build them together into a combined matrix.

When this code executes, the data is combined and then collapsed. For duplicated linkages, averages of weightings are calculated. The product is a .csv matrix file that can be fed back into MentalModeler (Gray et al., 2013) to produce a visual display of the linkages between UKNS components according to Aura CDT focus groups. The combined and collapsed result will be analysed and discussed in Chapter 4, and forms the base onto which further complexity is added in Chapter 5, and tested in Chapter Figure 4.9.

Olazbel et al. (2018) code can also generate .csv files which show other metrics, such as standard deviation, coefficient of variation, and whether there is a sign change between weightings. These metrics can show whether there is a spread of weightings from different focus groups. Higher spreads between the weightings can show disagreements between focus groups, or interpretation errors by the investigator.

Power-interest matrices process

Power-interest matrices were employed in this thesis to help identify and know how to approach relevant stakeholders for interview in the Diving stage of the thesis (Phase 2: Diving into Marine Social-Ecological Action Situations Chapter 5), and to try to make the power dynamics between different entities of the system more explicit. Exercises 3 and 4 of the focus group (

Appendix I

Focus Group Structure (for Facilitator use) were designed to allow participants to share their knowledge of stakeholders and power dynamics within the context of “An Expanding Offshore Wind Industry in the UK North Sea”.

In exercise 3, participants spent 10 minutes identifying marine experts or users who could act as representatives for the interacting components they had chosen in exercise 1. It was encouraged that these representatives were written onto the relevant post-it notes in preparation for exercise 4. Then, the offshore wind expansion context and the concepts of power and interest were introduced to the participants, who were asked to deliver their own concept interpretations. In exercise 4, participants were encouraged to place the post-it notes onto a graph of power and interest, to display the relative power and interest of different UKNS group representatives.

Power-interest matrices analysis

After the focus groups, the results of the power interest matrices were digitised onto Microsoft Excel, through a process of creating a translucent X-Y scatterplot, placing a photograph of a focus groups Power-Interest Matrix behind the plot, and plotting points that corresponded to the centre of each post-it note. Each point was then labelled with the correct representative, component, and the homogenised (see **Analysis IV above**) primary category the component had been placed into in the focus group. Finally, the points from each focus group were added onto one master scatterplot. Results and discussion of these focus group exercises can be found in Chapter 4. The results are also used in Phase 2 of this chapter to inform how to approach marine users for interview.

3.6 Phase 2: Diving into Marine Social-Ecological Action Situations

This phase describes the methodology that was used to dive further into important, complex, and nuanced interactions that are occurring in the UK North Sea, to more firmly answer RQ1. To help draw together findings, the social-ecological action situation (SE-AS) framework (Schlüter et al. (2019) was selected. Rationale for its use over other frameworks is discussed in part 3.1.1 of this chapter. This methodology was used to more closely examine social-ecological interactions and develop a set of linked action situations (AS) that are occurring in the UKNS. Analysis and results of this process can be found in Chapter 5.

3.6.1 Method selection for exploring social-ecological action situations

Findings from Chapter 4 – which show the most important, complex, and variably perceived linkages within the UK North Sea system – partially inform method selection for Chapter 5. According to Aura CDT, Offshore Wind shares complex, important and uncertain interactions with coastal communities, local and international fisheries, the ecosystem (especially benthic fish) and oil and gas. In addition, National Government and The Crown Estate (TCE) were found to have high-power and interest in the expansion of offshore wind in this area. They are highly connected entities of this system, which take on increasing relevance later in the thesis (for example in helping to answer RQ3), and which also proved difficult to incorporate into a fuzzy cognitive map. The relationships of these components were intended to be investigated in Chapter 5, but in the end, there was not time to analyse oil and gas, national government, TCE and the marine ecosystem data in as much depth. Regardless, Chapter 5 seeks to unpick complex relationships between and around offshore wind, communities, fisheries and ecologies by following the processes outlined in this phase of the methodology.

With unpicking of the interactions between the above entities in mind, this phase looks to use methods which can gather and combine complex data from a range of expert perspectives, and can be modified/adapted/transformed to fit within the SE-AS framework.

The Social-Ecological Action Situations Framework in this study

Figure 3.8 graphically displays how SE-AS are conceptualised with a system. In this study, the network at the base of the figure is revealed through the fuzzy cognitive map (FCM) constructed by the focus groups (Chapter 4). The areas of highest interest have been empirically selected through the results of Chapter 4 – which highlight important and uncertain interactions that are mostly relevant to offshore wind.

The core difference between Schlüter et al.'s graphical illustration of emergent SES in Figure 3.8 and the layout of this thesis (Figure 3.9) is that the emergent phenomena in my case are not known. The thesis is exploratory rather than explanatory in orientation, as I aim to find out what emergent phenomena could be associated with the expansion of the offshore wind industry in the UK North Sea. Therefore, developed AS will be incorporated back into the FCM, and the FCM will be run (Chapter 6) to deduce which emergent phenomena could be expected.

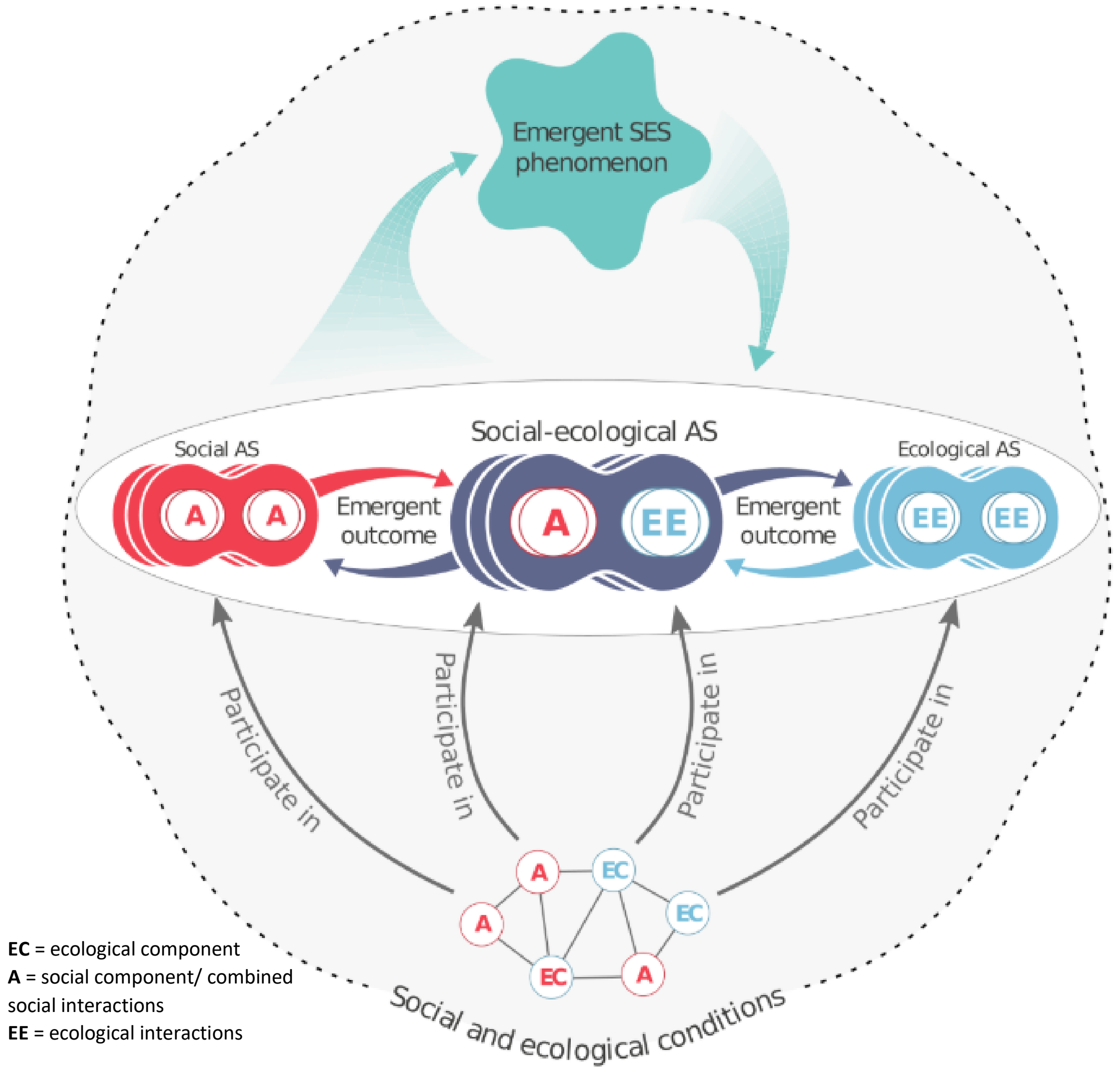


Figure 3.8 Displays how Schlüter et al. (2019) consider the emergence of social-ecological phenomena. It begins with a network of interactions between entities (base of figure). Key interactions, which are identified by their theoretical or empirical relevance, are abstracted into action situations (AS) (middle of figure), which capture relations and interactions between humans and nonhuman entities that are core causes of SES phenomena. Each AS has emergent outcomes which can affect other ASs, and each AS can be either social, social-ecological, or ecological. Linked action situations are hypothesised to produce system-wide emergent phenomena of interest (top of figure).

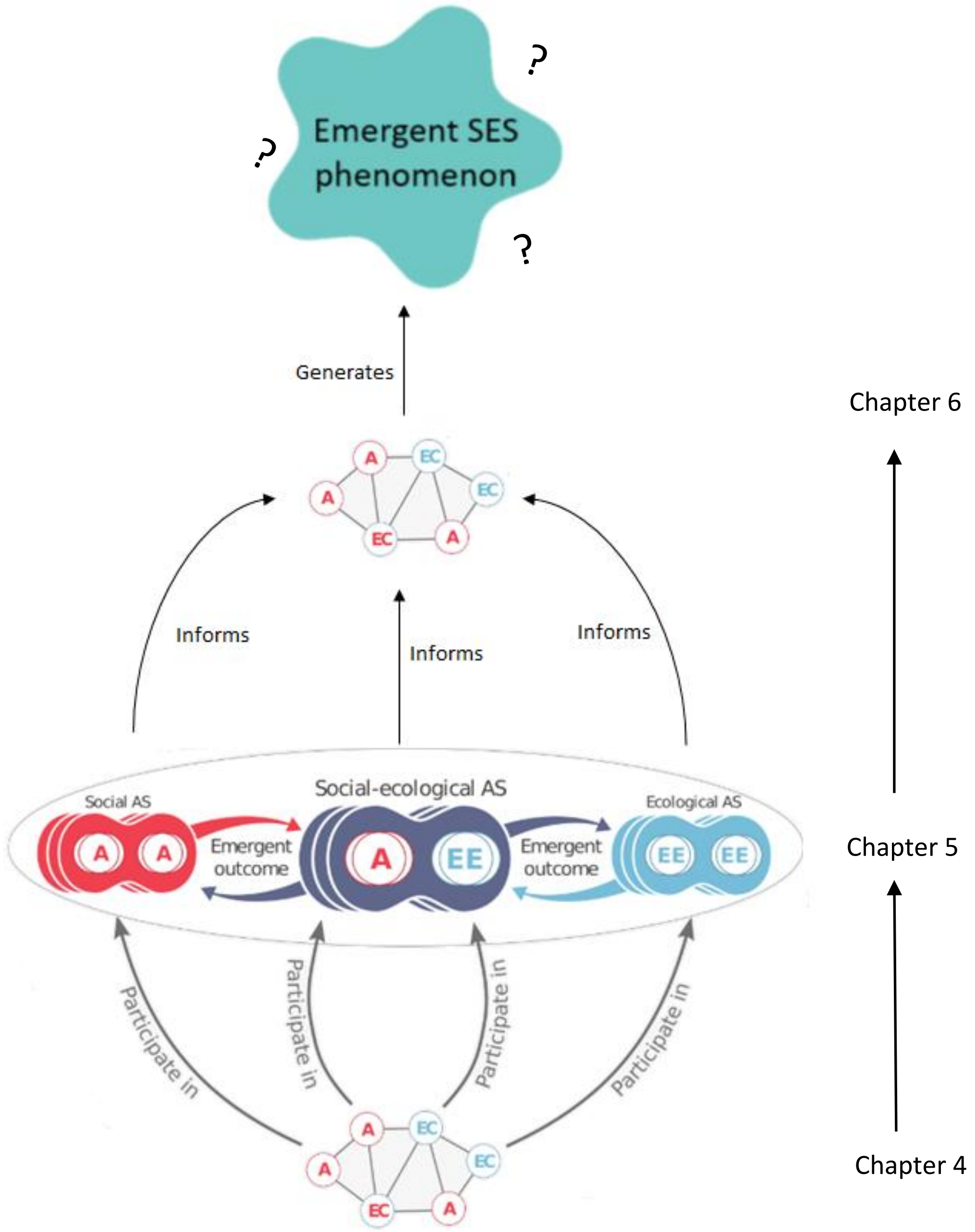


Figure 3.9 Depicts how Schlüter et al.'s (2019) SE-AS framework will be adapted for this project in order to try to explore potential effects instead of explaining known effects of the expansion of offshore wind in the UKNS. Labelled to the right of each layer of the graph is the relevant empirical chapter of this thesis.

Method selection

To gain more in-depth data on the complex interactions which constitute an AS, semi-structured expert interviews were chosen as a method. These are known to be a useful method for gaining insights into complex relationships, as well as for triangulating data obtained through other methods such as focus groups (Reed et al., 2009). Semi-structured interviews, rather than structured or unstructured interviews, were chosen because I wanted to guide interviewees through a set of questions based on revealed linkages from the focus groups, while also giving them opportunities to convey what they consider to be important dynamics and relationships for components where they have expertise. The semi-structured approach offers more of an opportunity for me to draw together inferences and recognise unexpected patterns that emerge from the interviews. This inductive approach is more conducive to exploration of potential or emerging social-ecological phenomena – it allows responses to be fully explored, and for me as the researcher to be responsive to relevant social-ecological information being raised by the interviewee (Legard et al., 2003). We do not yet have a full idea of how offshore wind expansion in this area will affect other parts of the system – so a structured and by extension more deductive approach is not appropriate here.

The semi-structured interview method has some clear strengths, but there are also some generic limitations of this method of data gathering. Shackleton et al. (2021) point out that some argue that people's perceptions and opinions on social-ecological phenomena are subjective, and what they are comfortable saying in an interview situation can be affected by their positionality and biases. An employee of the offshore wind industry may be more reticent to outline the negative effects of an offshore wind development, whilst at the same time overstating some positive outcomes. It is important that I am transparent in my process of analysis and interpretation, noting where I suspect there may be biases altering the pattern of discussion. To further identify and understand biases, one can find a range of participants who can deliver differing perceptions on the same social-ecological phenomena. Other methodologies designed to achieve unbiased convergence of opinion on complex issues, such as the Delphi technique are well established (Hassan et al., 2019), and could potentially have been used for a social-ecological study like this. However, I felt that securing marine expert buy-in for three intensive questionnaires as per the Delphi technique would be less successful than the appeal of a single hour-long interview for prospective participants.

Interview-based methods are best suited to contributing to SES studies when they are combined with other sources such as observational or instrumental approaches (Shackleton et al., 2021), as this helps to reduce potential bias and subjectivity. Within the context of any interview, it is also not possible for an expert to call to mind all relevant information they have on a subject of discussion. To counteract bias, subjectivity and incompleteness of information, once action situations have been drawn from interview data, they will be compared to AS from other perspectives, and in some instances to relevant literature in a series of short analyses in Chapter 5.

3.6.2 Methodological process: semi-structured key informant interviews

Recruiting participants

The scale of RQ1 (UK North Sea wide) alongside the vaguely defined boundaries of this social-ecological system, meant that the process of identifying appropriate participants for interview was difficult. For this analysis, a total of 22 key-informant interviews were conducted, with a total of 24 participants taking part [6]. Identification of marine experts for these key informant interviews was an iterative process that involved purposive selection of people with relevance to or knowledge of one or more of my areas of interest (Shackleton et al., 2021). These areas emerged in Chapter 4:

- Offshore Wind
- Coastal Communities
- Fisheries
- Ecosystem
- Oil and Gas
- Marine Governance

This stage of research has an idiographic aim – I am searching for distinct facts and processes about how different UK North Sea components interact with one-another. As such, the sample size of participants should be small enough that individual interview results have a locatable voice within the study (Robinson, 2014). Normally, this would suggest that between 3-16 interviewees are sufficient for the study. However, because I wish to analyse a range of action situations, this number has been increased to 22. What follows is a description of how I identified my interviewees using a purposive sampling strategy (Robinson, 2014). This assured that I could get participants with relevant expertise to speak on the identified areas of interest.

For offshore wind-based interviewees, I approached potential interviewees through events organised by my doctoral training centre (Aura CDT), as well as the University of Durham's Energy CDT which is a part of Durham Energy Institute. Through fieldtrips to the Ørsted East Coast Hub, as well as Dogger Bank Wind Farm's operations and maintenance centre – which is owned by Equinor – I was able to secure two interviewees directly associated with the offshore wind sector.

Three of my interviewees came from The Crown Estate. Two of these were borne from a failed attempt at securing a Crown Estate internship – the employee providing feedback was keen to provide it over Teams, and in that discussion revealed their interest in my PhD project. From there I had a discussion with another employee to work out how best The Crown Estate could support this

[6] Most interviews had one interviewee. Interview six had two interviewees, interviews ten and sixteen each had the same two interviewees, and interview eleven also had two interviewees.

work – which resulted in identification of two Crown Estate employees to interview with expertise in my areas of research interest.

Attendance at the Aura conference in January 2024 facilitated connection with several relevant potential participants. One marine consultant helped me to arrange several interviews, both with them and with other marine consultants who had expertise in offshore wind, fisheries and natural capital approaches to management, as well as to a fisheries expert who works in academia. Separately, an employee of the Offshore Renewable Energy Catapult connected me via email to interviewees that work at Grimsby dock and fish market, North-East Lincolnshire Council, for the Crown Estate, and a south-east inshore fisheries advocate.

I also made a few connections at the SMMR conference in Bristol in June 2024: an expert from the resilience of coastal communities project, an expert in bio-physical seabed interactions, and a fisheries social expert from Defra.

For oil and gas-based participants, I made a connection at an OEUK (Offshore Energy UK) Roadshow event in Durham in March 2024, and subsequently interviewed one of their OEUK colleagues. Separately, one of my supervisors with prior experience of researching oil and gas in the North Sea, made a few academic suggestions, one of whom (working in the energy transition institute at Robert Gordon University), kindly agreed to an interview.

Table 3.5 displays when the foci of this study were explored through the interview process. Several interviewees were experts in multiple areas, so their interview number is repeated across different components. Interviews occurred between January and August 2024, with the majority occurring between April and July. Table 3.5 shows how several interviews were not completely focussed on the areas of anticipated action situations for this study. Interviewees with expertise in Anthropogenic Climate Change, Local Governance and Natural Capital, for example, were purposively chosen to provide context on UK North Sea system dynamics that had been mentioned but not expanded upon by focus groups in the first empirical stage of this thesis.

Table 3.5 Shows which interviews of the study were most pertinent to which components.

Component (bold = core component)	**Interview Number (blue = analysed interviews)**
Anthropogenic Climate Change	2
Coastal Communities	3, 4, 5, 6, 14
Ecosystem	13, 15, 19
Local and International Fisheries	7, 8, 9, 10, 15, 16, 18, 22
Local Governance	6
National Government	17, 22

Natural Capital	12
Offshore Wind Industry	3, 5, 11, 18
Oil & Gas Industry	20, 21
Ports	7, 8, 9
Research	10, 16
The Crown Estate	1, 4, 19

Even with a purposive sampling approach, it proved difficult to find ideal participants who could speak with expertise on coastal communities and the marine ecosystem. For coastal communities, it was only possible to gain insights from expert perspectives within governance and social science rather than actual community representatives, whose spheres do not overlap with my own, and who are often only known locally. For the marine ecosystem, there was a mismatch of scientific approach: some ecosystem scientists I approached felt it was too difficult to qualitatively convey ecosystem interactions in the interview format, and suggested I incorporate quantitative data which exists in the literature into my action situations. I unfortunately did not have the time to follow up on these suggestions, but as outlined in the conclusions in section 7.4, this offers an avenue for future research.

Structure of interviews

Interviews were mostly conducted online over Teams, although one interview occurred in-person at Durham's Geography Department (interview 3), and three were done in-person while on a day trip to Grimsby Port (interviews 7, 8, and 9). Interview duration was typically around one hour.

The semi-structured interviews were broadly split into two parts: marine experts were first given the opportunity to discuss what they perceived to be the most important social, ecological and industrial interactions between the component(s) they had expertise in, and the rest of the UKNS. After this, they were tasked with critically evaluating Aura CDT perceptions (Chapter 4) of the links between their entity and others in the UKNS system. This was done by presenting participants with a relevant slice of the system, as perceived by Aura CDT in its FCM form, as an object for discussion. These interviews were designed to answer several research sub-questions based around RQ1:

- How is the expert positioned within their area of expertise?
- What does the participant perceive to be the key social-ecological dynamics at play between their component(s) of expertise and other entities of the UK North Sea system?
- How does the portrayal of their component area(s) of expertise by Aura CDT compare with how they perceive it(them)? Could this be improved through reconceptualization?

- To what extent does the participant (dis)agree with the links and weightings assigned by Aura CDT between their component(s) of expertise and other UK North Sea Components?

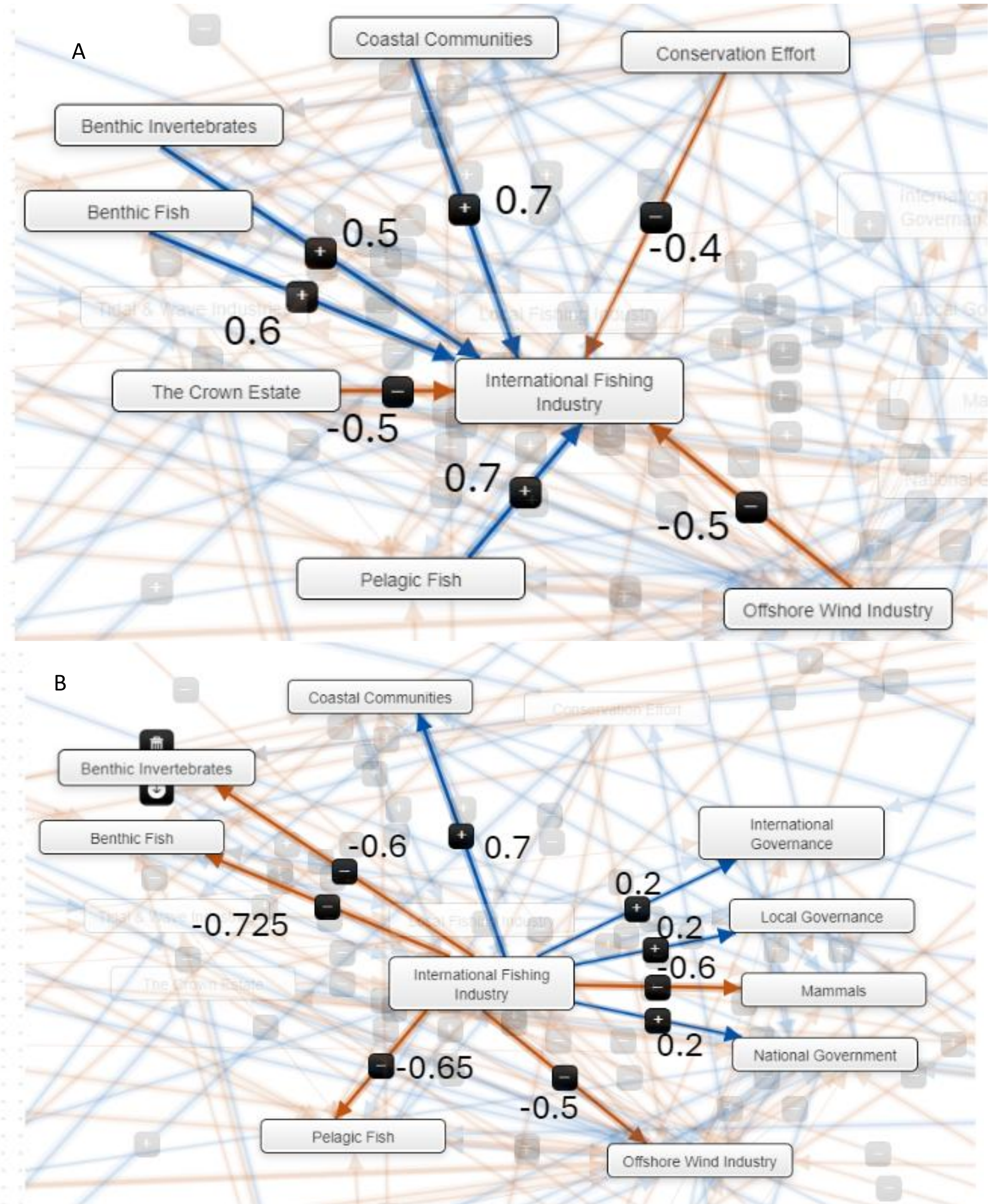


Figure 3.10 Relational excerpts from the Aura CDT aggregated FCM, highlighting only the linkages to (A) and from (B) the International Fishing Industry component. Each linkages weighting is shown with a numerical label. Orange arrows represent negative effects, blue arrows represent positive effects.

A generic interview structure can be found in Appendix VIII. I tailored this general structure based on my prior knowledge of the participant and their expertise, as well as research I undertook prior to each interview to learn more about each participant.

Because the fuzzy cognitive mapping approach to study the relationships between social-ecological entities was new to all participants, 8 minutes near the start of each session was dedicated to showing and explaining how the FCM was constructed, and which part of the FCM each interview would be in part critiquing. Figures were prepared ahead of each interview, to act as objects for discussion. These figures were partial products of the aggregated FCM produced by Aura CDT students in the 1st stage of research (Chapter 4). An example can be seen in Figure 3.10, which shows the weighted linkages to (A) and from (B) the international fishing industry. The second part of each interview would use this kind of object for discussion, to help hone and improve parts of the fuzzy cognitive map that related to the expertise of the participant. The participant would be encouraged to evaluate the linkages mapped by Aura CDT. Thus, the marine expert interviews were used to help explain, contextualise, and ratify data from Aura CDT.

Methods for Interview Analysis

This sub-phase details the methods I used to analyse the material generated through interviews. It begins with an explanation of how interview transcripts were recorded, before detailing the procedure that was followed for transcript analysis.

Transcripts of each interview were recorded using Microsoft Teams' in-built recording software for online meetings, or a combination of the Olympus Digital Voice Recorder (model no. VN-732PC) and a standard mobile voice recorder as backup for in-person interviews. Each recording was then uploaded to Otter AI for transcription.

Each interview transcript was then analysed on the NVivo interface using coding techniques that are based in grounded theory – an approach which seeks to develop interpretations, theories, and findings which are grounded in evidence produced through fieldwork (Glaser & Strauss, 1967). This inductive method has hopefully allowed for interrogation of transcript data to generate insights into SE-AS that are occurring in the UK North Sea. This research took a more Straussian approach to literature ahead of interviews, meaning I had done some research relating to each topic of discussion before interviewing participants (M. Alammar et al., 2019). This research came from facilitating focus groups (Chapter 4) that covered these topics, as well as having undertaken a literature review in Chapter 2 that delved into how the UK North Sea system is constituted. Furthermore, I took some time to prepare for these expert interviews by reading up on the participants themselves.

I also took a more structured Straussian approach to coding to allow for natural emergence of Action Situations – using open, axial and selective coding (Corbin & Strauss, 2008; M. Alammar et al., 2019) to better understand the complex and dynamic relationships between UK North Sea components. I performed this iterative process for two sets of interviews, split according to the aspects of the UK North Sea System that each participant had expertise on. Due to time constraints, I chose to focus on interviews which focussed on offshore wind interactions with coastal communities, fisheries, and the marine ecosystem. Interview numbers can be found on Table 3.5.

The methodological procedure for coding is taken from Corbin & Strauss (2008). First, each transcript is read without notes from beginning to end which helped me enter the life of a marine expert. From there I conducted open coding: labelling raw data (phrases or lines from an interview transcript) with concepts and relationships to capture the essence of what is being said. If necessary, I attached an annotation to the concept to reflect my interpretation of what is being said. An example of this process can be found in Appendix IX. Once this was completed for the full interview, I reflected on the concepts and memos and endeavoured to identify themes that had come up through the course of the interview – a process of axial coding (Corbin & Strauss, 2008). These themes helped pull together concepts which I reflected on as a part of the interview analysis.

Breaking away from the procedure outlined by Corbin & Strauss (2008), the results and reflections of each interview were not used to guide further data collection. Instead, a similar interview structure base was used for all interviews, which was partly a methodological remnant of my own positionality as a physical scientist transitioning into social research, but also a bid to retain transparent and unbiased results whilst covering several of the core linkages identified in Chapter 4.

I developed action situations based on the themes I identified, through a final process of selective coding. These action situations, alongside lower-level concept codes that were based on direct linkages on the aggregated FCM from Chapter 4, will be incorporated into a final FCM that can be ran in Chapter 6 to answer RQ2, 3 and 4.

3.7 Phase 3: Modelling Emergent System Properties of Offshore Wind Expansion

This phase contains the methodological process that was followed in the third phase of the research, which combined the fuzzy cognitive mapping exercise results Chapter 4 with key informant interviews from results Chapter 5. No new frameworks or methods were used, so there is no method selection sub-phase here. The results of the methods followed in this phase are used to directly answer RQ2, and provide a vantage point from which to discuss and formulate an answer for RQ3 and 4 (Chapter 1).

3.7.1 Methodological process

Assembly of data from results Chapters 4 and 5

For the final assembly of the data for this thesis, Aura CDT's aggregated FCM acted as a basemap. As in methods Phase 1 and results Chapter 4, the MentalModeler software was used initially to combine the data from Chapters 4 and 5 (Gray et al., 2013). Data gathered in Phase 2: Diving and laid out in Chapter 5 were incorporated onto Aura CDTs aggregated FCM using the following rules:

- Where an expert described a UKNS entity or interaction not previously identified in the Aura CDT FCM, it was added to the map.
- An expert weighting of strength of effect between two UKNS entities always superseded an Aura CDT weighting.
- If an expert disagreed with an interaction, it was removed from the FCM.
- Where an expert gave a weighted value for the strength of effect from one entity to another, this was directly incorporated onto the FCM.
- Where multiple experts gave weighted values for the strength of effect from one entity to another, these weightings were averaged.
- Where an expert gave a textual description of the strength of effect from one entity to another without supplying a numerical weighted value, the following weightings were used to reflect their perceptions:

Table 3.6 Shows how weighted values were applied to textual descriptions of effects given in interviews, giving some examples of what language might correlate with.

Effect descriptor	Weighting	Examples of language used in interviews
Strong positive	0.85	"a really high impact" "a powerful influence onto"
Moderate positive	0.50	"average strength" "middle of the road" "modest effect"
Weak positive	0.15	"a small effect" "a low impact" "a slight change"
Neutral	0.00	"no overall effect" "no net effect"
Weak negative	-0.15	"a small negative impact" "a minute negative effect"
Moderate negative	-0.50	"average negative effect" "a middling poor effect"
Strong negative	-0.85	"a harmful impact" "a strongly adverse effect on"

- Where no interpretable weighting was found in the textual description of an interaction, the code N/A would be used, and the Aura CDT original weighting would be maintained

Timestamped quotations from the interviews were included on the final FCM to preserve transparency in how I interpreted and bought together weightings describing the interactions between entities.

Outline of the mathematical background of fuzzy cognitive maps

Structural analysis of FCM data is outlined in Chapter 4. Here, I briefly outline how the semi-quantitative weighted matrix of an FCM can be used as a modelling tool to test how a system might evolve over several timesteps. Though many articles outline the mathematics behind FCM models (e.g. Kosko, 1986; Kok, 2009; Felix et al., 2019), I have drawn mostly on Papageorgiou & Kontogianni (2012). This provides a useful methodological primer and application of fuzzy cognitive mapping in environmental decision making and management, making use of modern algorithms and describing their application to a field closely related to my own work. I provide a brief outline here of how FCM works for modelling, but for a comprehensive and more mathematically intensive treatment, please refer to sections 5 and 6 of Papageorgiou and Kontogianni (2012).

In an FCM, components are related to each other by weighted interconnections. The weighted interconnections have a value in the range of [-1,1], which represents the type (positive/negative/neutral) and strength of influence (weakest at 0, stronger towards 1 or -1) from one component to another. This corresponds to Table 3.3.

Additionally, each component is ascribed an initial activation level within a range of [0,1], which broadly represents the current abundance of each component within the system. An activation level of 0 indicates the minimum extent, and an activation level of 1 indicates the maximum extent. Here is an example of how activation level is calculated: the component “Aggregates” (which represents the amount of aggregate extraction occurring in the UKNS region) uses the unit “quantity dredged, millions of tonnes per year”. The minimum activation level, 0, is aligned with the minimum possible amount of aggregate extraction – 0 million tonnes. The maximum activation, 1, is aligned with available proxy statistics for marine aggregate extraction. In this case, this comes from the British Marine Aggregate Producers Association’s Area Dredged statistics for English and Welsh waters (BMAPA, n.d.), which shows that the maximum amount of aggregate extracted per year between 1998 and 2022 was 23.68 million tonnes in 1999. These statistics also show the most recent statistic for yearly marine aggregate extraction, 20.00 million tonnes, which is taken to represent the current activation level of 0.84. The calculation used to reach an activation level of 0.84 is:

$$\frac{average\ or\ current\ value - minimum\ value}{maximum\ value - minimum\ value}.$$

A full list of components and their minimum, maximum and initial activation levels, as well as references to the data sources they were gained from can be found in Appendix XI. As the Aggregates example above illustrates, these activation levels can be based on limited datasets or datasets which do not fully match the UKNS study area. It should therefore be stressed that they are estimates of abundance of each component, and could be improved upon with a deeper and more systematic review of the literature, and as better data become available. For example, statistics on benthic invertebrate abundances are drawn from Frid et al. (2009) and only reflect benthic invertebrate abundances up to 2008. Furthermore, some components are understood by participants through units that are difficult to formally quantify. For instance, Coastal Communities uses community wellbeing as the unit upon which activation level is based. As data for this and some other metrics are not currently available, the initial activation level is set to the average: 0.5.

In an FCM model, the initial state is defined by each component being at its starting activation level. The model then runs in iterations, which can be considered timesteps. At each new iteration, the activation level (or abundance) of each component ($A_i^{(k+1)}$ in equation below) changes based on the sum of the weight of inward connections to the component (w_{ji}), multiplied by the current activation level of components that affect said component ($A_j^{(k)}$). All of this is modulated by a sigmoid threshold function (f), which acts to keep activation levels for each iteration bounded within the [0, 1] range. The use of a threshold function hinders direct quantitative analysis of component relationships, but instead allows the user to identify qualitative patterns of system behaviour. The model setup can be described by the following equation (Papageorgiou and Kontogianni, 2012):

$$A_i^{(k+1)} = f(A_i^{(k)} + \sum_{\substack{j \neq i \\ j=1}}^{N} A_j^{(k)}.w_{ji})$$

Where:

$A_i^{(k+1)}$ = Activation level of component at next iteration

$A_i^{(k)}$ = Activation level of component at current iteration

$A_j^{(k)}$ = Current activation level of other components at which affect component

w_{ji} = weights of associated linkages

f() = sigmoid threshold function

Model iterations are executed until the activation levels of every component have stopped fluctuating because the system has reached a steady state. Of course, in the real world a truly steady and unchanging state does not exist: weightings are not static in reality, and activation levels of components are affected by all manner of interactions beyond the capacity of participants to include. The FCM is the best approximate of how a system interacts relationally.

FCM modelling software use for Chapter 6

Whilst I used MentalModeler for gathering together FCM data, the FCM Expert software was used for scenario modelling. Felix et al. (2019) highlight FCM Expert (Nápoles et al., 2017) as one of the most recent, general purpose, and complete software tools for modelling FCM-based systems. It includes tools to optimise network topology, and allows users to configure their own model parameters within the tool (Felix et al., 2019). After experiencing some issues trying to use MentalModeler's scenario interface for modelling, and realising that it lacks the ability for users to set activation levels (which represent the abundance of components in the system) for components, I decided to transfer my data to FCM Expert. This involved converting it into .csv format using the MentalModeler interface, then after some minor alterations (such as changing names to 3-digit abbreviations and writing in 0 values into blank cells), importing the .csv to the new software.

I opted to use the modified inference algorithm outlined by Papageorgiou & Kontogianni (2012) in their FCM methodological primer, and also followed their guidelines in using the sigmoid function to bound the activation levels. After running the model under several different scenarios for offshore wind expansion (detailed in Chapter 6, I compared the tabulated results using box- and line- graph functions in Microsoft Excel.

Chapter 4: Scoping the UK North Sea System with Aura CDT

This first empirical thesis chapter analyses and reports on focus group data that was gathered to help scope out how UK North Sea (UKNS) social-ecological entities interact with one another. This scoping analysis presents fuzzy cognitive maps (FCMs), both individual and then aggregated, alongside a power-interest matrix produced by these focus groups. Together they depict how the focus groups, which were comprised of Aura Centre for Doctoral Training (CDT) in offshore wind energy and the environment PhD students, perceived these UKNS relationships. These data have been gathered and processed through methods detailed in Chapter 3, Phase 1: Scoping the UK North Sea System, and are used to partially answer RQ1, as well as to lay the groundwork for answering the other research questions posed in this thesis. In this chapter, FCMs are used to understand perceptions of social-ecological systems (SESs) through sharing of knowledge and analysis of structure (Gray et al., 2015). The chapter begins with a qualitative analysis of the individual FCMs produced by each focus group, before incorporating a structural and quantitative interpretation each (4.1). Perceived confidence ratings between groups are then briefly compared (4.1.3), before the process for aggregation of focus group component categories is described (4.2). What then follows is a brief qualitative interpretation of the aggregated map (4.3.1), before an overall structural analysis occurs (4.3.2), which leads on to an analysis of how the weightings for certain linkages on the FCM varied between focus groups (4.3.3). The results of each focus group's second task - to construct a power-interest matrix on the phenomenon of an expanding offshore wind industry in the UK North Sea, are then displayed ensemble, with key features of each quadrants potential representatives then being highlighted (4.4). Finally, all of the results are discussed, their quality and that of the methods used are critiqued, and how these findings will be used in the next stage of this research is outlined (4.5). Chapter 5 will incorporate much more complex detail on the linkages between different UKNS components, before extended uses of FCMs, such as analysis of functions through scenarios (Gray et al., 2015), will occur in Chapter 6.

4.1 Individual Focus Group Fuzzy Cognitive Map Results

4.1.1 Qualitative interpretation of individual maps

The FCMs produced by each focus group reveal how each group perceives the UKNS system to function. Each map illuminates how participants understand social-ecological phenomena, such as positive or negative feedbacks, conflicts, and synergies that may exist within the system (Gray et al., 2015). Nodes on the following maps represent the connected components identified by each focus group. Orange Arrows represent negative effects, whilst blue arrows represent positive effects between components (Figure 4.1). The direction of the arrow represents the direction of effect, and the thickness of the arrow roughly represents the strength of effect as perceived by focus group participants. Thin black arrows represent uncertain effects: these represent cases where participants expressed awareness of an effect between components (and the direction of that effect) but were unsure about the extent or quality of that effect and the complexity of the linkages involved. The colour of each node reflects the aggregated categorisation of that component to allow for easier comparison between FCMs (see Section 4.2.1). To access more results, including notes on the effects, actual weighting values for strength of effect, and confidence ratings, please see instructions in Appendix X. These include the .mmp data files for each FCM, and the link to the MentalModeler website where the files can be uploaded and data observed.

Aggregated Categorisation Key and Arrow Meanings for Fuzzy Cognitive Maps

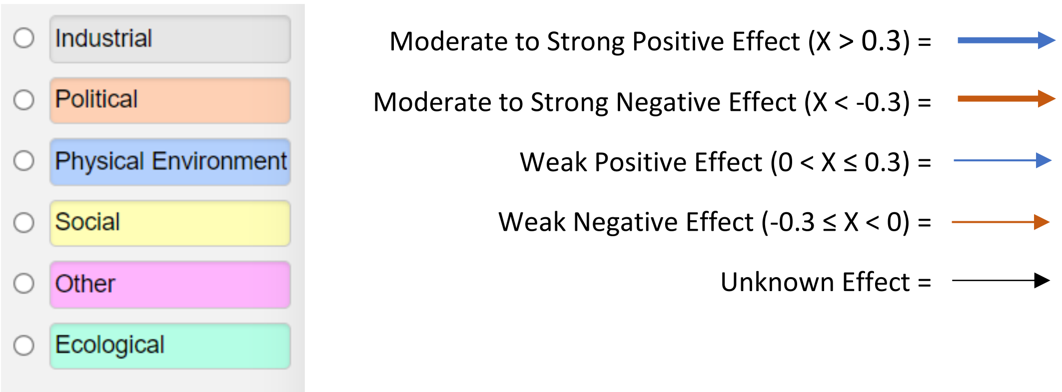


Figure 4.1 Key to show what node colour and arrows represent on the FCMs in this chapter.

Focus Group 1 – 4 participants

Like all focus groups, Focus Group 1 centres offshore wind on their FCM (Figure 4.2). From a visual inspection, it is the most highly connected and central component of their system. On their FCM, they display direct antagonistic effects between offshore wind and fisheries, offshore wind and shipping, offshore wind and sediment distribution, and currents and weather. They display direct synergistic effects between coastal communities and fisheries, coastal communities and sports and recreation, the oil industry and maintenance vessels, and offshore wind and air travel (inferred to mean crewed aircraft and the aircraft industry). Reflecting the group's limited expertise in ecology, the relationships between ecological components include a lot of unknown effects. Incomplete delivery of some instructions (due to this being the pilot group) mean several components on their map - for example, sediment distribution and political – are not configured to be able to rise or fall in value, which may have led to some unclear claims on the links between certain components. For example, the positive effect from fisheries to political would suggest that if fisheries were to expand, so too would politics – which does not make sense.

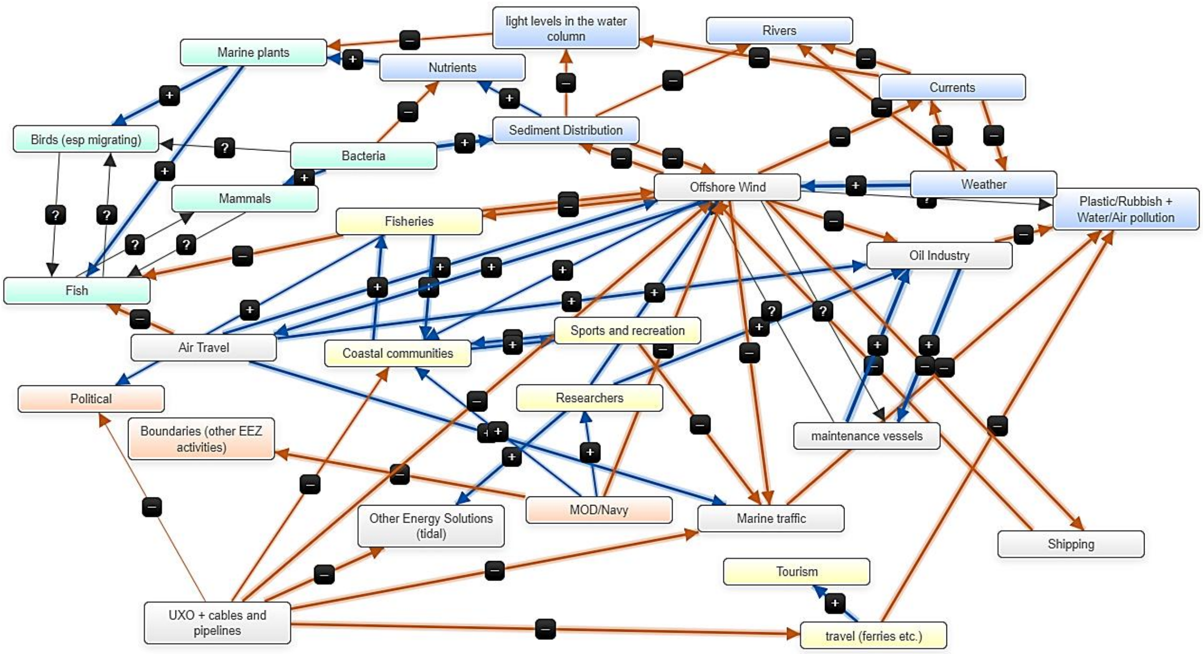


Figure 4.2 Digitised Fuzzy Cognitive Map produced by Focus Group 1.

It is possible to identify from Focus Group 1's FGM some knock-on effects that an expansion of offshore wind may cause. For example, offshore wind growth would cause a decline in fisheries activity, which would carry through to have negative effects on coastal communities. In the same vein, it may also cause an increase in fish abundance. No clear feedback loops were identified on any of the focus groups FCMs.

According to Focus Group 1's FCM, increased offshore wind developments cause declines in marine traffic. This FCM would also suggest that an increase in marine traffic would cause a decrease in the amount of plastic/rubbish + water/air pollution. A decrease in marine traffic causing this increase does not make logical sense, which may suggest that participants of this focus group were not fully understanding how to unpack their knowledge of the marine system into the framework of an FCM. This may also be reflected in their spread of confidence ratings (see section 0). The difficulties in transferring participant knowledge into FCM form highlight the importance of the data homogenisation stages that occur after the gathering of focus group results. Another example supports the use of transcript analysis to ratify linkages in FCM: the relationship between offshore wind and sediment distribution on Focus Group 1's FCM tells us that offshore wind has a negative effect on sediment distribution, which on its own does not mean a lot to a viewer of this FCM.

However, during the session when I asked Speaker 4 of that group to clarify what they meant by sediment distribution, the qualitative response added a lot more texture to the relationship. Speaker 4 highlighted that increased subsea infrastructure, such as offshore wind turbine bases, causes an increase in the rate of sediment erosion, and that this in turn can affect the types of nutrients found in the water column. This additional insight helps relationships that were well described but poorly displayed on the FCM make more logical sense. Qualitative insights into the causal relationships between entities in the UKNS are more fully explored in Chapter 5, which uses data from marine expert interviews to develop a set of linked social-ecological action situations.

Focus Group 2 – 5 participants

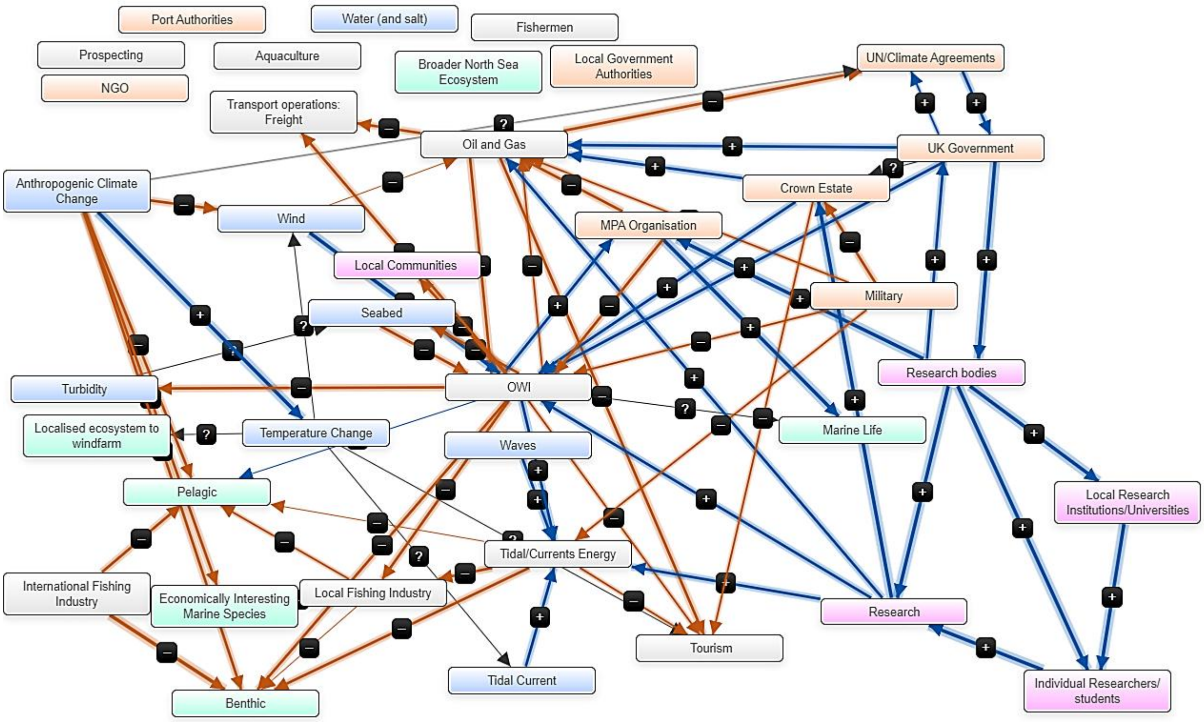
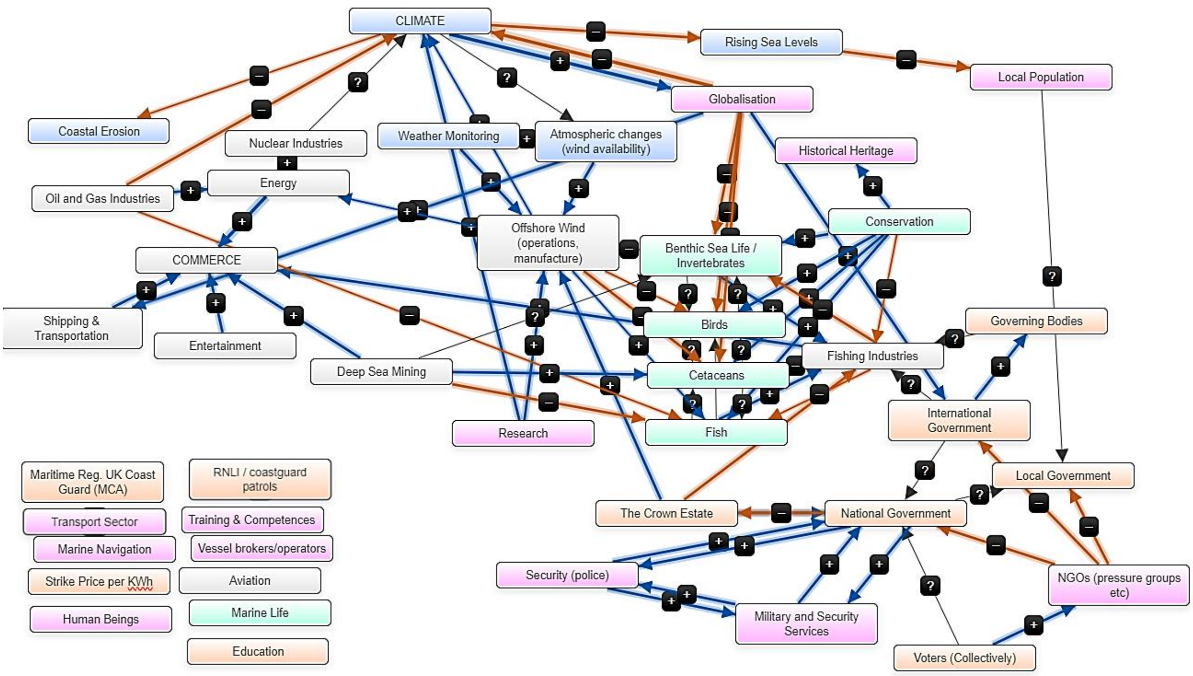


Figure 4.3 Digitised fuzzy cognitive map produced by focus group 2.

On Focus Group 2's FCM (Figure 4.3), there is an overall antagonistic relationship between the offshore wind industry component (OWI in Figure 4.3) and oil and gas, although Speaker 5 of this group stated that there are some positive effects of oil and gas onto offshore wind, such as offshore expertise. Focus Group 2, unlike Focus Group 1, bought in entities that could be considered at larger scales than the UKNS, but that regardless influence system function. Most clearly, anthropogenic climate change had negative effects on benthic, pelagic, and economically interesting marine species, and UN/climate agreements had a synergistic positive relationship with UK government. Energy industries uniformly had a negative impact on tourism, whilst the military had negative impacts on energy industries. Most negative impacts between socio-economic entities were assigned whilst considering the spatial squeeze that the UKNS is increasingly coming under: if one industry grows, it takes up space that other industries could have used. Despite some expertise in marine ecosystems amongst this group, the ecological entities remained quite vague and poorly connected to each other and the rest of the system in this FCM. There is a brief mention of local communities, but it is only connected with the offshore wind industry and there is no overall social category identified by this group, suggesting that it may not be considered important by these participants when considering how the system functions. Finally, several components (found at the top right of Figure 4.3) were identified but remained disconnected throughout the focus group exercises, potentially due to time constraints. These components were not taken forward in the research.

Focus Group 3 – 7 participants

Figure 4.4 displays the linkages between different entities of the UKNS system according to Focus Group 3. Much like in Focus Group 2, the participants did not have time to connect every component they had identified – those unconnected components are displayed at the bottom left of Figure 4.4



. A feature of this FCM is that some of the categories (commerce and climate) were included in the FCM as unifying terms for a set of components. Anything that related to commerce had a positive link directed to it. Climate was reconceptualised once it was on the map to represent climate change. A notable and frequent occurrence on the group-based FCMs is that it is difficult to assign weighted linkages that connect with governance entities (here for example local governance, national government, and international governance). This may be because the variety of effects wrought by policy effect other entities of the system in a wide range of ways, both positively and negatively. Focus group 3 have also categorised some components in curious ways: weather monitoring has been categorised as a component of the physical environment, even though it is a human process of monitoring and reacting to the physical environment. A similar sort of categorisation has occurred where conservation is labelled as an ecological component.

Offshore wind on this FCM has an overall negative effect on benthic sea life/ invertebrates, birds and cetaceans, but positive effects on fish. As above, the full transcript uncovers the complexity that the map displays, as Speakers 7, 4 and 2 of this group broke this connection down to include both positive and negative effects: negative effects caused by construction noise causing migration and affecting reproduction, but stronger positive effects due to habitat formation, tidal breaking, and calm water creation. They also said there is a temporal element to this relationship, with construction of wind farms causing most of the negative effects, and the state of the farm during operation causing the suite of positive effects.

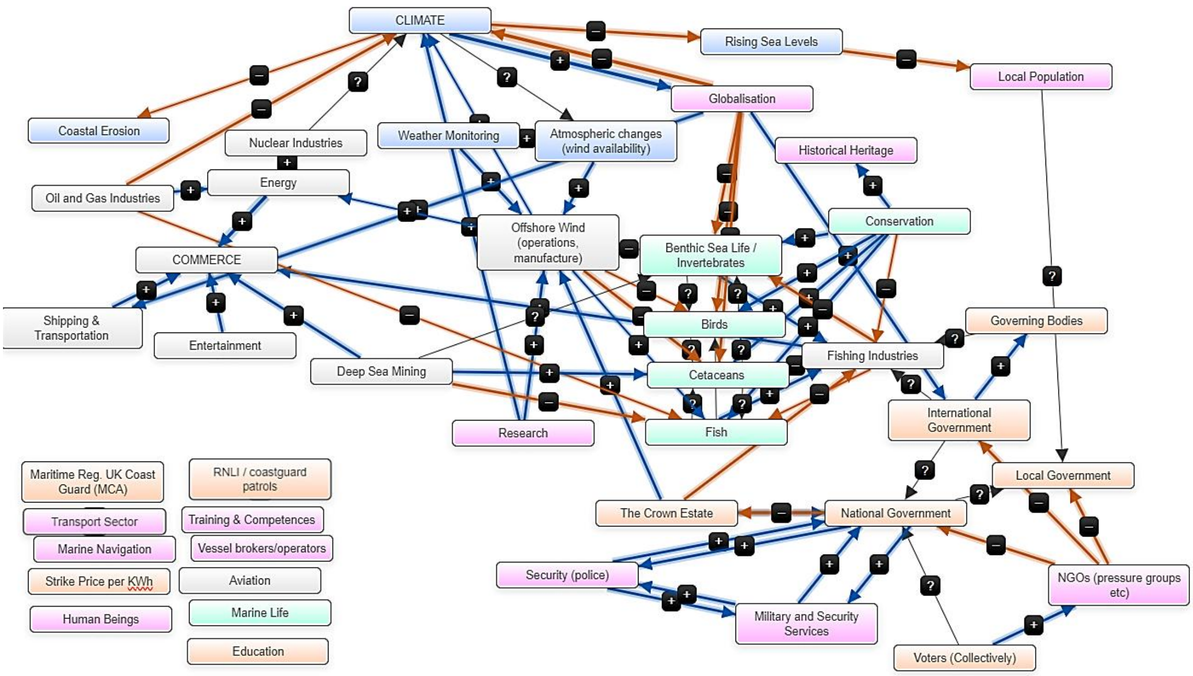


Figure 4.4 Digitised Fuzzy Cognitive Map produced by Focus Group 3

Focus Group 4 – 4 participants

Focus Group 4 had a smaller FCM than other focus groups, and quite different perspectives on what the important relationships were in the UKNS. Their FCM was much more focussed on the offshore wind industry than other groups. For example, their social components (named labour within their group session, which is split between industrial and social in Figure 4.5) break down the offshore wind workforce as opposed to lumping it into one overarching offshore wind node as the other focus groups had. They also broke wind infrastructure down into turbines, cables and energy transmission, and operations and maintenance efficiency. They even qualified some physical environment components by relating them directly to offshore wind developments - for example, the suitable marine geology/ sediment node relates directly to how suitable an area might be for offshore wind developments.

The expansion of offshore wind concepts made Focus Group 4's work more difficult to align with that of the other focus groups during the homogenisation stage of the project. Much detail was lost through this process, as due to the regional scale of the project, a lot of the offshore wind-based nodes were aggregated together. This highlights trade-offs that can occur in aggregation of individual FCMs in order to achieve an overall regional view, especially with polycentric perspectives of how a system is composed.

Focus Group 4 were the only group to include certain extrinsic economic factors – such as LCoE (levelised cost of energy), Energy Price and Energy Demand. This may have been more readily included due to the focus this group had on the offshore wind industry. Where social and industrial factors were a focus, a lack of attention was given to the physical and ecological entities in the region, almost certainly due to the engineering and economics foci of the participant's own research.

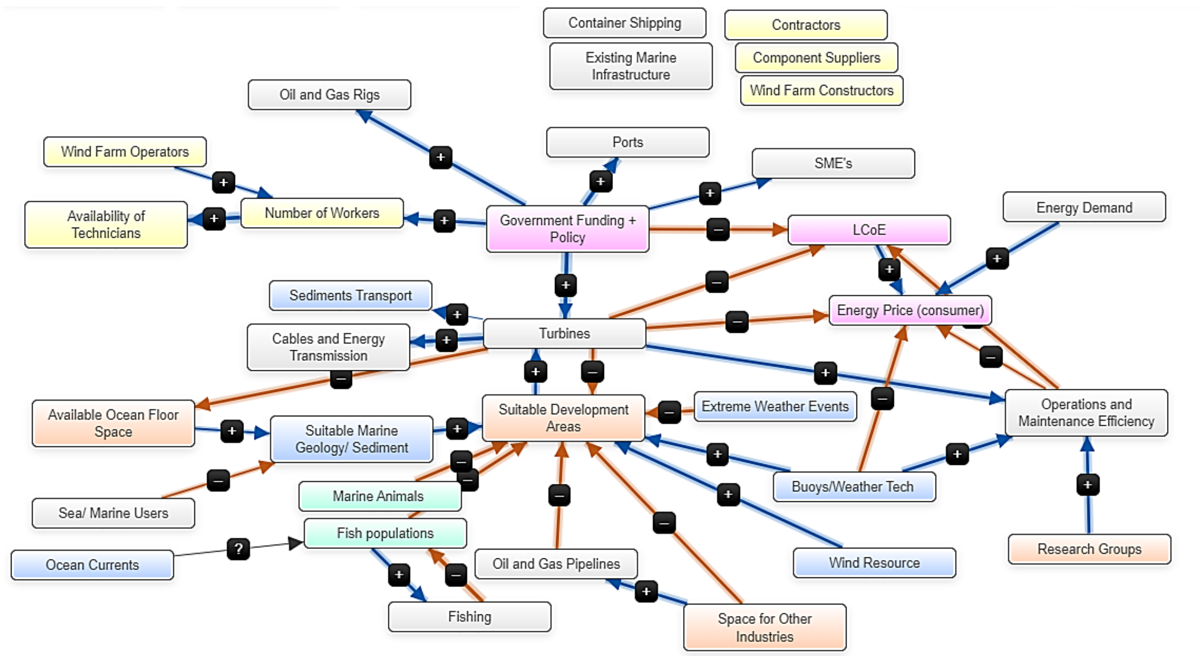


Figure 4.5 Digitised Fuzzy Cognitive Map produced by Focus Group 4.

4.1.2 Structural properties of individual fuzzy cognitive maps

Quantitative metrics allow for comparisons between different individual and grouped FCMs (Gray et al., 2014). Table 4.1 quantifies the main structural features of the individual FCMs produced by the focus groups, both before and after the homogenisation stage. It shows the number of connected components (N) and number of linkages (L). Focus Group 3 had the largest N & L both pre- and post-homogenisation, perhaps due to their larger group size of 7 participants. Focus Group 4 had the lowest N and L, with the L being particularly low compared to other groups. Homogenisation had variable effects on the number of components; Focus Group 1 saw a small increase, Focus Group 2 maintained 29 components, and Focus Groups 3 and 4 saw decreases. These trends are broadly similar for homogenisation of the number of connections, except that Focus Group 1 saw a larger increase in the number of connections, and Focus Group 2 saw a small decrease.

Table 4.1 Quantification of the group-based FCMs created by Focus groups 1-4, both before and after the homogenisation (Hom) process, which homogenised the terms and scale used between all focus groups in preparation for aggregation of FCMs (see Chapter 3).

Focus Group	1	2	3	4	Hom 1	Hom 2	Hom 3	Hom 4
Number of Participants	4	5	7	4	4	5	7	4
Number of Components (N)	29	29	34	28	32	29	31	21
Number of Connections (L) [7]	65	69	74	37	89	64	71	29
Density (L/N^2)	0.08	0.08	0.07	0.05	0.09	0.09	0.08	0.07
Connections per component (L/N)	2.24	2.38	2.18	1.32	2.78	2.21	2.29	1.38
Driving Components	3	5	8	10	3	5	5	7
Receiving Components	9	9	8	7	13	13	8	5
Ordinary Components	17	14	16	10	16	11	17	7
Complexity (receiving/driving)	3	1.8	1	0.7	4.33	2.6	1.6	0.71

The density function (Table 4.1) acts as an index of connectivity, with high densities representing a large number of causal relationships between variables (Papageorgiou and Kontogianni, 2012). All individual maps had relatively similar densities, with homogenised Focus Groups 1 & 2 having the highest at 0.09, and Focus Group 4 having the lowest at 0.04. These densities were similar to those found across the studies of Özesmi & Özesmi (2004), who interpreted this as a relatively low density, suggesting a low overall level of connectivity. They also cautioned to only compare approximate results from across other studies in the literature, as other factors affect values, such as length of

[7] Note - this number does not include any “0” weighted connections.

text, duration of interview/ focus group, skill of facilitator. The process of homogenisation appeared to cause a uniform increase in density by 0.01 (Table 4.1). The connections per component (L/N) were broadly similar across the pre- and post-homogenised maps (Table 4.1). Notable exceptions included homogenised map 1, which had a high of 2.78 L/N, and the Focus Group 4 maps, which both had far lower values: 1.32 L/N pre-homogenisation, and 1.38 L/N post homogenisation. Focus Group 4's map had a notably lower level of connectivity according to this statistic.

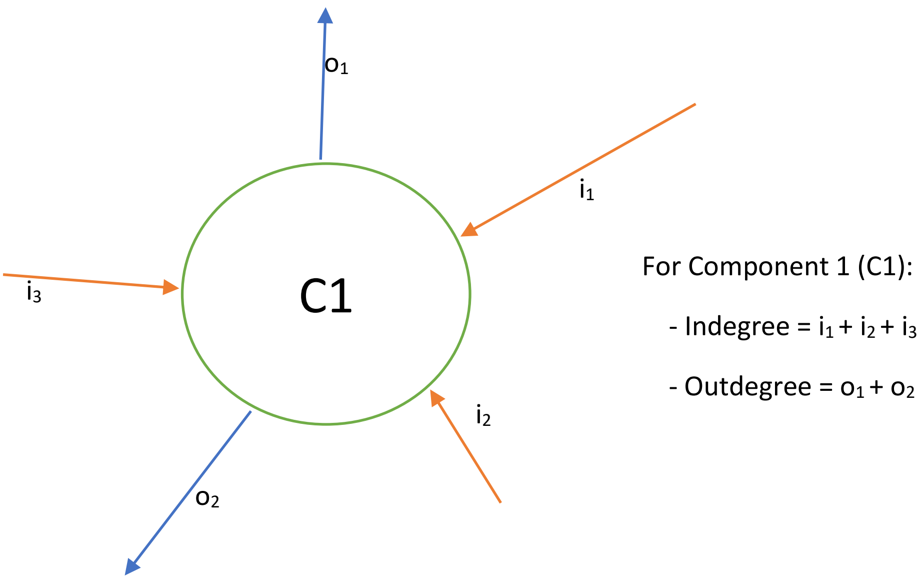


Figure 4.6 An example for how the indegree and outdegree of a component is calculated.

Other structural properties of FCMs include driving, receiving and ordinary components, for which one must first calculate indegree and outdegree (Figure 4.6). Indegree shows the cumulative strength of variables entering a component, whilst outdegree shows the cumulative strength of variables leaving a component (Figure 4.6, Özesmi & Özesmi, 2004). If a component has a positive outdegree and no indegree, it is considered a driving component. If a component has both a positive indegree and outdegree, like the example component in Figure 4.6, it is an ordinary component. Finally, if a component has a positive indegree and zero outdegree, it is a receiving component. The number of receiver components can be considered an index of a map's complexity (higher numbers meaning more complexity), whilst the number of driving components indicates a more hierarchical system, and/or an increased "flatness" to a map upon which causal arguments are not well elaborated (Özesmi & Özesmi, 2004). The ratio of receiving to driving variables can therefore tell us about the complexity of the FCMs. Focus Group 4 were the only group to have more driving components than receiving components both pre- and post-homogenisation (Table 4.1). Focus Groups 1 and 2 both showed consistently high complexity ratios, suggesting that many outcomes and implications of the system were considered in these groups (Eden et al., 1992). Pre-homogenisation, Focus Group 3's map had an equal number of driving and receiving variables. Post-homogenisation, there were significantly fewer driving components. The majority of components were classified as ordinary, aside from in Focus Group 4, which showed the same number of driving components as ordinary components both pre- and post-homogenisation.

4.1.3 Confidence ratings

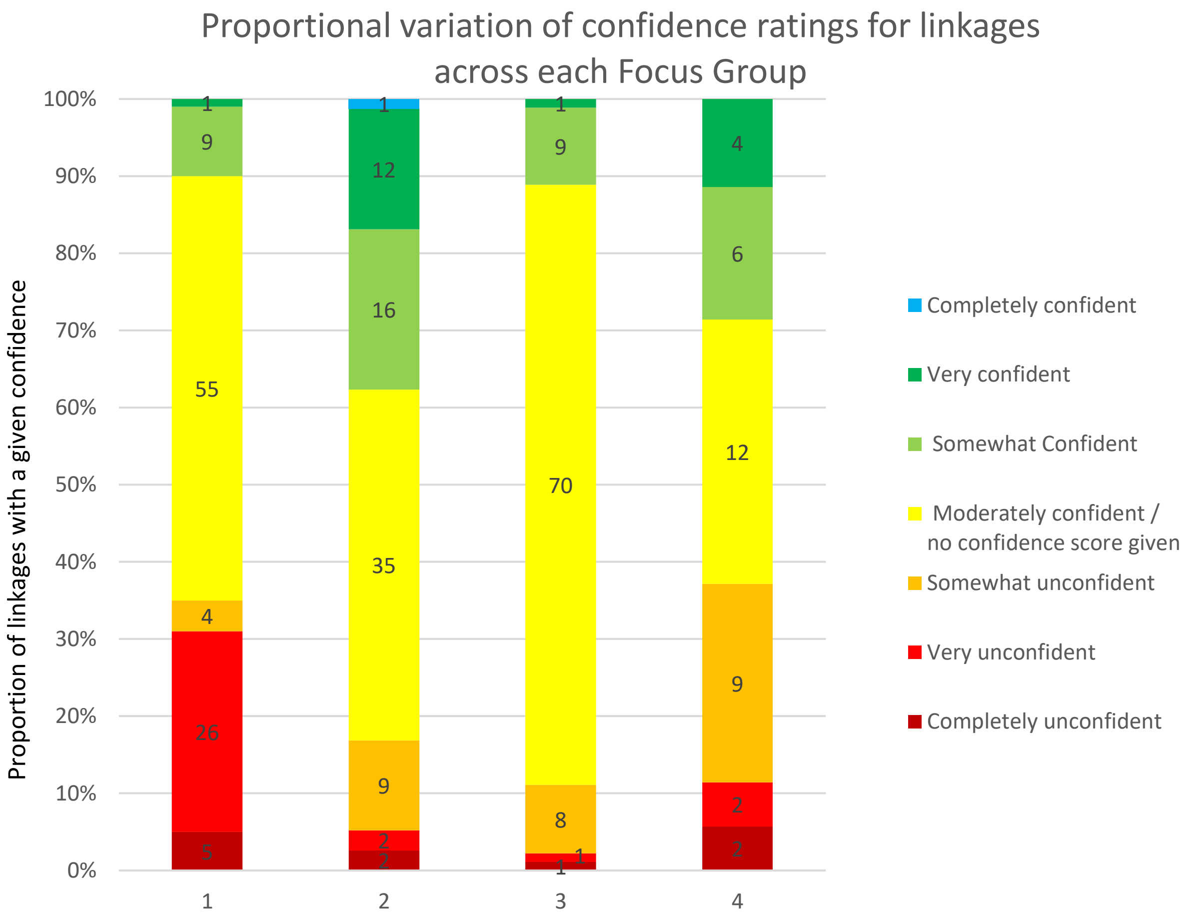


Figure 4.7 How the confidence rating in linkage identification and weighting varied within and across focus groups. Confidence ratings were qualitatively applied during and after each focus group by the focus group facilitator. Numbers within the bars denote the actual number of linkages assigned a given rating in each focus group.

Confidence ratings were applied to the linkages between different components of each focus groups' FCM. Inter-focus group comparison of confidence ratings can reveal which groups the facilitator perceived to be more or less confident in the identification and weightings of linkages. Figure 4.7 displays the variety of confidence scorings for each focus group. Focus Group 1 had a high proportion of "very unconfident" ratings, suggesting that this group were less certain than other groups about the linkages and weights they were adding to their FCM. Focus Group 2 had a high proportion of “Somewhat confident” and “Very confident” ratings. Focus Groups 3 and 4 had relatively similar proportions of confidence ratings – both sets of ratings fit quite well to a standard normal distribution. The core difference between these two focus groups is the number of “moderately confident / no confidence rating given” variables. Focus Group 3 had 70 linkages in this category, whereas Focus group 4 only had 12. As well as Focus Group 3’s FCM being much larger, the group size (7 participants) was considerably larger than Focus Group 4 (4 participants). In Focus Group 3, this meant that participants would more frequently form small groups of 2-3 participants to work on a certain part of the FCM, which meant there were multiple conversations happening at once. This was much harder for me to keep a track of in the facilitatory role, even with the ability to listen back to the transcript post-focus group session. As a result, whilst there were many more linkages discussed by Focus Group 3, there were also many fewer opportunities to assign a confidence rating and understand some of the meanings behind the linkages themselves.

4.2 Component Categorisation

4.2.1 Aggregating categories

Table 4.2 Shows how the differing categorisations from each focus group were bought together through homogenisation into aggregated categories by the researcher. Blue indicates physical environment, purple indicates political, green indicates ecological, pink indicates other, which variously signified components that were considered either in all categories, having no distinct category, or not falling into any category. Grey represents industrial, which is an accumulation of economic, industrial, and infrastructural categorisations. Yellow represents social. Some of Focus group 4's categorisations crossed between established overall categorisations, and so were considered to fall into two aggegregated categories. Labour (dark yellow) falls into both social and industrial categories, whilst constraints (dark pink) falls into both industrial and other categories.

Focus Group Categories				Overall Aggregated Categories	Appears in X Focus Groups
1	**2**	**3**	**4**		
Physical	Physical Environment	Climate	Environmental	**Physical Environment**	**4**
BIO (biological)	Nature	Ecology	Non-human Life	**Ecological**	**4**
	In All	No Distinct Category		**Other**	**3**
	Does not fall into any category				
			Constraints		
Economical	Industry	Commerce	Infrastructure	**Industrial**	**4**
Infrastructure	Energy		Other Industries		
			Labour		
Social				**Social**	**2**
Political	Governmental	Government		**Political**	**3**

Table 4.2 displays how the categories elected by each focus group were qualitatively combined into one set of aggregated categories. The categories of Physical Environment, Ecological, and Industrial were the only categories which were consistently identified by the focus groups. Political as a category was used by three out of four focus groups, whilst Social was only fully present in Focus Group 1, and partially present through the Labour category identified by Focus Group 4.

4.2.2 Categorisation results

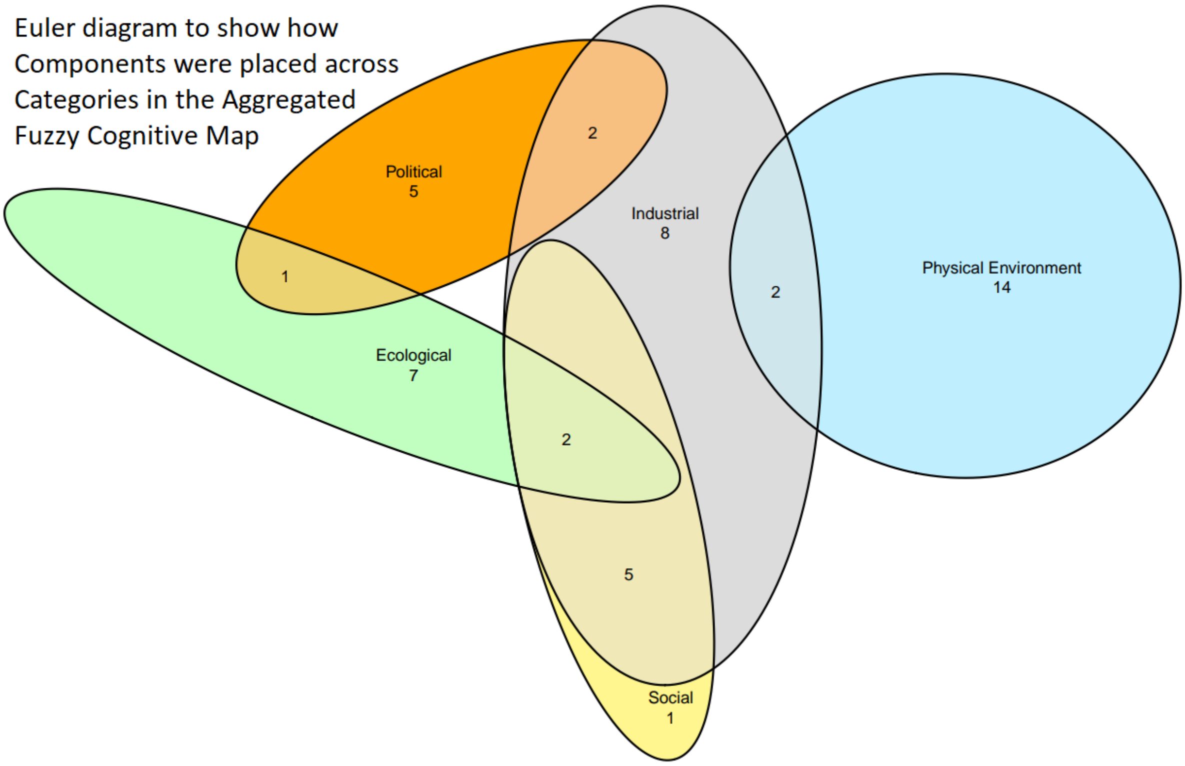


Figure 4.8 Euler Diagram showing the number of components within and across all categories aside from the "other" category in the aggregated FCM, which is not included due to its generic and broad nature.

Within each focus group, how components were categorised varied. Many components were deemed to cross the boundaries of these categorisations. Figure 4.8 shows how these categorisations looked when the focus group results had been aggregated together. The category with the most components is industrial, with 19 components. This is followed by physical environment (16), ecological (10), then political and social (both 8). The area of largest overlap between two categories is between social and industrial, which share 7 components. Industrial shares 11 of its 19 components with other categories. The euler diagram shows how within this social-ecological system, the ecological (biotic and abiotic features) are far more easily considered to fall within a distinct category, whereas the social (economic, political, cultural, technological) features often have much more overlap when it comes to how they are understood and categorised. The two components that are placed within industrial, ecological and social categories are local and international fisheries. The nature of the fishing industry means it is at the epicentre of many marine social-ecological interactions, and as such fisheries studies are increasingly taking on more of a social-ecological perspective (e.g. Kittinger et al., 2013; Stephenson et al., 2018; Salgueiro-Otero & Ojea, 2020).

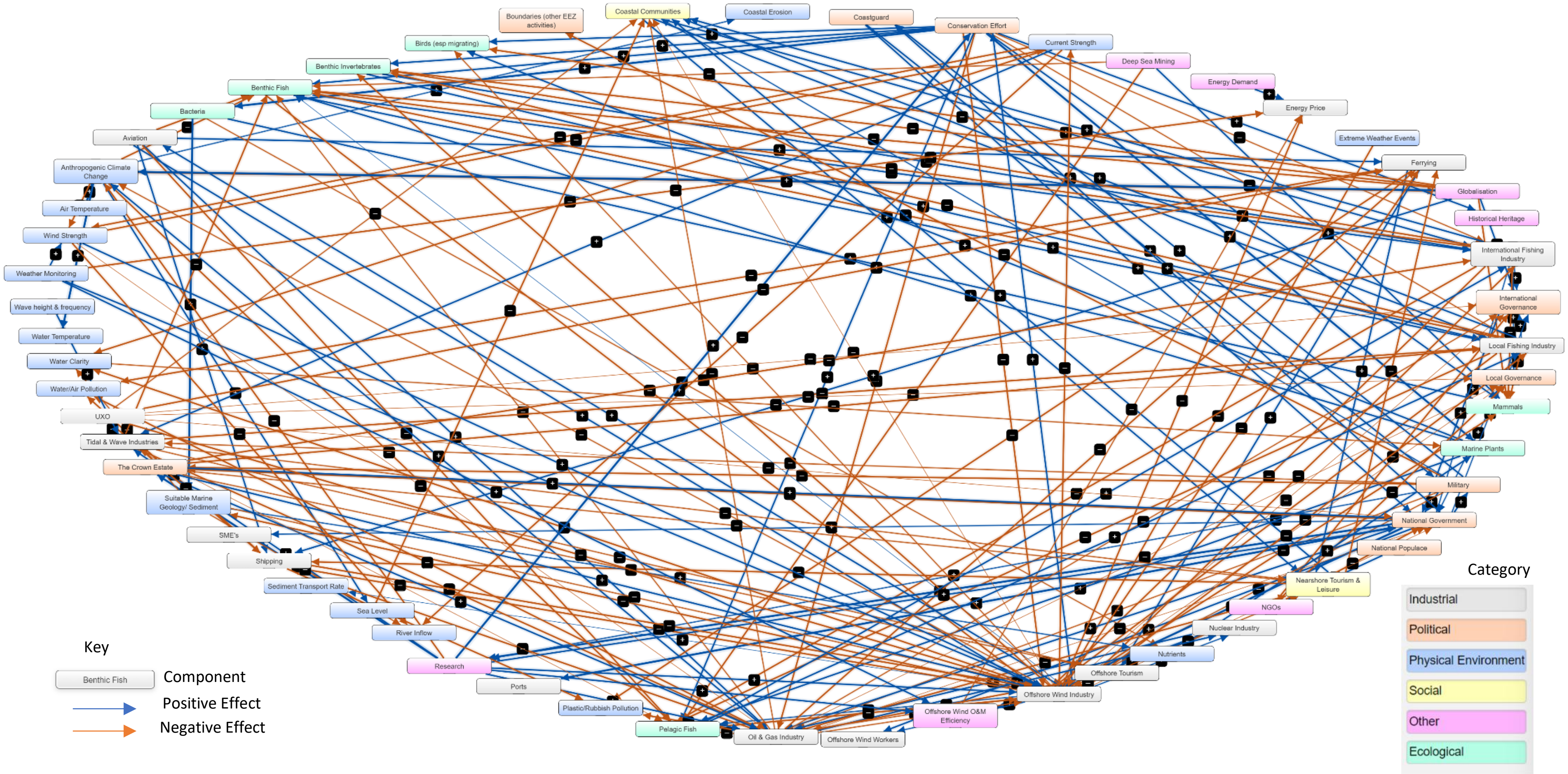


Figure 4.9 Aggregated Fuzzy Cognitive Map depicting Aura CDT perceptions on the effects different UK North Sea social-ecological entities have on one another. Weightings and category details can be accessed by clicking on individual lines of effect in the MentalModeler interface. Components are categorised by colour, though many components fall into multiple categories (see ***Error! Reference source not found.****).*

4.3 Aggregated Fuzzy Cognitive Map Results

The aggregation of four Aura CDT focus groups' knowledge of the linkages between different UK North Sea components is visualised in Figure 4.9. The relationships between different components when defined like this in terms of strength according to weightings, represents the "networked structure of a system" (Gray et al., 2015, p.3). A brief qualitative and more extensive quantitative analysis of these data follow. In the literature FCM analysis often involves some form of scenario analysis, based on running the FCM as a semi-quantitative model to test how change in a part of the system may result in change elsewhere. I do not undertake this step here in Chapter 4, as Chapter 5 first uses expert interviews to further validate and improve the gathered data. Chapter 6 is where I run the aggregated FCM as a model to test how expansion of offshore wind may affect other entities in the UK North Sea.

4.3.1 Qualitative interpretation of aggregated fuzzy cognitive map

The size of the aggregated FCM (Figure 4.9) is striking, to the point where it is hard to discern a lot of information from a purely visual inspection. It is possible to pick out more central components by comparing the number of linkages attached to each one. According to this joint perception from Aura CDT students, components such as the Offshore Wind Industry, Oil and Gas Industry, National Government, Coastal Communities, Benthic Fish, and Local and International Fishing Industries look more highly connected than other nodes. It can also be seen that marine species components and Coastal Communities are largely receiving components.

4.3.2 Structural analysis

Table 4.3 shows the main quantitative structural features of the aggregated fuzzy cognitive map, which contains the combined knowledge of all 4 focus groups. There are 57 components, and 204 connections, giving 3.58 connections per component, which is significantly higher than in any of the individual fuzzy cognitive maps. However, the density remains low, at a value of 0.06. This suggests an overall low level of connectivity between components.

The most common component type by far is ordinary, which accounts for 33/57 of the components. There are significantly more receiving components than driving components, which is reflected in the overall complexity ratio of 2.4. This suggests a moderately high degree of complexity for this map.

Table 4.3 Structural properties of Aggregated FCM

Name of property	Value
Number of Components (N)	57
Number of Connections (L)	204
Density (L/N^2)	0.06
Connections per component	3.58
Driving Components	7
Receiving Components	17
Ordinary Variables	33
Complexity (receiving/driving)	2.4

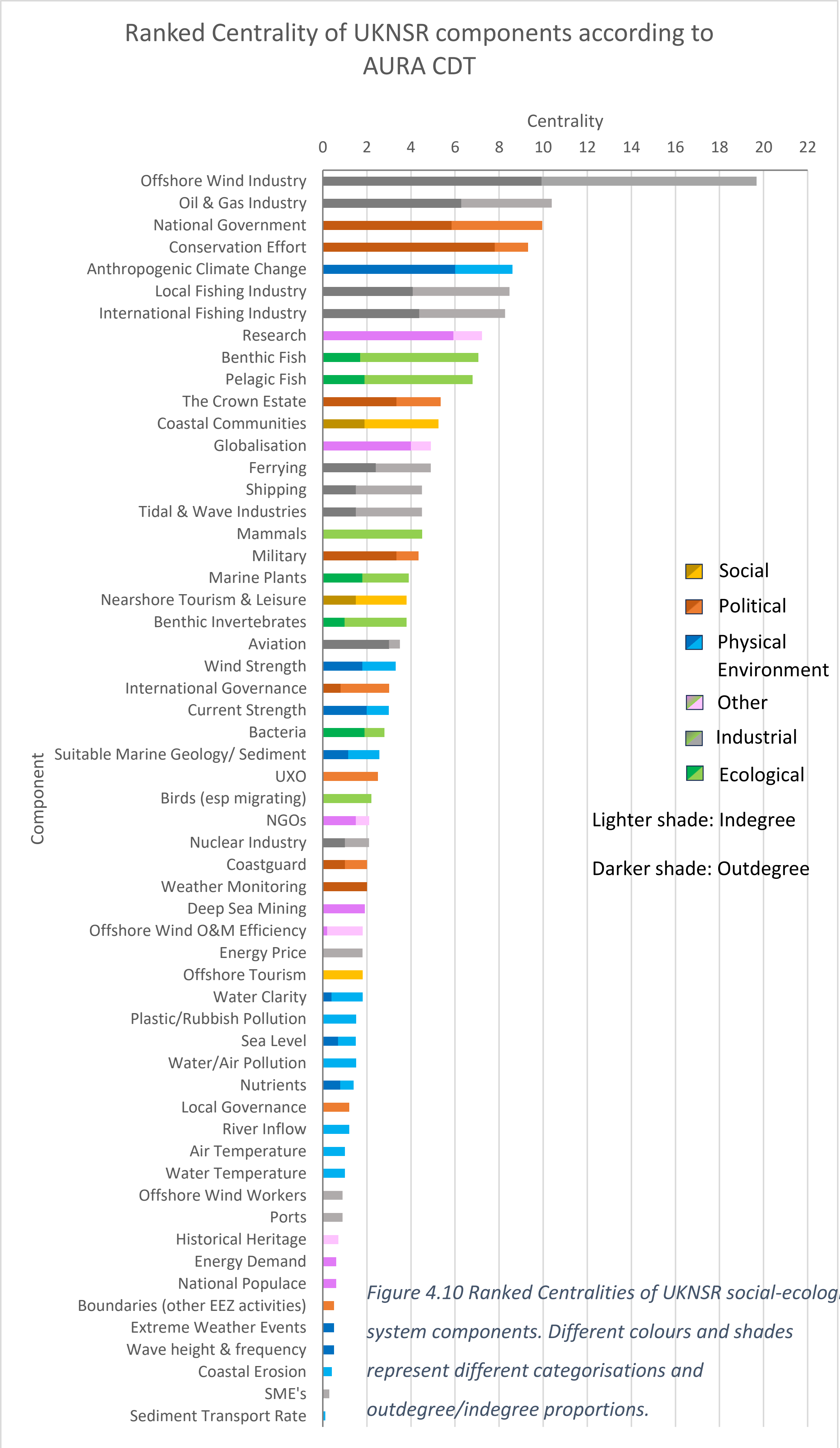


Figure 4.10 Ranked Centralities of UKNSR social-ecological system components. Different colours and shades represent different categorisations and outdegree/indegree proportions.

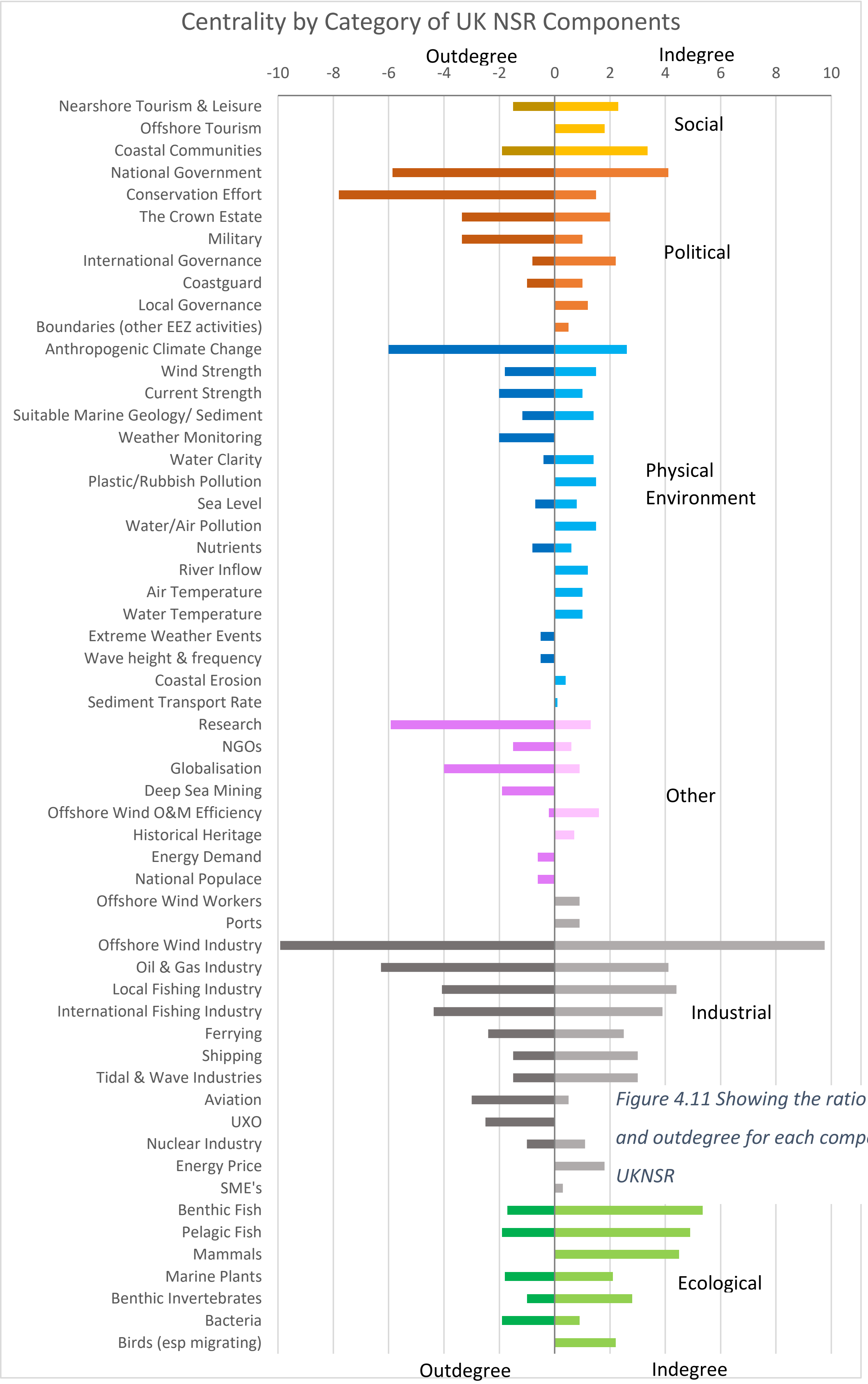


Figure 4.11 Showing the ratio of indegree and outdegree for each component in the UKNSR

The centrality of individual components within the aggregated FCM is calculated by summing the cumulative indegree and outdegree of a given component. It shows how connected a variable is to other variables within the system. The ranked centralities, according to Aura CDT students, are displayed in Figure 4.10, colour coded to show which overall category each component was placed in. The results show that industrial and political components are the most central parts of the system in question. The Offshore Wind Industry has the highest centrality score, with a centrality value of 19.68 – almost double that of the next most central component. This is followed by Oil & Gas Industry (10.39), National Government (9.95), and Conservation effort (9.30). Anthropogenic Climate Change has the highest centrality of any physical environment component, with a centrality of 8.60, whilst the highest ecological components, benthic and pelagic fish, have centrality of 7.05 and 6.80 respectively. Coastal Communities, the highest centrality social component, has a centrality of 5.25.

The components with the highest degrees of centrality are most commonly ordinary components. Driving components uniformly had a low degree of centrality (Table 4.4), suggesting that they may not actually be crucial components for driving the system. Aside from (Marine) Mammals, receiving components also had relatively low centrality in the system.

Table 4.4 The relative centrality of driving and receiving components in the aggregated FCM

Driving components	**Centrality (Outdegree)**	**Receiving components**	**Centrality (Indegree)**
Unexploded ordnance (UXO)	2.50	Mammals	4.50
Weather Monitoring	2.00	Birds (esp migrating)	2.20
Deep Sea Mining	1.90	Energy Price	1.80
Energy Demand	0.60	Offshore Tourism	1.80
National Populace	0.60	Plastic/Rubbish Pollution	1.50
Extreme Weather Events	0.50	Water/Air Pollution	1.50
Wave height & frequency	0.50	Local Governance	1.20
		River Inflow	1.20
		Air Temperature	1.00
		Water Temperature	1.00
		Offshore Wind Workers	0.90
		Ports	0.90
		Historical Heritage	0.70
		Boundaries (other EEZ activities)	0.50
		Coastal Erosion	0.40
		SME's	0.30
		Sediment Transport Rate	0.10

When the centrality scores are organised into the core categories from the focus groups, certain trends emerge when the ratio of indegree and outdegree is compared (Figure 4.11). Nearly all ecological and social components show a higher indegree than outdegree, suggesting that they tend towards being receiving, or impacted components. By contrast, physical environment and industrial components tend to have a much more even spread of indegree and outdegree. Components within the political category tend to have a larger outdegree than indegree, suggesting that they tend towards being driving components of the system. Industrial components had the overall largest combined centrality (72.71), followed by political (35.65), physical (31.87), ecological (31.05), other (19.81), and social (10.85).

4.3.3 Weightings analysis

Weightings describe the strength of an effect from one component to another in an FCM (Gray et al., 2015). During aggregation of the FCMs, when different weightings were given by different focus groups for the same relationship between components, the weights were averaged. Table 4.5 displays the suite of averaged weightings, along with the standard deviation, count and if there were any sign changes between different focus group’s assigned weightings.

Table 4.5 Weighting analysis for aggregated FCM linkages for which two or more focus groups assigned a weight. Count = number of focus groups a given connection is weighted in. Mean = average weighting. SD = Standard deviation. Sign Change = does the connection share the same sign across all individual FCMs? Range = difference between highest and lowest FCM values. Data is arranged in order of standard deviations, highest to lowest. Range = difference between highest and lowest weighting values for a given component.

Effecting Component		**Affected Component**	**Count**	**Mean**	**SD**	**Sign Change**
Offshore Wind Industry	→	Tidal & Wave Industries	2	0.000	0.707	YES
Oil & Gas Industry	→	Offshore Wind Industry	4	-0.175	0.650	YES
Offshore Wind Industry	→	Coastal Communities	2	-0.050	0.636	YES
Suitable Marine Geology/ Sediment	→	Offshore Wind Industry	3	-0.167	0.577	YES
Offshore Wind Industry	→	Benthic Fish	2	0.075	0.459	YES
Offshore Wind Industry	→	Oil & Gas Industry	3	-0.167	0.416	YES
Local Fishing Industry	→	Benthic Fish	4	-0.550	0.370	NO
Local Fishing Industry	→	Pelagic Fish	4	-0.525	0.340	NO
Conservation Effort	→	Benthic Fish	2	0.700	0.283	NO
Conservation Effort	→	Birds (esp migrating)	2	0.700	0.283	NO
Conservation Effort	→	Mammals	2	0.700	0.283	NO
Conservation Effort	→	Pelagic Fish	2	0.700	0.283	NO

Oil & Gas Industry	→	International Governance	2	-0.300	0.283	NO
International Fishing Industry	→	Pelagic Fish	4	-0.650	0.265	NO
Offshore Wind Industry	→	Pelagic Fish	2	0.225	0.247	NO
Wind Strength	→	Offshore Wind Industry	4	0.700	0.231	NO
International Fishing Industry	→	Benthic Fish	4	-0.725	0.222	NO
Research	→	Oil & Gas Industry	2	0.650	0.212	NO
Military	→	Offshore Wind Industry	2	-0.350	0.212	NO
Benthic Fish	→	International Fishing Industry	2	0.600	0.141	NO
Benthic Fish	→	Local Fishing Industry	2	0.600	0.141	NO
Offshore Wind Industry	→	Offshore Wind Industry	2	-0.600	0.141	NO
National Government	→	Offshore Wind Industry	2	0.850	0.070	NO
The Crown Estate	→	Offshore Wind Industry	2	0.650	0.070	NO
Research	→	Offshore Wind Industry	3	0.766	0.058	NO
Research	→	Tidal & Wave Industries	2	0.8	0	NO
Pelagic Fish	→	International Fishing Industry	2	0.7	0	NO
Pelagic Fish	→	Local Fishing Industry	2	0.7	0	NO
Weather Monitoring	→	Offshore Wind Industry	2	0.5	0	NO
Offshore Wind Industry	→	Local Fishing Industry	2	-0.5	0	NO
Offshore Wind Industry	→	Shipping	2	-0.5	0	NO
Offshore Wind Industry	→	Suitable Marine Geology/ Sediment	2	-0.5	0	NO
Oil & Gas Industry	→	Shipping	2	-0.5	0	NO

The count displays the frequency of occurrence for a given linkage across focus groups. The highest counts therefore reflect to an extent the best known and most obvious linkages of the area according to Aura CDT students. These are displayed in Table 4.6, and show that the offshore wind industry is known to affect and be affected by the oil and gas industry, and be affected by wind strength, research, and marine geology and sediment. They also show the well-known effect of fisheries on fish populations.

Table 4.6 Most frequently mapped linkages in the UKNS by Aura CDT focus groups.

Effecting Component	→	Affected Component	Count
Oil & Gas Industry	→	Offshore Wind Industry	4
Local Fishing Industry	→	Benthic Fish	4
Local Fishing Industry	→	Pelagic Fish	4
International Fishing Industry	→	Pelagic Fish	4
Wind Strength	→	Offshore Wind Industry	4
International Fishing Industry	→	Benthic Fish	4
Suitable Marine Geology/ Sediment	→	Offshore Wind Industry	3
Offshore Wind Industry	→	Oil & Gas Industry	3
Research	→	Offshore Wind Industry	3

Standard deviation, the range and whether there has been a change of sign all speak to how varied the weightings are for the same linkage between different focus groups. The highest possible standard deviation across this range is 1, and the lowest is 0. The standard deviations can be compared to discern the extent of consensus between the focus groups for the strength of effects between variables: the higher the value, the greater the disagreement.

Table 4.5 shows that the nature of the linkages between the Offshore Wind Industry and several other components are contested between Aura CDT focus groups. These focus groups disagree on offshore wind's effects on Tidal and Wave Industries, Coastal Communities, Benthic Fish and the Oil and Gas industry, whilst also being uncertain on how the Oil and Gas Industry and the Suitability of Marine Geology and Sediment effects the offshore wind industry. The latter linkage here may be explained by the highly varied way in which marine geology and sediment was conceptualised on each focus groups fuzzy cognitive maps. These named linkages also exhibit sign changes amongst the various focus group weightings, suggesting fundamental differences of perspective on how offshore wind developments interact with them, from within the same doctoral training centre. In addition, though all focus groups agreed that local and international fishing industries have a negative effect on benthic and pelagic fish populations in the UK North Sea (UKNS), there is disagreement on the extent of these effects, especially with regards to local fisheries.

4.4 Power-Interest Matrices Results

Power-interest matrices are a top-down analytical tool widely used in stakeholder analyses (Reed et al., 2009). They are used to identify, categorise and visualise stakeholders and their interactions and allow patterns to emerge that facilitate stakeholder management. I have applied them to the focus group results for two reasons. Firstly, they help to make power dynamics between different entities more explicit within the UKNS system, through production of a simple graph. Secondly, they helped me to become more familiar with the range of people who represent different UKNS entities, and so start to develop ways to approach them in the second stage of the research (Chapter 5).

Production of the matrices occurred in the latter part of each focus group (see Appendix I. Participants were required to first identify representative stakeholders for the connected components they had identified of the UKNS system, and then place these representatives onto a power-interest matrix on the theme of an expanding offshore wind industry in the UKNS. Figure 4.12 displays the combined results of the exercise from all four focus groups. The matrix is split into four quadrants to help delineate the different groups of representatives according to their power and interest in the expansion of the offshore wind industry: subjects (top left) have high interest and low power, key players (top right) have high interest and high power, the crowd (bottom left) have low interest and power, whilst the context setters (bottom right) have low interest, and high power (Reed et al., 2009). A higher proportion of industrial and political components fall within the Key Players quadrant, indicating their high power and high interest in the expanding offshore wind industry. Representatives of the social and ecological components featured much less on this map than those of other categories, and could consistently be found in the subjects quadrant: their location in the subjects quadrant reflects an interest in the expansion of the offshore wind industry but a limited ability to affect its growth. Arguably, however, politically categorised organisations such as Defra and The Crown Estate, which appear as key players on the power-interest matrix, may have some capacity to represent UKNS ecology, because some proportion of their workforces are involved in activity which aims to conserve or regenerate marine life (see Defra, 2023; The Crown Estate, 2025).

Representatives of physical environment-based components are mostly spread across the low power half of the matrix (Figure 4.12) – the Subjects and the Crowd. The one high-power physical environment exception was the Met Office, which represented a Weather Monitoring component. Many components were assigned more than one category (see Figure 4.8), and this component was found in both physical environment and industrial categories (Figure 4.8).

The quadrant with the lowest number (5) of representatives were the context setters, whilst the highest (24) was found in the key players. The very highest power and interest representatives tended to be either national or international governance bodies, offshore wind energy organisations, or other energy interests such as oil and gas-based organisations.

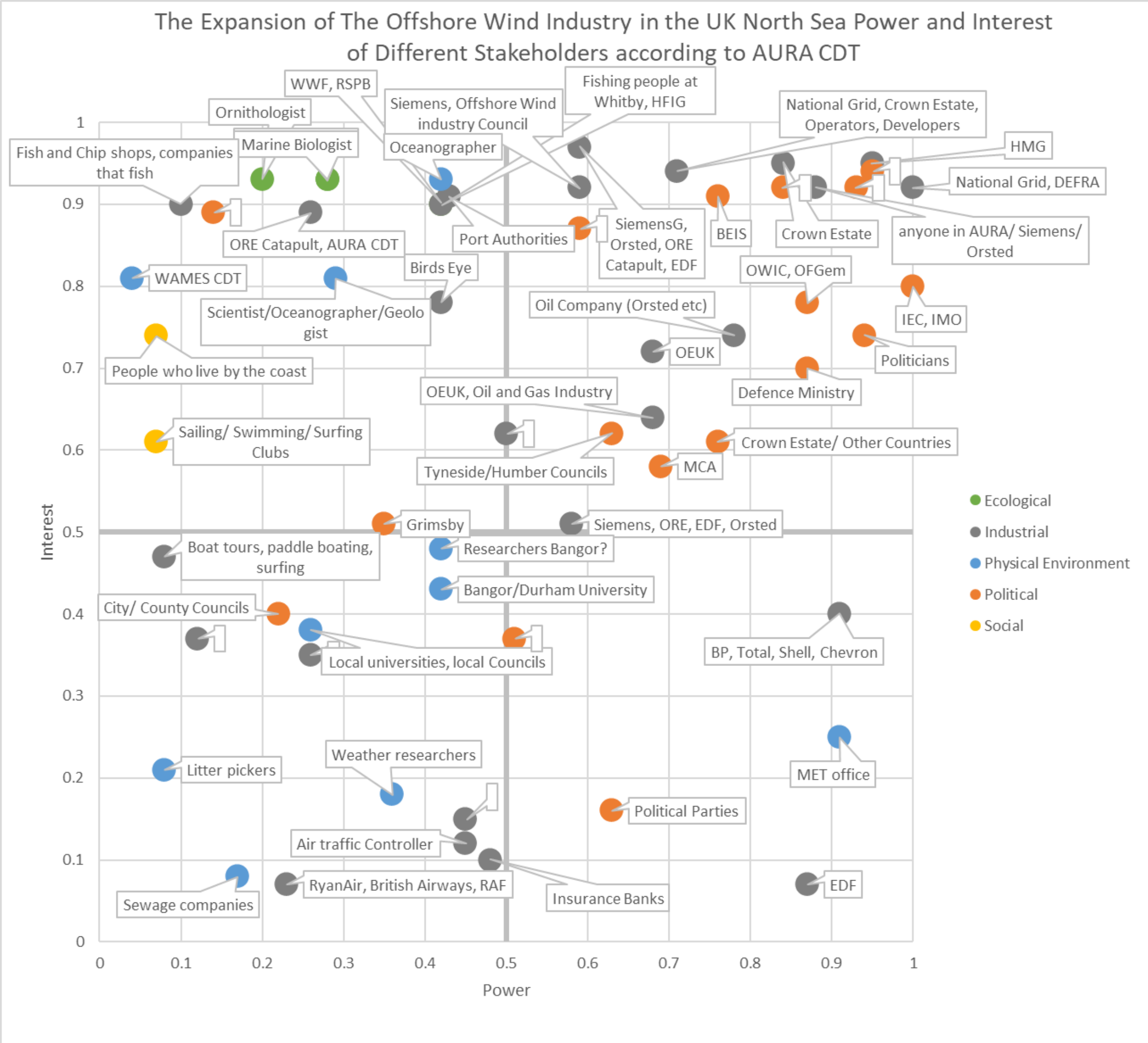


Figure 4.12 Aggregate matrix from four focus groups to show how power and interest of different entity representatives in the UK North Sea vary according to their broad social-ecological categorisations. Labels denote the representative individual/group/organisation of a given component, with empty labels occurring when a focus group did not directly name a representative for a given component before placing it onto a matrix. Additionally, some representatives appear multiple times, reflecting their placements by different focus groups. Different quadrants represent different types of stakeholder: Top Left = Subjects (high interest, low power), Top Right = Key Players (high interest and power), Bottom Left = Crowd (low interest and power), Bottom Right Context setters (low interest, high power).

Abbreviation meanings:

***BEIS** = Department of Business, Energy and Industrial Strategy - subsequently split in 2023 to Department of Business and Trade, the Department for Science, Innovation and Technology, and Department for Energy Security and Net Zero (GOV.UK, 2023)*

***BP** = British Petroleum*

***DEFRA** = Department for Environment, Food and Rural Affairs*

***EDF** = Électricité de France*

***HFIG** = Holderness Fishing Industry Group*

***HMG** = His Majesty's Government*

***IEC** = International Electrochemical Commission*

***IMO** = International Maritime Organisation*

***MCA** = Maritime and Coastguard Agency*

***MMO** = Marine Management Organisation*

***OEUK** = Offshore Energy UK*

***OfGEM** = Office for Gas and Electricity Markets*

***ORE** Catapult = Offshore Renewable Energy Catapult*

***OWIC** = Offshore Wind Industry Council*

***RSPB** = Royal Society for the Protection of Birds*

***WAMES CDT** = Wind and Marine Energy Systems and Structures Centre for Doctoral Training*

***WWF** = World Wildlife Fund*

4.5 Discussion

Four focus groups, each comprised of between 4-7 individuals from Aura CDT, each produced a fuzzy cognitive map for this study. Each focus group's map can be considered a collection of their shared knowledge of the UKNS system. These fuzzy cognitive maps were then further aggregated together to produce a final, larger FCM, which are a depiction of Aura CDT's shared knowledge of UKNS system interactions (Gray et al., 2015).

Key findings of this chapter are that the aggregated FCM maintains a high complexity but low overall connectivity, with most interactions centralised around the offshore wind industry and a few other industrially and politically categorised key components. Results from the power-interest matrix help to validate power dynamics displayed in the aggregated FCM, and outline how different stakeholders should be approached in a later phase of this research. Finally, some of the relationships that focus groups most consistently identified on their FCMs were variably weighted, suggesting that the complexity of these interactions warrant further investigation in later chapters.

The maps produced by individual focus groups are qualitatively easier to digest; always being laid out with the offshore wind component(s) towards the centre, and often being spatially configured with components sharing the same category being physically nearby one-another. By following lines of effect across several nodes, it is possible to discern potential knock-on effects between components, although no feedback loops can be identified. Synergistic and antagonistic or competitive relationships between components are also highlighted by positive or negative effects cycling between two components. A feature of the FCM method is that linkages between components can be considered a summary of the complex effects occurring from one entity to another. This is both a benefit and a limitation: the abstraction of complex information helps to illuminate system-wide relational structures yet, at the same time, it can also result in an overall loss of detail. To mitigate this loss, some of the detail and contextual information has been partially retained by attaching linkage and weighting explanations from transcripts to the linkages themselves, where possible (Appendix X).

The clear centrality of the offshore wind industry within all maps likely reflects the orientation of this study and the knowledge biases of participants, who themselves are all part of an offshore wind-based doctoral training centre. Their expertise on the central topic of this thesis is advantageous in that it provides a thorough depiction of offshore wind-based interactions. However, this bias is not conducive to how social-ecological systems studies should be carried out; normally the aim is to develop an un-skewed, balanced and holistic perspective of the interactions between all different components of a system, for fear of not taking into consideration important interactions that are not directly related to offshore wind. Chapter 5 seeks to partially rectify this shortcoming by incorporating data from a wider array of perspectives.

There are some limitations of using fuzzy cognitive mapping as a framing for social-ecological interactions: for this relational map to make sense, components have to be described in such a way that their value could rise or fall. Participants often found this factor difficult to adhere to, with each group still incorporating components with no value marker onto their FCM – for example, seabed in focus group 2 and weather in focus group 1. Due to the complex suite of effects that governance structures have on the components of any social-ecological system, it was also difficult to accurately incorporate components of the political category onto each FCM. A framework designed to digestibly distil these complex suites of effects - the social-ecological action situation (SE-AS) framework – is used to complement the FCM approach in the next Chapter. Finally, fuzzy cognitive mapping of social-ecological systems is also rarely seen at the regional scale (Kok, 2009; Papageorgiou and Kontogianni, 2012). Most studies have been conducted at local scales such as that of lake ecosystems (e.g. Özesmi & Özesmi, 2004), because of the relative ease of matching individual perceptions that produce FCMs to local-scale interactions. For the Aura CDT participants, summarising regional-scale relationships that would often be geographically variable at smaller scales into single arrow linkages was implicitly a difficult exercise.

4.5.1 Structural interpretations

The low overall density of individual FCMs would suggest a low level of connectivity between UK North Sea system components. This statistic stands in sharp contrast to an increasing perception that ocean systems are intertwined and highly connected systems (e.g. Österblom et al., 2017), and could be interpreted as suggesting that the UKNS is in a more resilient reorganisation or growth stage of its adaptive cycle (Gunderson and Holling, 2002; Chapter 2). It is more likely, however, that the limited time given to the focus groups to complete the mapping task, and participant knowledge being broadly focussed on offshore wind contributed to the low overall connectivity of these maps.

Most focus group FCMs showed high levels of complexity through their ratios of receiving variables to driving variables, which Özesmi & Özesmi (2004) would interpret as meaning that many outcomes and implications of system interactions had been considered by the participants. This gives some reassurance, in a context where the connectivity of these maps is relatively low, as it confirms that the multiple repercussions of potential changes to system dynamics were being considered by focus group participants. In particular, the FCMs of focus groups 1 and 2 displayed high complexity scores. By contrast, focus group 4’s map contained a higher ratio of driving components over receiving components, which suggests causal relationships were not as well elaborated.

In contrast to the focus group FCMs, the aggregated FCM (Figure 4.9) contained so many components and linkages that it went some way towards losing one of the strengths of the FCM method – the ease of access to understand how the components of a system relate to one another. The aggregated map had significantly more connections per component than the individual focus group maps, but broadly similar density (connectivity) and complexity scores. It also maintained the desirable higher number of receiving as opposed to driving components (Table 4.3). This suggests that despite aggregation increasing the size and overall inclusion of components into the system, the overall structural qualities of the system have not degraded.

4.5.2 Power, interest, and centrality

Centrality scores of the aggregated map show once more the bias towards the offshore wind industry as a component of focus within this complex system. Beyond this bias, centrality highlights the perceived relative importance of key industrial and political actors of this anthropogenically dominated system. This perception is reinforced in the power-interest matrix, which displays industrial and political representatives of components as being key players in the system: these players have both high power and high interest in the expansion of the offshore wind industry. When power-interest and centrality are split by category, as seen in Figure 4.11 and 4.Figure 4.12, a correlation can be observed between the outdegree scores and the power of different UKNS representatives. This makes sense, as outdegree measures the cumulative strength of the outward effects from a component, which can otherwise be considered its ability to influence other components. In this way, the power-interest matrix and the FCM validate each other by cohesively identifying certain entities within the system as having more or less power to effect change.

In Chapter 3 I explained how the allocation of different representative stakeholders into the power-interest matrix informs choices about how to effectively engage with different stakeholders in the next phase of this research. Power-interest matrices were originally developed within management studies to test how emergent strategic intents are met by the responses and aspirations of powerful stakeholders (Eden & Ackermann, 2013). The results of this type of matrix often help specify how certain stakeholders may be engaged for instrumental ends (Reed et al., 2009). In the context of my research on the UKNS, I use the results of the power-interest matrix to help identify which stakeholders should be engaged for expert interviews exploring some of the more complex relationships in the UK North Sea System and how best to reach them (Chapter 5). Key players - for example, energy industries, National Government, and The Crown Estate - have high interest in and power to affect the expansion of the offshore wind industry. They are likely, therefore, to have the impetus and resources to contribute to this research by, for example, providing appropriate employee(s) for interview. From a softer skills perspective, high power actors may also appreciate a higher degree of formality when being approached. Subjects are also likely to be interested in contributing to this research, especially as this analysis has revealed social and ecological entities in the UK North Sea system are on the receiving end of many effects of the expansion of the offshore wind industry. A lack of power for subjects, however, means often that the structures associated with powerful organisations may not be in place. As such, approaching these stakeholders for interview may be more ad-hoc than for powerful actors. Representatives with low interest will generally be more difficult to engage for an interview, especially the low power “crowd” who have very little buy-in. Context setters may also be difficult to engage, but more effort should be put into engaging them as they could provide important information on larger scale dynamics that could affect the UKNS social-ecological system.

I am using a power-interest matrix here primarily as a way of understanding the positionality of different users and groups in preparation for the expert interview phase of the research (Guðlaugsson et al., 2020). One methodological limitation in my deployment of this power-interest matrix approach is that the establishment of concrete definitions of power and interest was left up to each individual focus group. Guðlaugsson et al. (2020) define stakeholder power as the ability of the stakeholder to exercise their influence to achieve desirable outcomes. To apply this within the context of my study, power should here have been defined as the power of a stakeholder group to have influence over the expanding offshore wind industry and its developments. Likewise, based on Guðlaugsson et al.’s (2020) work, interest here could have been defined as the impact of the expanding offshore wind industry on the given stakeholder group, both positive and negative. Although these meanings were broadly adopted by each focus group, clearer definitions would likely have improved participant clarity and power-interest matrix accuracy.

Another assumption that has been made is that the participants are fully cognisant of who has power and interest within the system. This relates to the previously evaluated choice to use Aura CDT students as participants, which is outlined in Chapter 3.5.1. Through their training and research, these participants have developed an academic awareness of the groups and entities that co-occupy the seascape with the offshore wind industry. However, they may have limited hands-on, stakeholder facing experience of how power dynamics are at play within this complex system. Their perceptions of power and interest in offshore wind expansion, as displayed in Figure 4.12, should not be interpreted as an objective display of UKNS power dynamics, but as a subjective depiction of power and interest of a group who themselves are interested in the success of offshore wind expansion in the UKNS.

A final issue with this approach was the difficulty participants had in identifying representatives for social, physical environment and ecological components. This can be seen in how only two ecological and two social representatives exist on the final power-interest matrix. The difficulty of representing non-human entities, and of identifying human entities to represent masses of a large size (i.e.

coastal communities) is an area where power-interest matrices may need adaptation when working within more interdisciplinary frameworks.

4.5.3 Highly complex, well known, and variably perceived: Aura CDT's fuzziest linkages

Analysis of the range of weightings given to linkages that were mentioned by multiple focus groups reveals a lack of consensus about how certain UK North Sea entities interact with offshore wind and each other. Disagreement could be caused by the variance in component conceptualisations across focus groups – though this was mostly tackled in the homogenisation stage of FCM aggregation. They could also be due to an actual lack of knowledge about a linkage, or because linkages are endeavouring to summarise a highly complex set of competing influences, which could lead to genuine uncertainty about the overall weighting of an interaction. FCM as a tool may not provide a sufficiently robust or detail-orientated framework to characterise some of these complex but important interactions. To give an example, focus group 1's FCM shows that offshore wind has a negative effect on sediment distribution, which is a simplistic depiction of a complex relationship, to the point of being somewhat meaningless. In the transcript for the focus group however, Speaker 4 verbally outlined the complexity of this relationship, highlighting that increased subsea infrastructure, such as offshore wind turbine bases, can, depending on the sedimentary environment, cause an increase in the rate of sediment erosion, which in turn can affect the types of nutrients found in the water column. Oversimplification of complexity in the FCM format speaks to some of Nair et al.'s (2019) critiques of the FCM approach, namely: incomplete consideration of the semantics of causality often leading to limited capture; limited representation and simulation of causal dynamics; a lack of inclusion of time relations; and limited ability to capture, and represent fuzziness. Regardless of whether FCM has limitations for capturing dynamics, this approach has highlighted the most frequently cited linkages that have the largest discrepancies in weighting. These discrepancies can be used to provide direction for further research in the thesis: if FCM cannot accurately capture a complex social-ecological interaction, then further research into the complex causal mechanisms at play using another more focussed framework, such as the social-ecological action situations (SE-AS) framework (Schlüter et al., 2019), could be used and fed back into the FCM framework. The results from this stage highlight some complex interactions that I intend to investigate further in later chapters: specifically, interactions between the offshore wind industry and the oil and gas industry, the offshore wind industry and coastal communities, the offshore wind industry and fisheries, and the offshore wind industry and marine ecosystem – highlighted by the lack of clarity on how developments affect benthic fish populations (Table 4.5). These results also highlight discrepancies between offshore wind and tidal and wave industries, as well as offshore wind and suitable marine geology/ sediment. However, I will not explore these interactions further because the novelty of tidal and wave industries makes it difficult to understand how the system may be affected by their future presence, and because (as previously explained) the focus groups faced difficulty when trying to incorporate sedimentary characteristics into an FCM.

4.6 Conclusion

This chapter has shown how the UK North Sea region is a complex, social-ecological system, with interconnected political, ecological, environmental, industrial and other components that affect each other to varying extents. Participants from Aura Centre for Doctoral Training in Offshore Wind Energy and the Environment present an aggregated perspective on this set of interactions, through use of the fuzzy cognitive mapping method. Structural analysis reveals an unexpectedly low level of connectivity, which is perhaps a result of the homogeneity of focus group participants coupled with the limits of this data collection technique. For the relationships that have been mapped, further analysis revealed a high level of complexity at both the focus group and aggregated map level, reflecting those outcomes and implications of system interactions had been considered by most groups.

Each linkage on the aggregated map represents a summation of the complex effects from one entity to another, and where there were discrepancies between focus groups on the weighting of a linkage, this has been targeted as an area of high complexity which merits further analysis in Chapter 5 of the thesis. The approach to different component representatives at this later stage of research has also been informed by use of the combined power-interest matrix, whose power scores at the category level correlate with the centrality (particularly outdegree) of different categorised components on the aggregated FCM.

The final aggregated fuzzy cognitive map is a semi-quantitative, graphical representation of the perceived relationships between different UK North Sea entities at the regional scale. From an analytical perspective, it provides a synopsis of many of the complex interactions that occur between different social-ecological entities within this area, especially as they relate to the offshore wind industry. At the level of each group's FCM, linkages can also be queried to determine why they have been assigned their specific weightings. The construction of the aggregated FCM is a foundational step towards production of a network map that could be used to improve marine governance processes such as marine spatial planning, and contribute to unfolding debates on the meaning of transformation from blue growth to a sustainable blue economy. To build on these interim conclusions, some of the core complexities of the system will be distilled from a range of marine expert perceptions in Chapter 5, before a revised model is run through several offshore wind expansion scenarios in Chapter 6 of this thesis.

Chapter 5: Visualising UK North Sea Interconnectivity with the SE-AS Framework

In this chapter, the SE-AS framework is operationalised to analyse and present interview data gathered with UK North Sea (UKNS) marine experts. The theoretical grounding for the social-ecological action situations (SE-AS) framework is outlined in Chapter 3.2. Interviews here were designed to drill down into a set of important relationships between the offshore wind industry and other UKNS entities identified via the analysis in Chapter 4. Relationships between wind and (i) coastal communities, (ii) fisheries, (iii) the marine ecosystem, and (iv) the oil and gas sector were all identified through the analysis within Chapter 4, whilst (v) marine governance was included as it is important to consider within the thesis aims. Due to time constraints, only the interviews that explored relationships between offshore wind energy and (i) coastal communities and (ii) fisheries will be analysed in this chapter. A directory of action situations (AS) (Table 5.1) and outcomes (Table 5.2) can be found in section 5.5 at the end of this chapter, providing definitions of and evidence for phenomena outlined throughout. AS consist of entities and the way in which they interaction. In the example Figure 5.1, The Crown Estate (TCE) and the offshore wind industry partake in a rule making interaction, whereby TCE designs and enforces rules that the offshore wind industry adheres to. The outcome of an AS affects the conditions under which other AS occur. In Figure 5.1, the outcome of the rule making AS is increased investment from the offshore wind industry to coastal communities.

Fuzzy cognitive mapping - the methodological approach used in Chapter 4 - has limits in its ability to capture and represent complex causal dynamics at play between different social-ecological entities within a system (Nair et al., 2019), especially with the increased fuzziness that must be considered when describing regional scale interactions. This complex quality makes it difficult to use fuzzy cognitive mapping as a tool to supplement the MSP process - one of the thesis' main aims - and so fuzzy cognitive mapping is complemented here with expert interviews and the SE-AS framework. Strengths that the SE-AS framework brings are that it helps present the core dynamics of social-ecological systems (SES) in a simple but still comprehensive structure, and that it has an emergent track record of disentangling relationships (especially those which are non-linear or undefined) in complex causal diagrams (Herzog et al., 2022). It can be used to help reveal spaces of decision making and agency in SES, thus highlighting the causal mechanisms through which entities of a system interact (Kimmich et al., 2023). Tools like the SE-AS framework, that can elucidate dynamics of a complex system, have the potential to inform marine management decisions that take place through the process of marine spatial planning (outlined in section 2.2.3).

A note on diagrammatic design

I have opted for a different visualisation of the AS and outcomes in this work to that in previous work on SE-AS (Schlüter et al., 2019; Herzog et al., 2022) (Figure 5.1), for four reasons. The first is that within the structure of the thesis, I am transforming a Fuzzy Cognitive Map (FCM) (Chapter 4) into linked SE-AS (Chapter 5) and then incorporating SE-AS data back into an FCM (Chapter 6). It therefore suits the thesis better to keep an SE-AS configuration closer in structure to that of an FCM in this chapter, especially being able to include the type of effect. Secondly, Herzog et al., (2022) cite the difficulties of differentiating some AS from outcomes, and that some AS can be matched to more than one AS definition. This visualisation accepts the fluidity between outcomes and AS, but highlights how outcomes act to improve, worsen or maintain other existent AS. Thirdly, my visualisation allows for representation of AS whose outcomes are not defined through the interview process, but which may still affect the functioning of the SES. This provides an increased depth of knowledge to incorporate into the final FCM in Chapter 6 and provides the reader with more insight into how the dynamics of the system are perceived. Finally, all interviewees talked about many interactions between entities that could not be considered AS because their outcomes were not elaborated on. This diagrammatic design has allowed me to display interactions alongside AS and outcomes in the individual SE-AS diagrams (Figure 5.2, Figure 5.7, Figure 5.9, Figure 5.13), contributing to the fullness of each interviewees knowledge whilst allowing for distillation of AS.

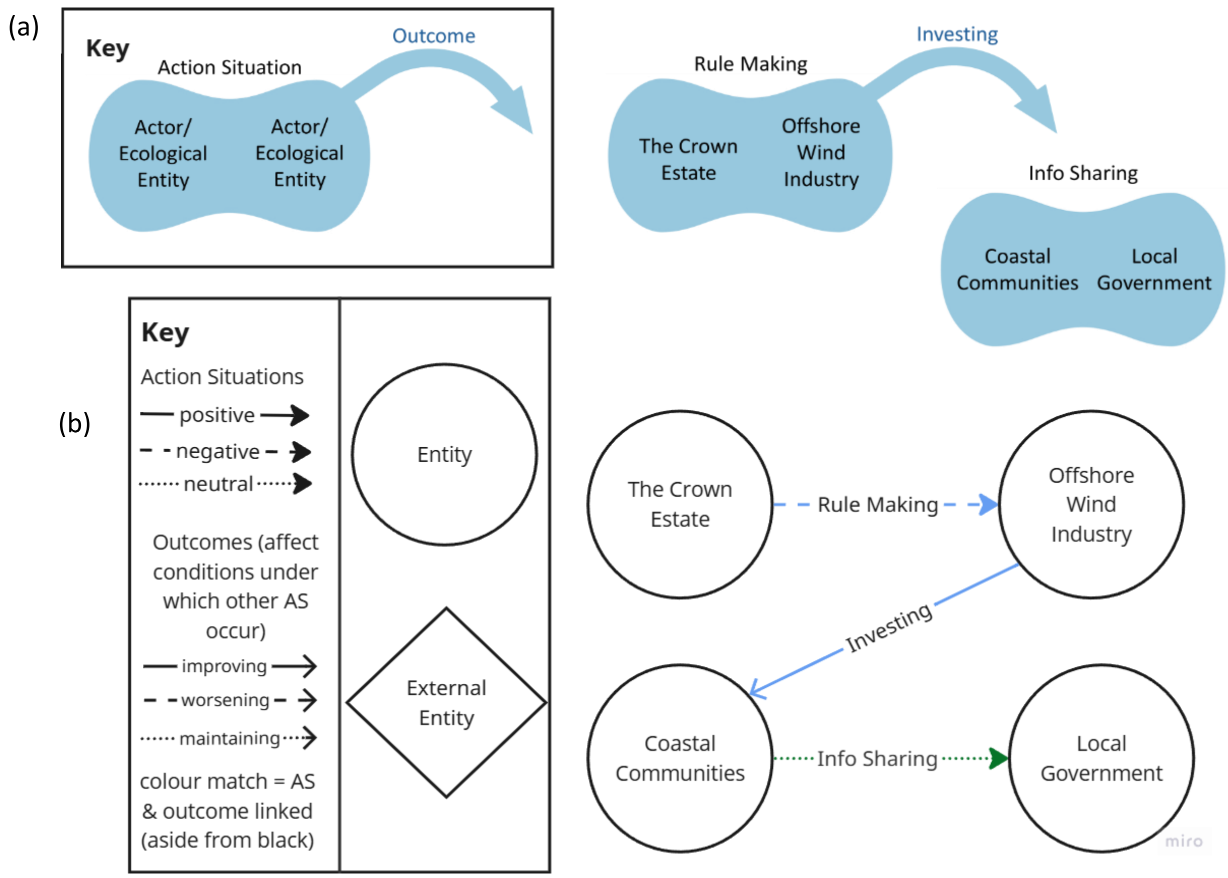


Figure 5.1 How diagrammatic representation of SE-AS varies between (a) previous studies (Schlüter et al., 2019; Herzog et al., 2022) and (b) this study. In (b), arrows represent AS and their direction, as well as whether the effect is considered positive, negative or neutral/no net effect. It also shows how outcomes can act to improve, worsen or maintain the conditions under which other AS occur. If a set of effects are matched in colour, this signifies their connection as AS and their directly associated outcomes.

5.1 SE-AS of Coastal Communities and Offshore Wind Energy

The relationships between offshore wind energy and the coastal communities that are impacted by its associated infrastructure are complex, multi-faceted, and under-studied. Local socio-economic impacts are known to be a weak area of consideration for offshore wind farm environmental impact assessments and environmental statements (Alem et al., 2020). Compound this with a lack of effective monitoring, which masks the differences between predicted and actual wind farm effects, and the difficulties in exploration of this complex area become apparent (Glasson et al., 2022). When asked to evaluate the effects that offshore wind energy has on coastal communities, one interviewee in this study bluntly remarked “That is a trick question, we don’t measure it” (I14). Neighbouring coastal communities come with a range of place-based characteristics (e.g. Office for

National Statistics, 2021). Because of this, studies which have so far analysed community perceptions of offshore wind developments are focussed on the local scale. Comparative case studies of the impacts of one offshore wind development on two local coastal communities, such as by Devine-Wright and Howes (2010), show that community responses to the same wind farm project can be very different, and will often vary depending on the place-based attachments that residents have to their local area. Devine-Wright and Howes (2010) showed that the residents of two nearby coastal towns have significantly different responses to the same offshore wind development on the North coast of Wales: Residents of Llandudno, whose place meaning is best captured through its scenic aesthetic beauty, emphasised the wind farm's coastal impacts as a consequence, worrying that the wind farm would fence in the bay. Residents of Colwyn Bay, who considered their town as formerly beautiful, but now run down and in decline partly due to a flux of outsiders, interpreted the growth of the offshore wind industry less negatively, considering it as a boost to local employment and prosperity (Devine-Wright and Howes, 2010). These variable place-based perceptions may explain some of the variety in perceptions of focus groups on the overall strength of the interactions between the offshore wind industry and coastal communities (Chapter 4).

Within the literature, interactions between local communities and offshore wind developments tend to revolve around engagement, with size of project changing which sort of engagement occurs. Policy makers used to promote active public engagement in smaller projects, whilst tending to prefer passive engagement for the larger ones that the offshore wind industry has been trending towards, due to NIMBY (not in my back yard) based preconceptions of the public as an ever-present danger to developments (Devine-Wright, 2011). As such, interactions between the offshore wind industry and coastal communities are somewhat unidirectional, reflecting the developers' goal of increasing social acceptance of a project within a community to assure that development can continue unabated. As well as advertising the potential socio-economic benefits of developments (i.e. increased employment prospects), the offshore wind industry also offers "community benefits" – payments made to communities affected by local energy developments – whose design and framing must be carefully considered to assure support of developments (Walker et al., 2014).

5.1.1 Marine expert introductions

An outline of the recruitment of marine experts and the interview structure is detailed in Chapter 3.8.2. Of the 22 interviews carried out for this study, five directly involved experts who could speak at length on the complex interactions of coastal communities with other entities within the UKNS system. To conserve their anonymity, interview participants will be referred to as Interviewees 3, 4, 5, 6a, 6b (an interview with two interviewees) and 14.

Interviewees 3 and 5 work in the offshore wind sector, on the North Sea facing coast of the UK, in stakeholder management-based roles. Interviewee 4 works for The Crown Estate. Interviewees 6a and 6b work together in economy and funding at a local council along the East coast of England, and Interviewee 14 is a marine social scientist. Although they are all experts in their own respective fields, these 6 participants clearly do not have comprehensive knowledge of the interactions between offshore wind, coastal communities and other interdependent entities across the UKNS. However, their combined expertise can illuminate some of the key linked AS and outcomes at play.

5.1.2 SE-AS from interviews

Interviewee 3 – offshore wind developer

Interviewee 3 identified four social AS linking different social entities in the UK North Sea (Figure 5.2). For a description and examples of what each AS or outcome means, consult

The first AS (green) in Figure 5.2 depicts support provided by the offshore wind industry to local governments in accessing funding for development of infrastructure. The outcomes are infrastructural and economic benefits to coastal communities and the offshore wind workers who live in those communities, as well as increased social acceptance. The second AS (light pink) that Interviewee 3 discussed were the conflicts caused by a growing offshore wind industry onto coastal communities (Figure 5.2). These included noise impacts of HGVs, especially during construction, as well as visual impacts, especially relating to onshore infrastructure such as substations. An associated AS is conflict resolution, which involves opening lines of communication with a local community to make them aware of potential impacts of a construction and giving them an opportunity to feed back their thoughts on a project. Both AS combine to influence a desired outcome: the social acceptability of large offshore wind energy projects for coastal communities (see social acceptance, Table 5.2).

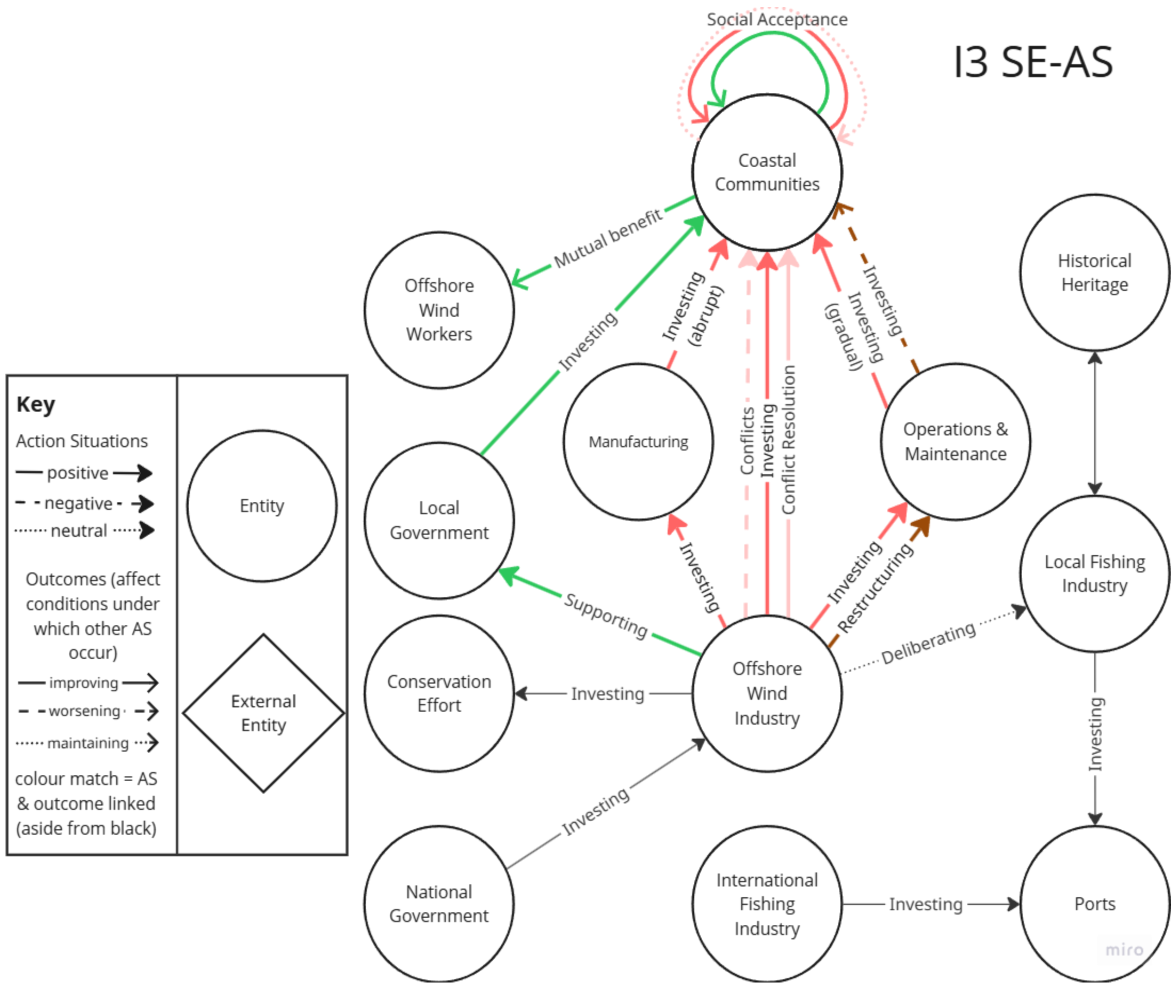


Figure 5.2 Diagram to show the causal relationships, action situations and outcomes discussed in Interview 3. Relationships with clear outcomes are colour coded and highlighted as linked action situations. Green arrow = Supporting and Investing AS and outcomes. Pink arrow = Conflict AS and outcomes. Red arrow = Investing AS and outcomes. Brown arrow = Restructuring AS and outcomes.

The third AS (red) identified by Interviewee 3 is the economic investment of the offshore wind industry to coastal communities through local employment (Figure 5.2). The rate of investment changes depending on which part of the offshore wind industry is the focus, with more abrupt investment for manufacturing of offshore wind components, and more gradual investment from operations and maintenance centres. No specific outcome was identified for this set of AS, though as shown, higher levels of local investment can increase local acceptability. One reason for lack of specific outcome may be that increased local employment could itself be considered an outcome of the expansion of the offshore wind industry.

In a final AS - specific to Interviewee 3's experience of the offshore wind industry's operations and maintenance activity – the offshore wind industry has restructured itself through time. This restructuring has reduced the necessity for offshore workers to have to live locally in coastal communities (Figure 5.2, brown). This complex AS reflects how the growth in size of infrastructure and its distance from the shore has caused a change in the way maintenance activities occur due to the length of commute times. Where offshore engineers used to take day trips on crew transfer vessels to wind farms close to shore, they now stay on service operation vessels for two weeks at a time at offshore wind farms far away from the shore. A more infrequent commute to port has meant that offshore wind maintenance staff have spread further away from the operations and maintenance centre itself, which means a lower proportion of employees live in the coastal community.

Interviewee 3 spoke to the growth of the offshore wind industry across UK waters, as well as its national and international imperatives for growth as a clean, secure energy provider. For them, “working with our communities… is really really important, because we need clean power” (I3). When the offshore developer discussed working with coastal communities, it was interpreted as working to resolve conflicts with coastal communities arising from offshore wind developments. Interviewee 3 discussed the plurality of effects that offshore wind could have on coastal communities, which depends on their landscapes and main drivers. For example, people in a local economy based around tourism could “have a different perception to offshore wind than somewhere that’s more industrial” (I3). A final, more personal narrative was based on their experience of how offshore wind positively affects more deprived coastal communities, such as Grimsby. Coastal communities which were built around the fishing industry across the east coast of England in the 20th century “lost the bottom out of” (I3) their main economic drivers due to the collapse of the North Sea cod stocks in the late 1980s (Beaugrand et al., 2022). Offshore wind acts as a “new economy generator” (I3) whose growth is bringing “the rest of the town and the place… on that sort of wave with us” (I3).

Interviewee 3 found the fuzzy cognitive mapping approach easy to understand, and was interested in developing “one of these charts for Grimsby or The Humber” (I3). However, when considering the variety and complexity of coastal communities across the UKNS, they found it challenging to confidently assign overall weightings to the relationships between it and many of the UKNS components. For example, between the offshore wind industry and coastal communities, “- there’s a lot of kind of positive, and there’s some kind of more negative things that we work with our communities to kind of manage… But on balance, I don’t know how I would balance that to say… that one is higher or one is lower” (I3). Revealing the interactions contributing to the complex regional scale relationship, by disentangling localised, place-based differences as well as subjectively different value streams such as economic benefit and visual/noise pollution, was a challenging but valuable task within this interview. It exhibits how a relationship summed up with a one weighted arrow in the fuzzy cognitive map in Chapter 4 is a summary of a highly complex and locally variable phenomenon.

Interviewee 4 – The Crown Estate

Being the owner and manager of the seabed, The Crown Estate (TCE) is a fundamental part of marine management in the UKNS. Interviewee 4, of TCE, found my description of how fuzzy cognitive mapping works “crystal clear” (I4). As such, many relationships between different UKNS entities were discussed and weighted. Figure 5.3 shows a set of interactions, social AS and related outcomes, which were identified by Interviewee 4 through the course of an interview with me. Two AS were identified. The first (blue) outlines how pressure for national government (enforcement of rules) to hit Net Zero targets affect the behaviour of TCE, pushing it to enable greater growth of the offshore wind industry. The outcome of this set of AS is the conversion of the seascape by the offshore wind industry meaning it can be used less by fisheries.

The second AS (deep yellow) is rule making (Figure 5.3). Here, TCE places rules onto offshore wind developers through the leasing process. These require offshore wind to benefit coastal communities in more ways as part of a lease, which has been displayed on Figure 5.3 as an outcome of increased investing.

Notably on Figure 5.3, the knowledge generation relationship between research and TCE is considered as work towards the same “vested interest” in that both entities are working to try and understand the marine environment better to inform marine management practices (I4). Though there are no outcomes directly associated with this AS, it does affect the way in which TCE interacts with other entities in the UKNS.

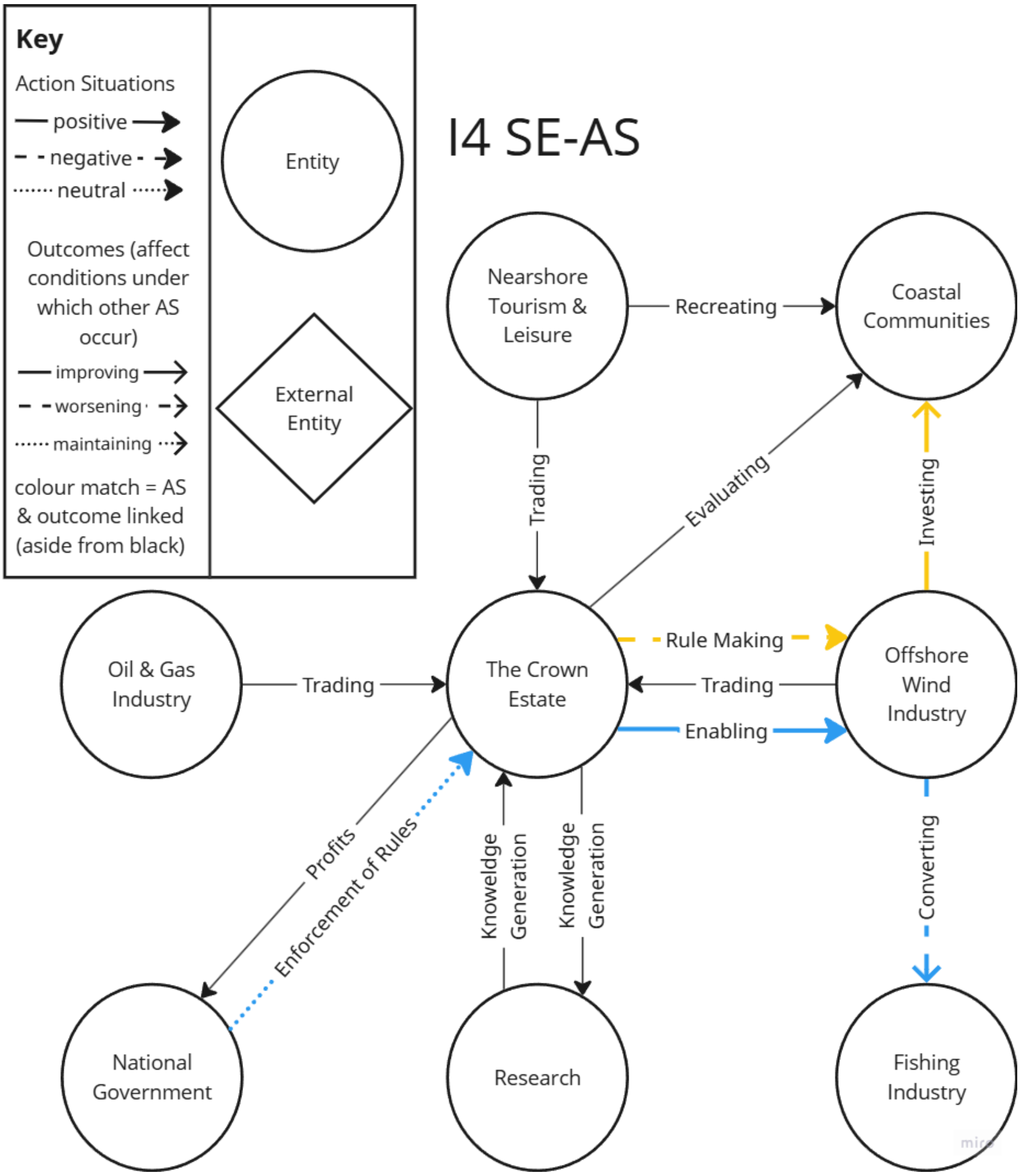


Figure 5.3 Diagram to show the causal relationships, action situations and outcomes discussed in interview 4. Relationships with clear outcomes are colour coded and highlighted as linked action situations. Blue arrows = Enforcement of Rules and Enabling AS and outcome. Yellow arrows = Rule making AS and outcome.

Outside of discussion directly related to UKNS interactions, Interviewee 4 and I discussed where TCE is with regards to its management strategies, and what it is seeking to move towards. Currently, “quite a lot of our work is very socio-economic focussed, which is understandable, because it is stuff we can measure through very traditional frameworks” (I4). What they are increasingly seeking to push in their management is engagement of coastal communities by industrial developers such as offshore wind "in the first instance" to better understand the needs and sensitivities of a community that could be impacted by development (I4). As such, a core part of the interview was based on how planning strategy is currently evolving towards "inclusion of more cultural values… and understanding how we're impacting them (coastal communities) beyond just jobs, employment, and you know, local economy impacts" (I4).

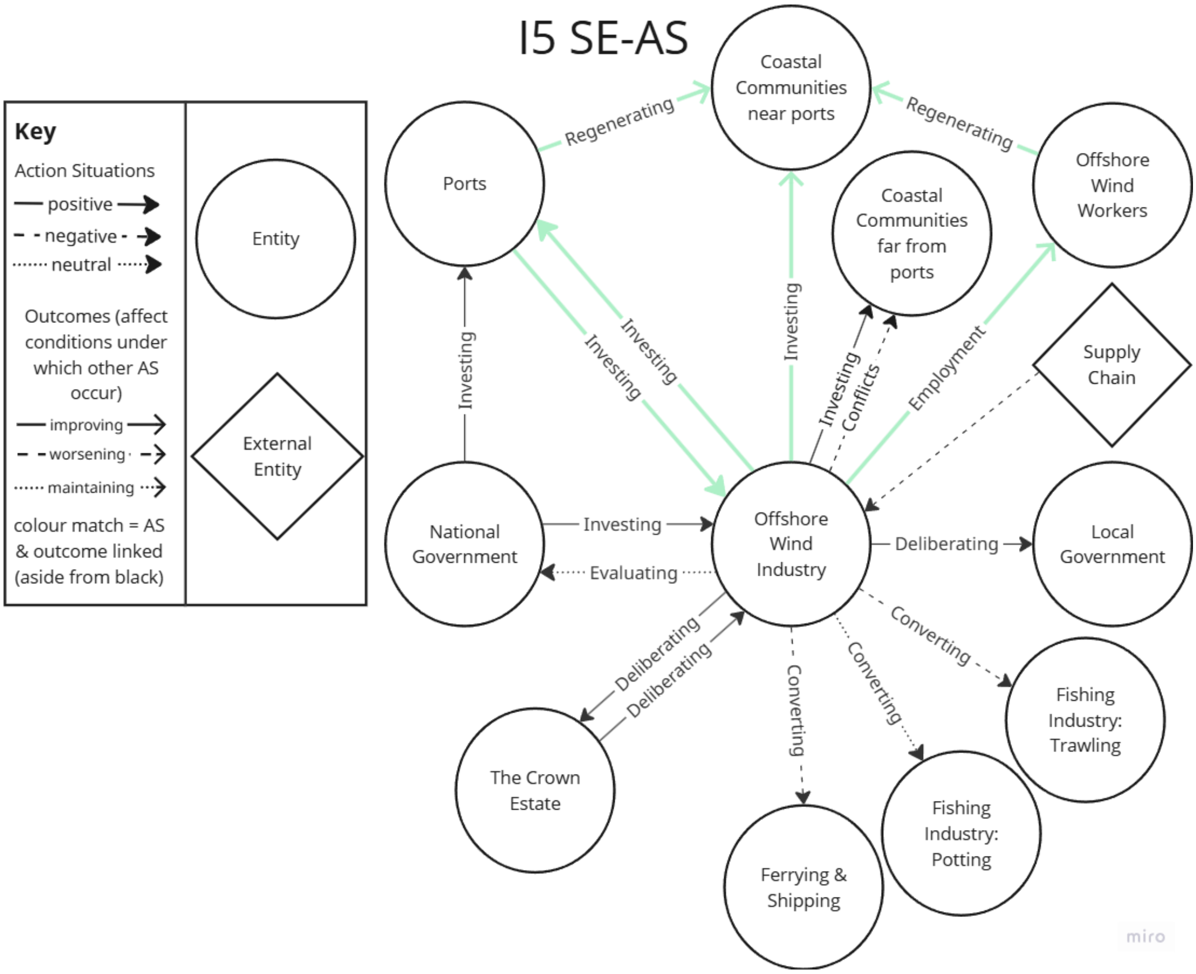


Figure 5.4 Diagram to show the causal relationships, action situations and outcomes discussed in interview 5. Relationships with clear outcomes are colour coded and highlighted as linked action situations. Turquoise arrows = Investing AS and outcomes.

Interviewee 5 – offshore wind developer

Interviewee 5's perceptions of the relationships between different UKNS entities, especially as they interact with the offshore wind industry, are displayed in Figure 5.4. One distinct social AS (turquoise) was identified (Figure 5.4): the "chicken and egg situation" of investment between ports and offshore wind developers, wherein "ports want developers to come (and use their available land), but they want a contract before they invest" in preparation of land for offshore wind developers (I5). This relationship varies between ports along the UKNS coast. Some ports, such as Teesside, gambled by investing in upgrading their facilities in order to attract big offshore wind developers. Others, such as Port of Tyne, had an offshore wind developer agree to a contract which included upgrading of facilities (I5). In Interviewee 5's view, the co-development of port infrastructure and offshore wind energy capacity produced several interlinked outcomes around coastal communities near to ports, namely increased employment, investment through community benefit schemes, and regeneration of infrastructure caused by more money flowing into the area.

Whilst the other relationships between UKNS entities discussed by Interviewee 5 do not have distinct outcomes, and therefore cannot be considered complete AS, some interesting dynamics were highlighted (Figure 5.4). Like Interviewee 4, Interviewee 5 alluded to how converting areas of ocean for offshore wind activity affected fisheries. But unlike Interviewee 4, they distinguished between trawl fisheries and potting fisheries, citing that pot fishers are allowed to come into offshore wind farm areas to fish for crab and lobster, but that trawlers are not (I5). They also distinguished between coastal communities near to ports, and more affluent coastal towns and villages "where their holiday homes are", that are further away from ports, such as in Norfolk where communities are facing "offshore wind fatigue" and "everyone is against it" because of disruption caused by cable corridors and converter stations connecting offshore wind energy to the grid (I5).

Much of the discussion outside of UKNS interactions with Interviewee 5 revolved around their area of expertise in the supply chain for the offshore wind industry. By its nature, the supply chain for offshore wind is beyond the boundary of what this thesis incorporates. It is mostly not located along the UKNS coastline (Figure 5.5). In fact, many of offshore wind's largest components must be shipped in from across Europe - "there's no tower facility, there is no nacelle manufacturing, (and) we still don't have export cables" (I5). However, the "tightening" offshore wind supply chain (I5) is jeopardising the growth ambitions of the offshore wind industry, especially in the USA, UK and EU (Zhao et al., 2023). Given that this thesis is trying to unpack the effects of the expansion of this industry, supply chain should be considered as an important, albeit larger scale and exogenous variable to the system in question.

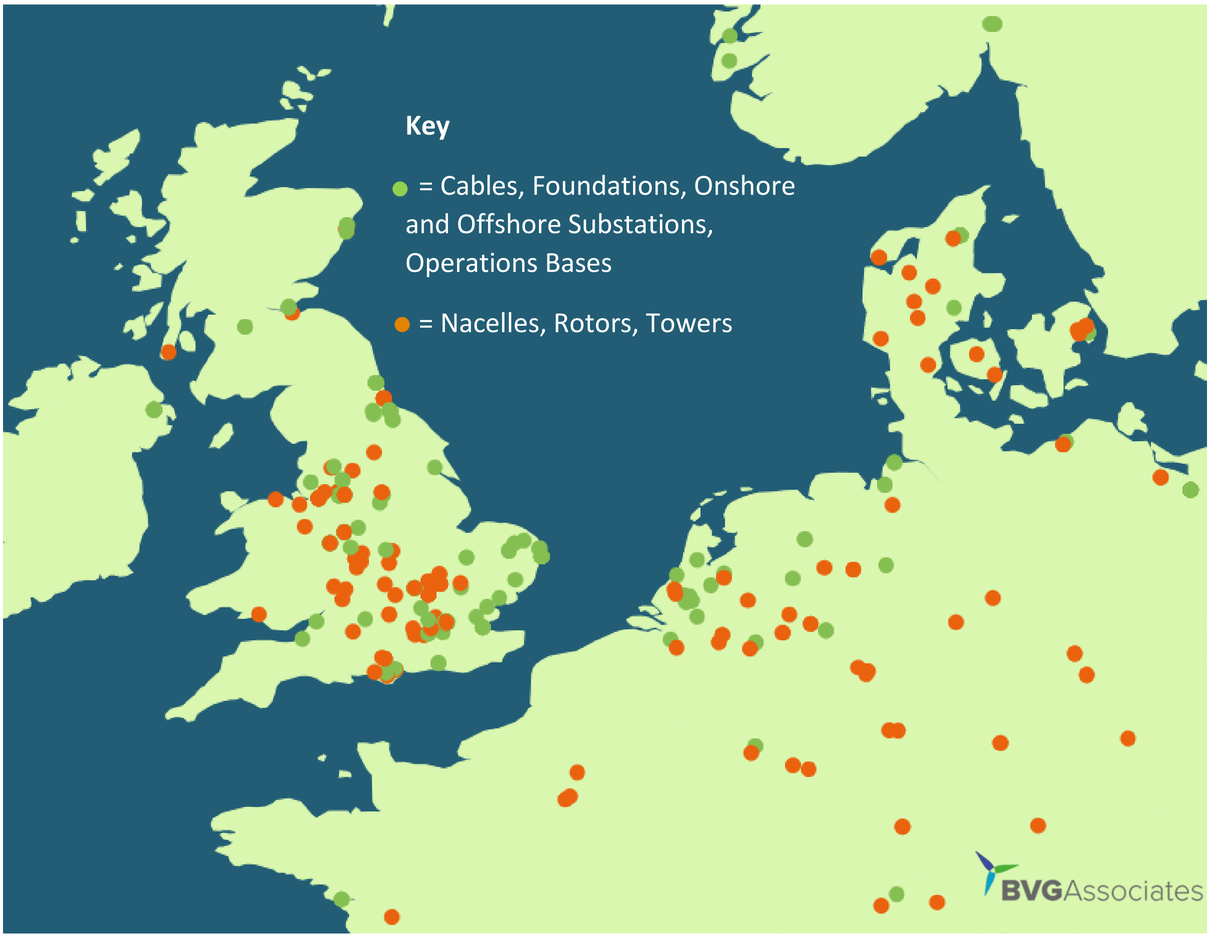


Figure 5.5 Map of Northwest Europe showing majority of European manufacturers in the offshore wind supply chain, from BVG Associates (2019). This data includes early stages of the supply chain, such as for parts used to create nacelles and cables.

Interviewees 6a and 6b – local government officials

Three AS were identified from the interview with Interviewees 6a and 6b, as well as a suite of other interactions (Figure 5.6). The first (deep pink) was the investing AS between the offshore wind industry and local government, whose outcome was the regeneration of coastal communities (Figure 5.6). Interviewee 6a cited in particular that it had helped to boost the local hospitality industry and "attracted a supply chain alongside it" (I6).

The second AS (light purple) described the suite of interactions that occur from the local to national scale between local government and economic partnerships, national government, and big businesses (which in our conversation mostly pertained to the offshore wind and oil and gas industries) (Figure 5.6). In this AS, big business, such as oil and gas or offshore wind developers, make enquiries to the national government for potential developments. This information is passed through national government to relevant local economic partnerships, who coordinate with local governments to develop offers of space to those big businesses to invest in their areas. Noticeably, this AS and outcomes are cyclical, forming a positive feedback loop with no distinct starting point. This suggests that the decision of what should be defined as an AS and what should be an outcome in this situation are somewhat arbitrary and open to interpretation, which reflects one of Herzog et al.'s (2022) critiques of the SE-AS framework. Given that big business in the UKNS is not rapidly expanding as the presence of this self-reinforcing, positive feedback loop suggests, there are probably other undescribed mechanisms at play that limit the growth potential of the big business node.

In the third identifiable AS (teal) for Interviewees 6a and 6b (Figure 5.6), information is shared from coastal communities to local government whilst local government evaluates the state of the community (what is the result of the current measures for coastal community wellbeing?) and disseminates relevant information with local economic partnerships. One outcome of this AS is that local government appreciates the need for more investment into their local area to help deal with the effects of deprivation, and so supports big business in moving to and investing in their area to provide jobs for local people. A tangential outcome is that at the regional scale, local government and local economic partnerships are thrust into competition with each other to provide the most desirable location for investment from big business.

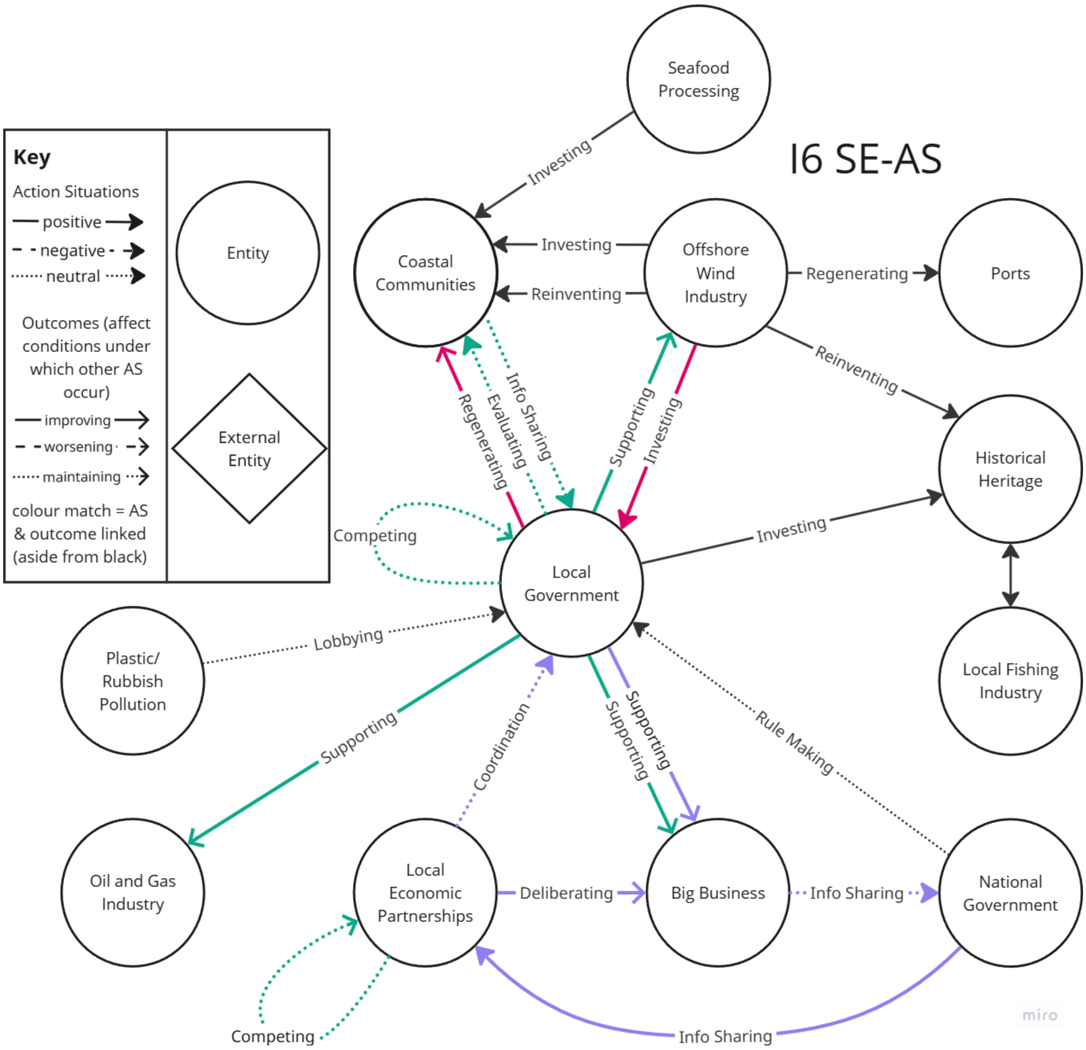


Figure 5.6 Diagram to show the causal relationships, action situations and outcomes discussed in interview 6. Relationships with clear outcomes are colour coded and highlighted as linked action situations. Deep pink arrows = Investing AS and outcomes. Light Purple arrows = Information sharing AS and outcomes. Teal arrows = Information sharing and Evaluating AS and outcomes.

Interviewees 6a and 6b are based in the Humber region and aim, through roles in local governance, to make their council area "thriving, low carbon, (and) powered by sustainable energy" (I6), by advertising their area to the world as a place to invest. Consequently, much of our discussion revolved around how this vision is being pushed, whilst being balanced with environmental issues and making the area "a nice place to live, work and visit" (I6). Local government's support of efforts to decarbonise industry in their area featured heavily in our discussion, though the core reasons for this push seemed to be borne of the fact that the Humber region "is the largest producer of carbon within the country" and from governmental guidance on "deadlines for decarbonisation" (I6).

Interviewee 14 – marine social scientist

Three AS were identified through the interview with Interviewee 14, alongside a suite of interactions whose effects are there but whose outcomes were not linked in or discussed (Figure 5.7). The first (purple) is the competition for resource between the international fishing industry and local fishing industry in the UKNS (Figure 5.7), which is broadly won by the larger "more industrialised" fisheries (I14). Outcomes of this AS change the interactions between the local fishing industry, coastal communities and nearshore tourism and leisure. A local fishing fleet is "an important part of place identity" for a lot of people, and its loss would be to the detriment of coastal communities (I14). The romanticisation of the small-scale fishing harbour with a colourful local fleet is often a draw for local tourism, and so in a similar way loss of local fleets would also cause a reduction in the extent of nearshore tourism and leisure.

The second AS (yellow, Figure 5.7) is knowledge generation from research and from observation of marine events such as the marine die-offs that recently occurred in the North-east of England (Defra, 2023). The knowledge being generated is on the presence and vulnerability of marine ecology. As Interviewee 14 pointed out, "coastal communities are not often very interested in the sea… or like not very interested in what is living there", because "it is just their background" (I14). Yet events and institutions that bring communities closer to marine life alter this dynamic. A potential outcome of this second AS is an increased amount of sparing of benthic invertebrates through conservation efforts (following Herzog et al. (2022); see Table 5.2). Notably, of the 5 interviews which focussed on AS related to coastal communities and offshore wind, this was the only directly identifiable SE-AS. All other AS were purely social action situations (S-AS).

The final AS (dark blue, Figure 5.7) offers an AS with the same actors but differently configured and with a different outcome to an AS which was discussed by Interviewee 4 (Figure 5.3, blue). Interviewee 4 outlined how national government enforces to hit Net Zero targets onto TCE, pushing it to enable greater growth of the offshore wind industry (I4). The outcome of this set of Interviewee 14's AS is the conversion of the seascape from that which can be used by fisheries to that used predominantly by the offshore wind industry. By contrast, Interviewee 14 described how rule making by the government and TCE does not specify which areas of communities should be considered by offshore wind developments (I14). If this specification was in place, the outcome would be "much better, co-designed, worked together sort of infrastructure and developments that are actually what a community wants and needs" (I14). The potential outcome has been summarised as collaborating, describing how offshore wind could work with communities as opposed to the current situation which in which offshore wind is working in the same space as communities whilst seeking their acceptance.

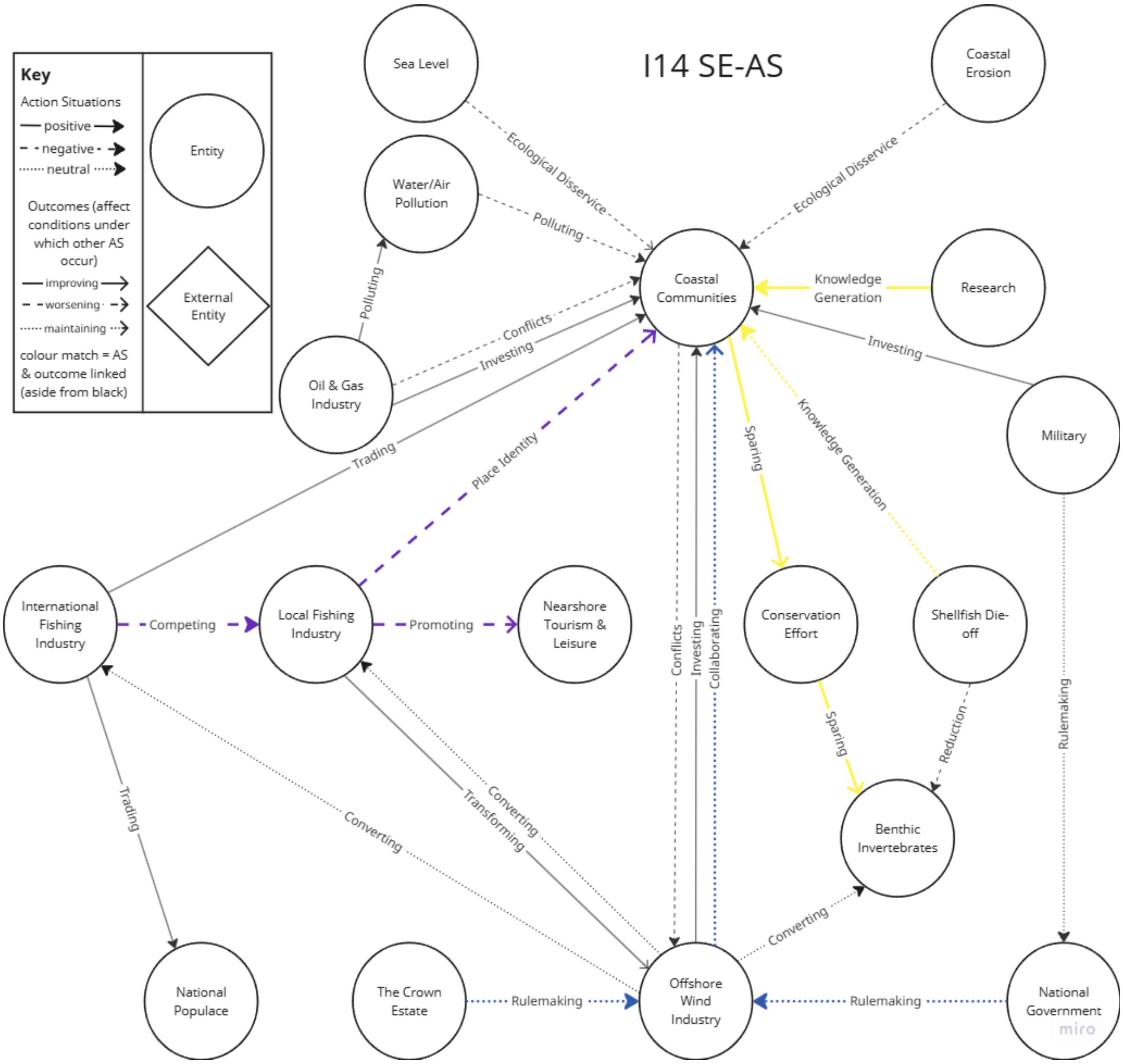


Figure 5.7 Diagram to show the causal relationships, action situations and outcomes discussed in interview 14. Relationships with clear outcomes are colour coded and highlighted as linked action situations. Purple arrows = Competing AS and outcomes. Yellow arrows = Knowledge generation AS and outcomes. Dark blue arrows = Rulemaking potential AS and outcomes.

A recurring theme in the interview with Interviewee 14 was the difficulties of summing up complex relationships with weighted lines of positive, negative or neutral effects. Particularly when speaking on coastal communities – their area of expertise – summing up causal relationships was “too big” or “too complicated” to even try to split coastal communities into smaller groupings within these communities (I14). All the way down to the individual, there were “different perspectives (of) and relationships with the place” which made it difficult to summarise relationships between coastal communities and other UKNS entities at the regional scale (I14). This, coupled with the challenge of being unable to specify a timescale around these connections (I14) – which is a known limitation of SE-AS (Herzog et al., 2022) – made for a challenging interview. However, with acceptance of the uncertainties inherent with this kind of research, we were still able to have a fruitful discussion which generalised some of the core social-ecological dynamics at play in the UKNS.

Conversation on how coastal communities are variably "shaped" featured heavily in this discussion (I14). Some factors which shape these communities are the variable connection to different livelihoods they attract or repel, as well as broader geographical qualities (e.g. the shape of a natural harbour promoting port development and activities) which encourage or dissuade those livelihoods (I14). An important addendum was a discussion of the artificial delineations of who qualifies as original within a coastal community, especially within areas strongly affected by tourism (I14). These factors and more combined to give an area "place identity" (I14), whose changes and evolutions produce impacts which are "less tangible", that "we are not very good at measuring" (I14).

5.1.3 Combined coastal communities and offshore wind SE-AS configuration

Figure 5.8 combines the information from five marine expert interviews together to diagrammatically explain the linked AS between different UKNS entities that interact with coastal communities and the offshore wind industry. A few steps were taken to combine the AS more neatly: big business, which was discussed by Interviewees 6a and 6b (Figure 5.6), was disaggregated into the offshore wind industry and oil and gas industry. The variable effects that different parts of the offshore wind industry have on coastal communities, which were discussed with Interviewee 3 (Figure 5.2), were amalgamated into one Investing AS. Combining instances of the same AS or outcomes was considered, however, the variable paths of origins and outcomes of each AS show how the same interaction can be considered in different ways. For example, "Investing" from the offshore wind industry to the coastal communities node is considered to be both an AS and an outcome by different Interviewees. Interviewee 3 considered investment, in the form of community benefit schemes and employment, as an AS whose outcome was increased social acceptability of offshore wind developments. Interviewee 4 considered investing as an outcome based on an AS of rule-making by TCE for offshore wind developers. Finally, Interviewee 5 considered investment as an outcome of another investment AS between offshore wind and ports. To a greater or lesser extent, all of these AS and outcomes are simultaneously taking place in the UKNS.

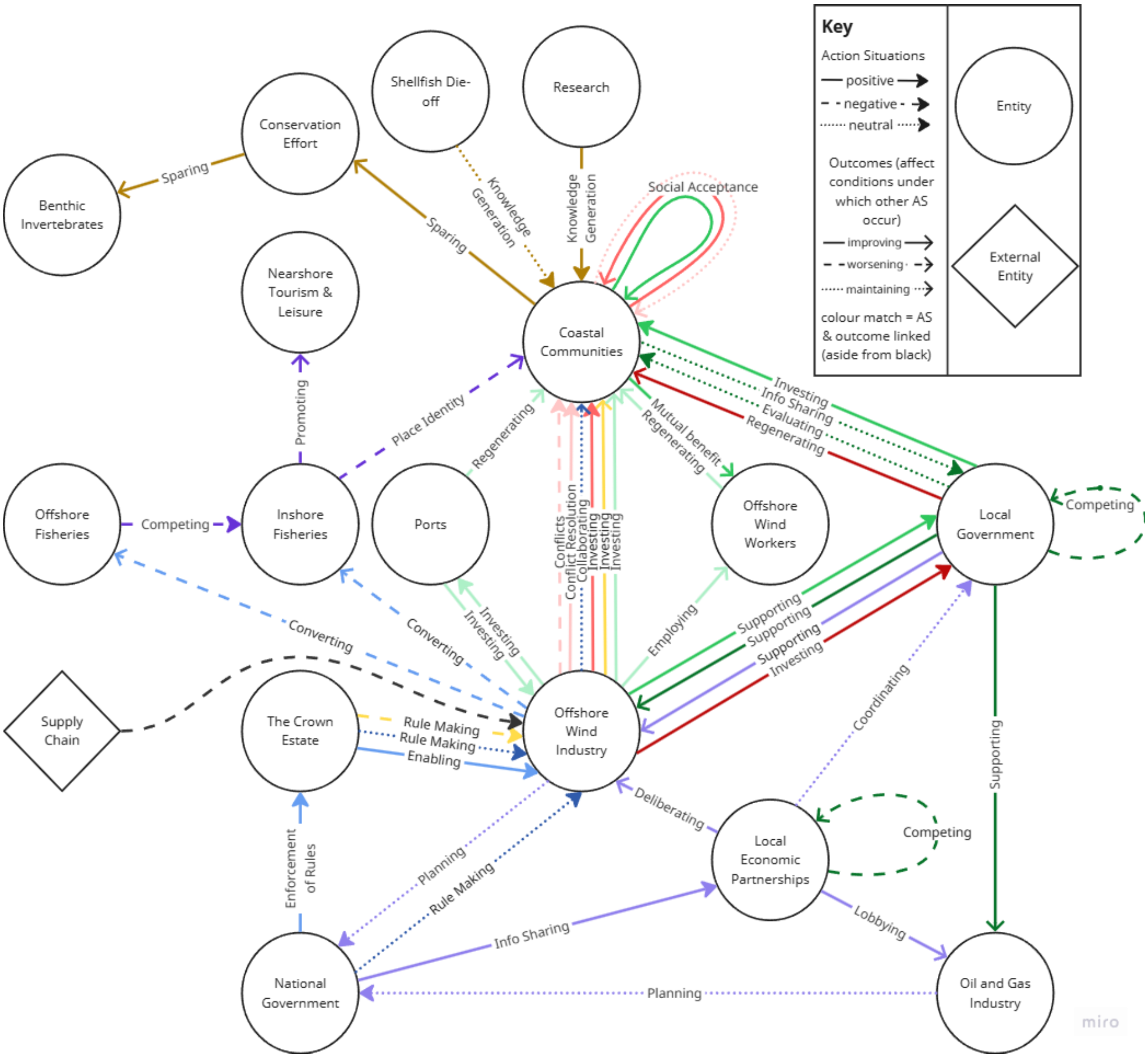


Figure 5.8 Combined SE-AS framework depiction of how different UKNS entities are perceived by six offshore wind industry and coastal communities experts. Green arrow = Supporting and Investing AS and outcomes. Pink arrow = Conflict AS and outcomes. Red arrow = Investing AS and outcomes. Brown arrow = Restructuring AS and outcomes. Blue arrows = Enforcement of Rules and Enabling AS and outcome. Yellow arrows = Rule making AS and outcome. Turquoise arrows = Investing AS and outcomes. Light Purple arrows = Information sharing AS and outcomes. Teal arrows = Information sharing and Evaluating AS and outcomes. Purple arrows = Competing AS and outcomes. Yellow arrows = Knowledge generation AS and outcomes. Dark blue arrows = Rulemaking potential AS and outcomes.

As well as defining and describing AS and outcomes of the core relationship between the offshore wind industry and coastal communities, Figure 5.8 depicts linked AS whose outcomes alter the rules and conditions under which the core relationship occurs, or which are affected by the core relationship. For example, the role of local government and local economic partnerships acting to support offshore wind developments on behalf of coastal communities has been illuminated (green and dark green, Figure 5.8), as well as how TCE and national government make and enforce rules for offshore wind developments (dark yellow and dark blue, Figure 5.8). The pressures on local fisheries from international fisheries and conversion of seascapes by offshore wind can be seen, as well as the cultural importance of local fisheries as contributors to place identity for a significant portion of coastal communities (dark purple, outcome of blue, Figure 5.8). Whilst most of the interconnections discussed by these interviewees were S-AS (mostly due to the social nature of the core entities discussed), the inclusion of benthic invertebrates also features on this framework as an outcome of a knowledge generation AS which combines marine research with witnessing of shocking ecological events such as shellfish die-off (yellow, Figure 5.8).

A final note for Figure 5.8 is that local fishing industry and international fishing industry have been renamed to inshore fisheries and offshore fisheries respectively, to more concretely link this map with the following section on offshore wind and fisheries. The logic behind this alteration is described in part 5.2.2.

5.2 SE-AS of Offshore wind Energy and Fisheries

5.2.1 Marine expert introductions

There is some discussion of fisheries in the interviews with experts focused on offshore wind and coastal community interactions (section 5.1). In this section, however, I analyse the perceptions of six different experts (across 5 interviews) whose knowledge is much more strongly geared towards fisheries and their interactions with offshore wind. To conserve some anonymity, I shall refer to them as Interviewees 8, 10a, 10b, 15, 18 and 19. Brief descriptions follow, to aid in understanding the positionality of their contributions to this chapter.

Interviewee 8 has a role in managing a port which specialises in fish processing and more recently offshore wind energy on the East coast of England. Interviewees 10a and 10b are consultants at a marine consultancy firm, with backgrounds in marine ecology, fisheries, monitoring and governance. Interviewee 15 is an ecosystem services scientist looking at the environmental and socio-economic effects of offshore wind farms onto fisheries. Interviewee 18 is an expert in fisheries liaison for offshore construction projects, who also has previously been an inshore fisherman, and involved in a fisherman’s association on the south-east coast. Finally, Interviewee 19 works for TCE on fisheries and impact assessments.

5.2.2 SE-AS from interviews

A note on how fisheries were delineated in this study

Interviewees 8, 15 and 18 redefined the UKNS entities of local and international fisheries, which had initially been selected by Aura CDT student in the 1st stage of the project (Chapter 4). The entities were altered to become inshore and offshore fisheries, respectively. The diversity of fisheries and their practices was noted by several interviewees during this stage of research (I8, I15, I18) with frequent affirmation that there is no single delineation that is appropriate for the full spectrum of habits, vessels and techniques. Inshore fisheries are broadly those which use small craft (often <12m length) to fish within 12nm of the UK coastline. Offshore fisheries, by contrast, are those which generally use larger (>12m) vessels to fish beyond 12nm from the coast within the study area (I15, I18), and those which could have their home ports either within or outside of the UK.

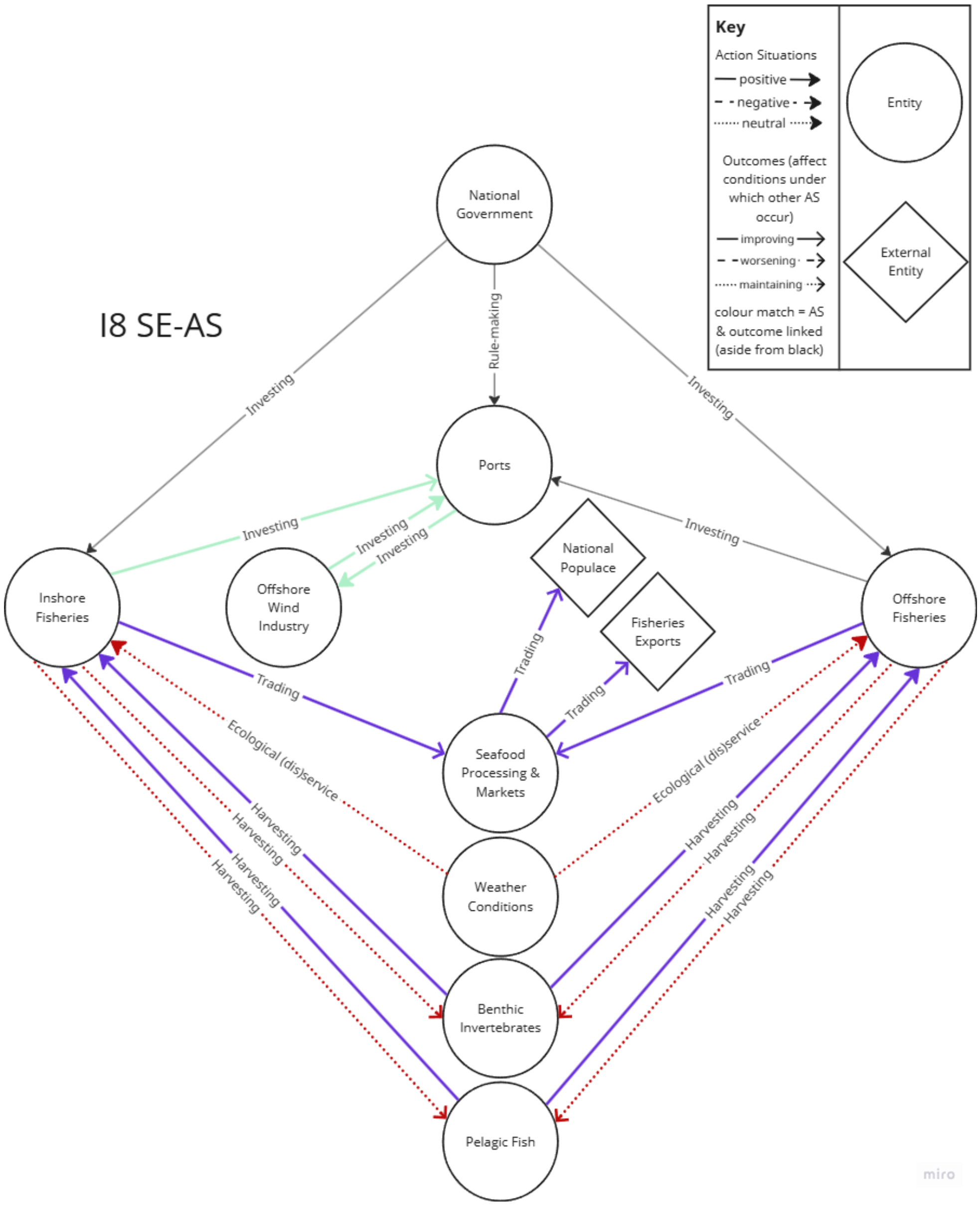


Figure 5.9 Diagram to show the causal relationships, action situations and outcomes discussed in interview 8. Relationships with clear outcomes are colour coded and highlighted as linked action situations. Light green arrows = Investing AS and outcomes. Dark purple arrows = Harvesting AS and outcomes. Dark red arrows = Ecological (dis)service AS and outcomes.

Interview 8 – port manager

Figure 5.9 highlights the three AS and associated outcomes from my discussion with Interviewee 8. The first AS (light green, Figure 5.9) was also discussed in Interview 5, and shows how investment between ports and the offshore wind industry provides mutual benefits for both entities. In reference to the importance of offshore wind within their port, Interviewee 8 even asserted “that if we'd have stuck with fishing, we'd have gone bust 15 years ago" (I8). The outcome of investment from offshore wind is that "it allows us to continue with the fish business, in a smaller way" (I8). In other words, with the investment to the port that Interviewee 8 works at from offshore wind, it stays in a financial position to be able to sustain the smaller, less commercially lucrative inshore fisheries as well. This fits in well with a philosophy to maintain fishing, because it is "absolutely part and parcel of the history of this community" (I8). Inshore fisheries contributing to preservation of historical heritage could have been an additional mapped outcome onto Figure 5.9. However, Interviewee 8's assertion that keeping crabbers in port was a "purely commercial arrangement… nothing sentimental or anything about it"(I8), suggested that the outcome was not worth including, according to Interviewee 8's perception.

The second AS (dark purple, Figure 5.9) is the harvesting of pelagic fish and benthic invertebrates by inshore and offshore fisheries. It leads to an outcome of trading fish through seafood processors and markets, and then through to the national populace. Interviewee 8 stressed the unpredictability and inconsistency of this outcome, saying that "sometimes we'll go weeks, and I mean, weeks into months losing money, knowing that it will come back and then we'll earn money" (I8). The purple harvesting AS contributes to this unpredictability through the variable behaviours of the stocks themselves. The third AS (dark red, Figure 5.9): ecological (dis)service bought on by variable weather conditions, weighs in heavily to the unpredictability of the harvesting AS, to the extent that its outcome conditions the harvesting AS itself (Table 5.1). "If the weather is crap… you know, stormy sea, there's no fish… because nobody is catching them" (I8). Adverse weather conditions can lead to poor fisheries landings, whilst good weather conditions lead to increases in landings.

A core theme of the discussion with Interviewee 8 was the multi-national nature of fisheries production. According to them, and confirmed by Seafish (2023), 80% of the national populace's fish consumption comes from imports, and 80% of our UK produced fish is exported elsewhere, mostly to European markets (I8). This is primarily due to our national whitefish preferences for cod and haddock, which is mostly sourced to the UK from fisheries in cooler Icelandic waters. In this study, where I am looking at a politically bounded SES (the UKNS coastline, out to the edge of its exclusive economic zone (EEZ)), it becomes hard to factor in the unbounded nature of entities such as fisheries, which operate at multiple scales and across multiple regions.

To keep the focus within the UKNS: "down onto Kent and all the way up the coast… up to Northumberland" most fisheries are inshore fisheries, predominantly geared towards benthic invertebrates, or shellfish, though there's always room for a few boats "to go out white fishing" (I8). However, Peterhead in NE Scotland "lands 50-60% of all the (fresh) fish in the UK", from the deeper waters at the North end of the study area, as well as beyond it, both directly North of Scotland and outside the UKNS EEZ towards Norwegian waters (I8). The geographical variety of fishing practices across the UKNS at this regional scale, as well as the sentiment that fisheries and ports "are so varied, it's unbelievable", based on their people, vessels and locations, meant that Interviewee 8 did not believe that you could come up with rules and regulations that would suit everybody (I8).

A final theme of the discussion with Interviewee 8 was their lack of interest in engaging beyond the commercial ventures of the port. The singular focus on ensuring the port's survival by maintaining and developing it meant that they do not get involved with government initiatives because when they have engaged in the past "they've mostly been a waste of time" (I8). Similarly, with environmental organisations and sustainable practices, though they think they are broadly a good idea, they did not think anything they could do would make any difference (I8). This mindset was reflected in Interviewee 8's thoughts on the fishing industry, which they described as "parochial… just interested in its own thing".

Interview 10 – marine consultants

Interviewees 10a and 10b provided insights into four social-ecological AS, as well as two social AS and a host of other interactions that are occurring within the UKNS. Because their discussion often revolved around considering some marine entities as lumped under larger categorisations (for example discussing fish populations without delineating pelagic and benthic fish), the AS diagram is more complex than those created within other interviews (Figure 5.10). The first AS (bright orange, Figure 5.10) describes their perception that converting the seascape to increase scour protection at offshore wind foundations could provide more habitat for benthic invertebrates such as crabs and lobsters. The outcome of this AS is that this would in turn provide higher catch-rates for inshore fisheries which predominantly practice pot-fishing (I10).

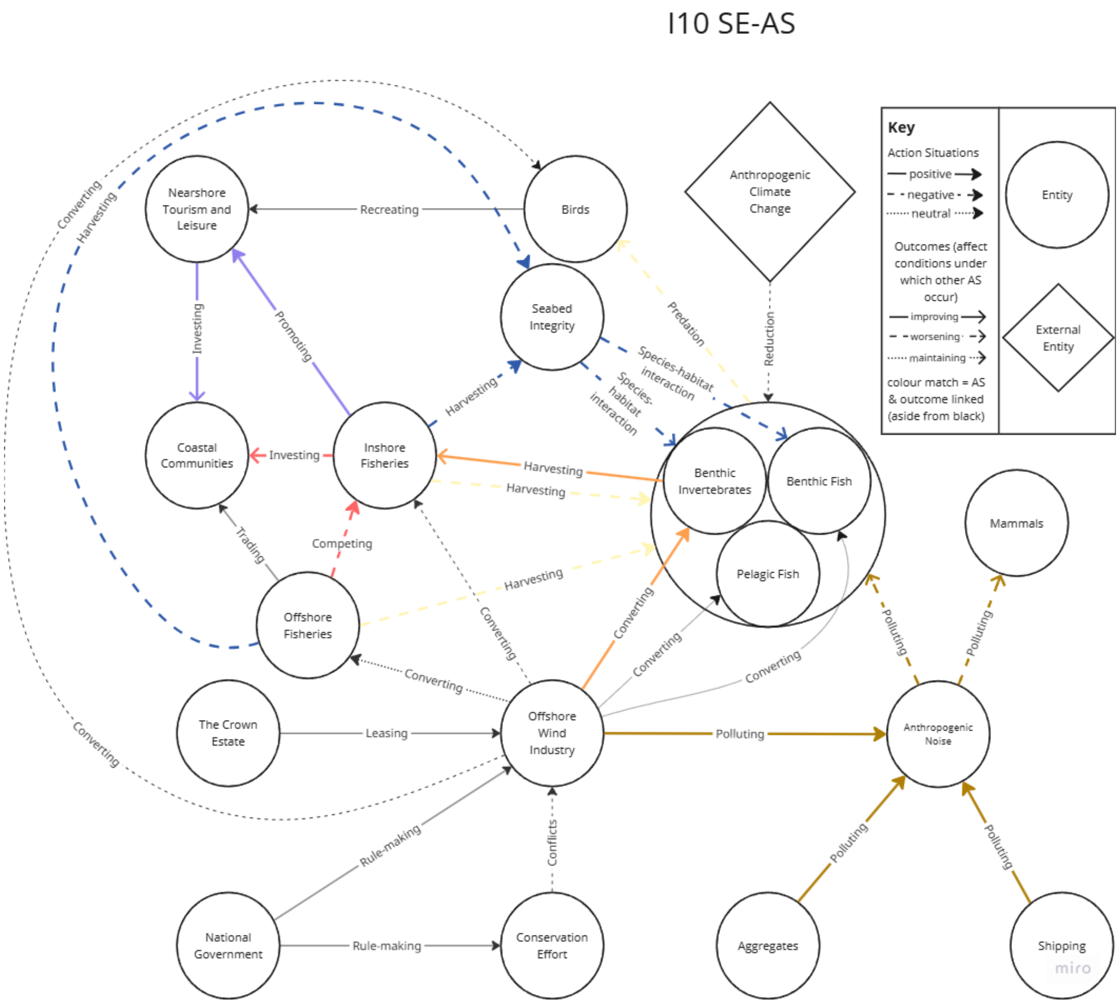


Figure 5.10 Diagram to show the causal relationships, action situations and outcomes discussed in interview 10. Relationships with clear outcomes are colour coded and highlighted as linked action situations. Bright orange arrows = Converting AS and outcomes. Dark gold arrows = Polluting AS and outcomes. Dark blue arrows = Harvesting AS and outcomes. Lavendar arrows = Promoting AS and outcomes. Bright red arrows = Competing AS and outcome.

A second AS (dark gold, Figure 5.10) relates strongly to a persistent theme of our discussion: cumulative impacts. In this AS, noise caused by anthropogenic activity, such as dredging for aggregates, shipping, and offshore wind turbine construction, cumulatively contribute to a polluting AS of anthropogenic noise. The outcomes of this AS are that fish species, benthic invertebrates and marine mammals are variably negatively impacted by this increased level of noise (I10). Importantly, Interviewee 10b highlighted that different species will have different thresholds for noise disruption and be affected in variable ways by anthropogenic noise. Pelagic fish, for example, have swim bladders that can be affected by both impulsive and ambient noise (I10).

The third AS (dark blue, Figure 5.10) involved the introduction and definition of a new entity, seabed integrity. This was not formally defined during the interview, so a definition from the Marine Strategy Framework Directive Good Environmental Status criteria D6 – Sea floor integrity, has been used. Sea floor integrity jointly describes the extent of physical damage to the seabed through human activities, as well as the condition of benthic communities at the seabed (Hill et al., 2012). In this third AS, the action of harvesting - to a greater extent by offshore and a lesser extent by inshore fisheries – results in a decline in seabed integrity (I10). The outcome of this AS is that benthic fish and invertebrate abundance declines. This AS happens additionally to AS four for interview 10 – the direct action of harvesting marine pelagic and benthic fish species, as well as benthic invertebrates – whose outcomes propagate through food webs to affect the extent to which birds can predate upon these species (light yellow, Figure 5.10).

AS five (lavender, Figure 5.10) is a social AS. It displays a newly defined AS called promoting (Table 5.1) which describes how the presence of one industry encourages proliferation of another. In this case, a greater presence of inshore fisheries encourages more tourists to coastal areas, thus encouraging more nearshore tourism and leisure. The outcome of this AS is increased investment into coastal communities, through the ability to draw in revenue through tourism. This AS and outcome has been previously examined by Reed et al. (2013) who examined the socio-cultural role of inshore fishing in the UK.

A final AS (bright red, Figure 5.10), depicts how offshore and inshore fisheries compete for resources. Larger and more economically powerful offshore fleets tend to outcompete smaller inshore fleets, “pushing them to the margins” (I10). The AS is a distillation of multiple phenomena, relating to both fisheries quota allocations and indirect food web mediated resource depletion. An outcome of this is that coastal communities receive less investment from inshore fisheries, which themselves have access to fewer resources. Comparison of the fifth and sixth AS with a similar AS described by interviewee 14 (dark blue, Figure 5.7) reveals the interconnected nature of inshore fisheries, coastal communities and nearshore tourism and leisure, and also shows the plurality of ways that action situations and outcomes can be variously described.

Interview 15 – Ecosystem Services Scientist

My interview with Interviewee 15 focussed on the interactions between commercial fisheries (both inshore and offshore), offshore wind and related UKNS entities (Figure 5.11). As a result of the interview, two AS were identified. The first (brown, Figure 5.11) depicts how conversion of the offshore environment by construction of offshore wind farms and their associated cabling infrastructure causes displacement of fisheries. The core outcome of this displacement is increased competition amongst fisheries as some vessels are forced away from their traditional fishing grounds and into other's areas to fish. Interviewee 15 also summarised additional outcomes of this AS: with fisherman having to travel further with increased fuel costs to start fishing and more frequent overnight travel incurring safety and wellbeing risks, and having to place more effort into fishing in new and unknown grounds with new hazards such as shipwrecks to continue to make their business viable (I15). An additional point that came from discussing this AS, which is important to take into consideration but difficult to map using SE-AS at this regional scale, was the local changes to ecological pressure caused by displacement of fisheries (I15). This was because local fisheries-based ecological pressures are based on many factors, from the type of vessel to the method of fishing, the target species, and the intensity of fishing.

The second AS (light blue, Figure 5.11), which relates to the first, is how the conversion of the seascape by the offshore wind industry impacts fish and benthic invertebrate populations, whose outcome is changes in yield to fisheries. Importantly, Interviewee 15 contextualised this by highlighting that impacts of offshore wind developments are "quite species specific" (I15). They can occur because of seismic surveys pre-construction, construction itself, or the ongoing operation and "presentness" of the wind farm (I15). These effects of offshore wind onto benthic and pelagic fish populations tend to be more obviously negative, although the overall change for benthic invertebrates is more nuanced, with lobsters been seen to aggregate around offshore wind turbines post-construction.

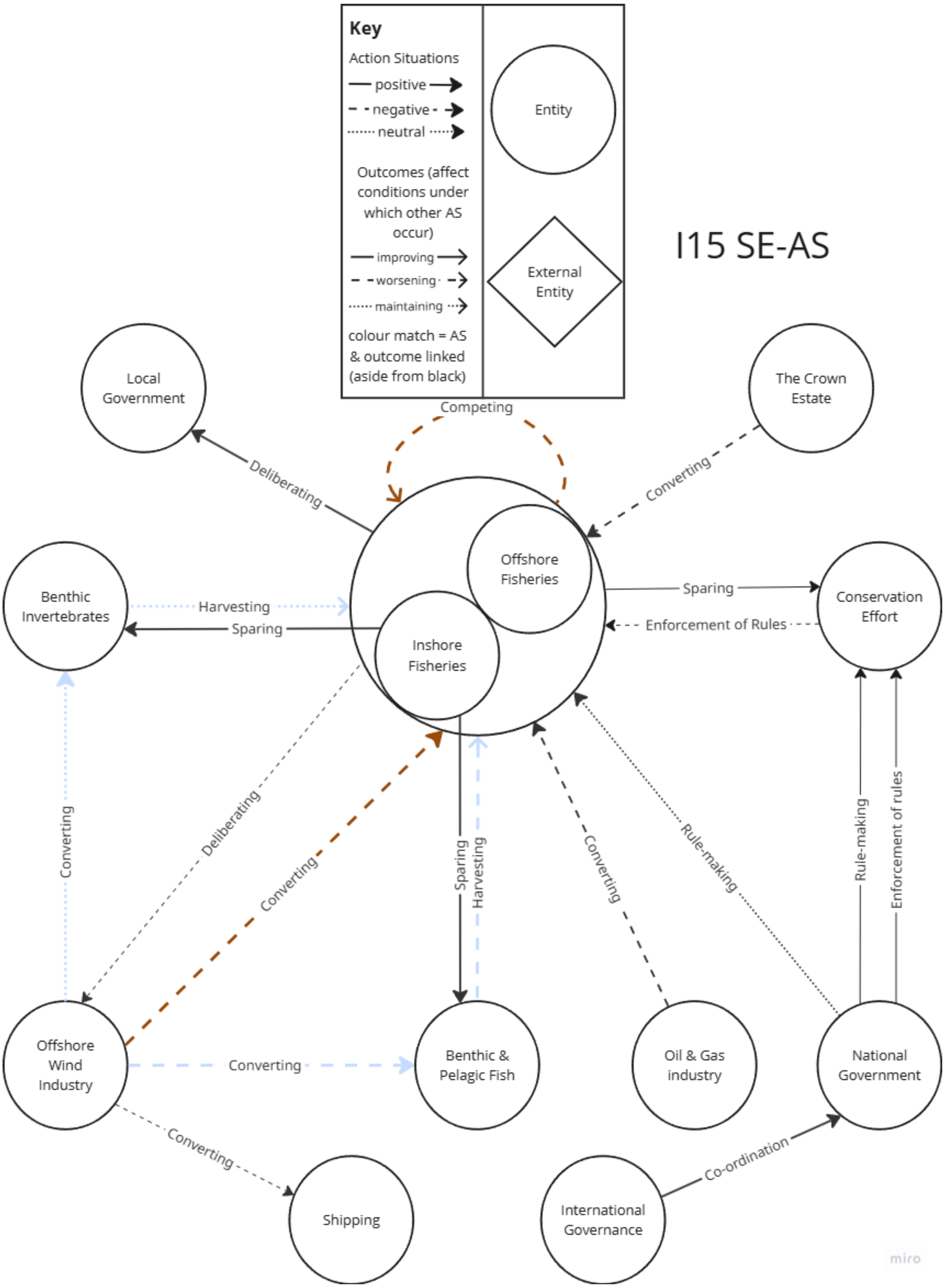


Figure 5.11 Diagram to show the causal relationships, action situations and outcomes discussed in interview 15. Relationships with clear outcomes are colour coded and highlighted as linked action situations. Light blue arrows = Converting AS and outcomes. Brown arrows = Converting AS and outcomes.

Interviewee 18 – Fisheries Expert

Interviewee 18 painted a picture of a seascape within which inshore fisheries face increasing pressures from other UKNS entities. Through our discussion, 5 core SE-AS were identified. The first (grey, Figure 5.12) depicts the competition between marine mammals, especially seals, and inshore fisheries for fish resources. Interviewee 18 said that seals, which have in recent years become far more prevalent in the UK North Sea, have a “significant impact” on these fisheries, through eating a great deal of fish, damaging of fishing gear, and damaging fish caught within gear (I18). The outcome of this action situation is a reduction in successful harvesting of fish by inshore fisheries. Conditions to this AS are that public perception and legislation prevents fisherman from doing anything about this, where half a century ago they might have applied for licences to cull seals that were affecting their catch (I18).

The second AS is an ecological one with anthropogenic drivers (light purple, Figure 5.12). This ‘reduction’ AS, involving anthropogenic climate change, fish populations and benthic invertebrates is complex, but can mostly be described by the trend of northward migration as a species response to warming waters. Interviewee 18 cited that in his fishing area, this had meant a loss of cod, but an increase in bass stock (I18). An outcome of this is increased pressure onto fisheries due to the necessity of changing harvesting practices.

The central set of AS described by Interviewee 18 revolves around seascape conversion caused by offshore wind expansion, which negatively impacts fisheries (pink, Figure 5.12). In this AS, conversion of fishing grounds to offshore wind farms is comprised of several impacts to inshore fisheries: a reduction in the amount of trawling that could occur, an overall reduction in methods available for fishing, an increase in subsurface hazards such as cabling, more navigational hazards (turbine arrays, especially by night, and marine traffic), displacement of fishermen from their grounds and increased distances needed to travel to suitable fishing grounds (I18). These impacts have the central outcome of causing conflict between inshore fishing associations and the offshore wind industry. A contributing AS to the converting AS is the rulemaking AS from national government to the offshore wind industry (dark red, Figure 5.12). Here, there are no licencing conditions under which an offshore wind developer has to deliberate with inshore fisheries as they develop their wind farm to take mitigating action so that developments are not as detrimental to inshore fisheries (I18). A linked AS that dampens the effect of the primary converting AS and its associated conflict-based outcomes is the employment of a commercial fisheries lead for most larger offshore wind developments. This presence allows for better deliberation between offshore wind developers and inshore fisheries, which can mitigate some of the negative effects of developments.

A fourth AS (yellow, Figure 5.12), depicts a response to the powerlessness fishermen felt in the face of offshore wind developments. In this AS, fisheries engage the Crown Estate, lobbying them to have greater consideration of where wind farms are built, which includes consultation with the fishing industry. The outcome of this AS is the Crown Estate coordinating with the offshore wind industry through the leasing process to be more considerate of fisheries that operate in and around their development areas. As a note, Herzog et al. (2023) use the lobbying AS purely for influence of political actors, whereas the Crown Estate sits across the boundary of both public and private sectors, being a publicly owned property business.

A final AS (dark green, Figure 5.12), depicts how coastal communities support inshore fisheries because of the outcomes the presence of inshore fisheries can provide. One outcome is the place identity that inshore fishing can provide to a coastal community, with fisheries in some coastal communities being a core part of a place's cultural heritage. An example given here was Whitstable, which "nails its identity to the Whitstable Oyster" (I18) Another outcome is the benefits that fisheries can bring to nearshore tourism and leisure ventures in coastal communities. Interviewee 18 referred to visitors looking to "see that colour fish being unloaded" in reference to the small brightly coloured fishing vessels of an inshore fleet (I18).

Prevalent through my talk with Interviewee 18 was the evolution of the interplays between offshore wind and inshore fisheries. Early developments like Thanet offshore wind farm were constructed with no consultation from fisheries, causing significant conflict amongst marine users. Much more recently, the Crown Estate's leasing process and many of the offshore developers themselves are gearing towards more thorough consideration of the impacts of developments to fisheries, with increasing likelihood of mitigations being put in place. Still, the best fisheries can hope for with further offshore wind developments is a "least worst" scenario. "There will always be a trade-off" between offshore wind developments and fisheries, a dynamic that which will continue to evolve as offshore wind seeks to build in further offshore waters where more lucrative offshore fisheries operate (I18).

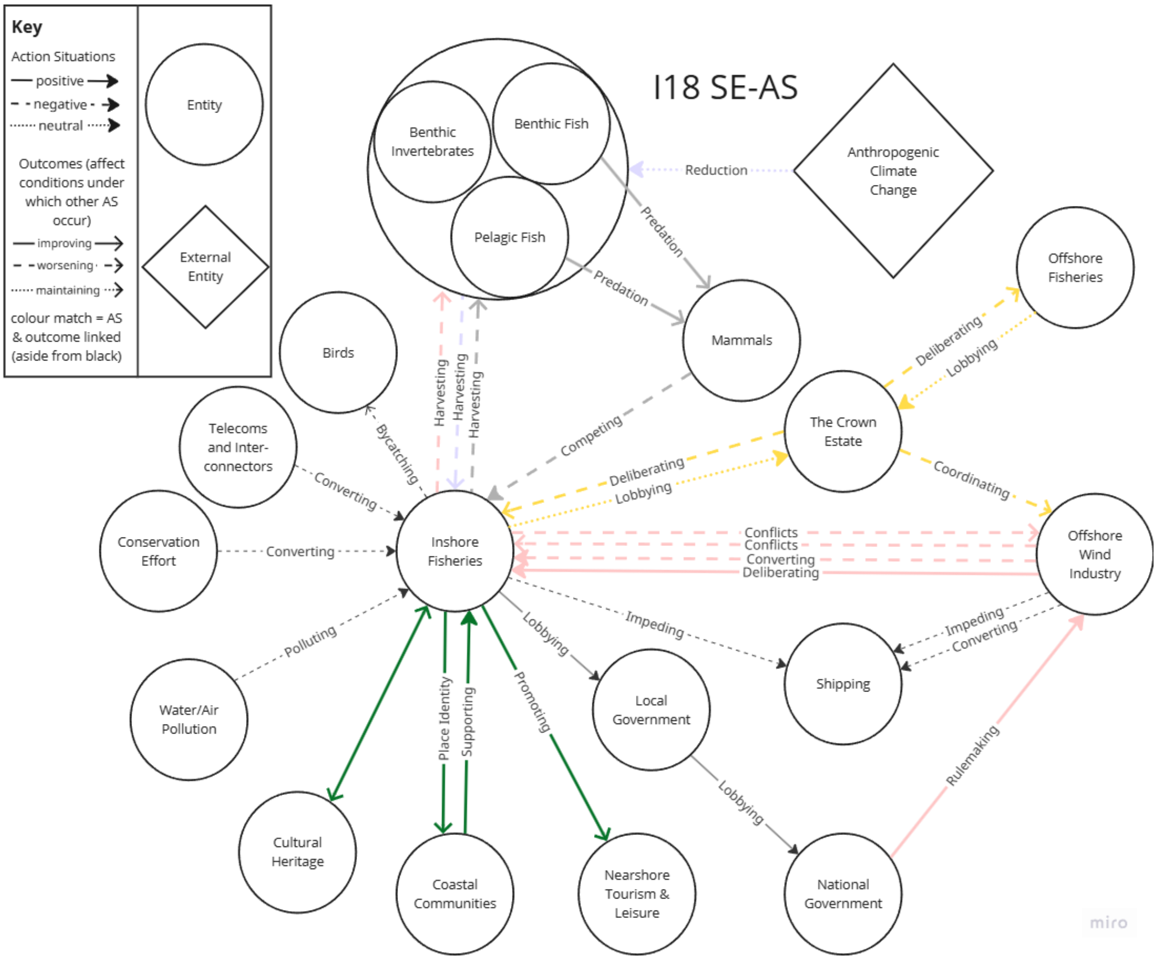


Figure 5.12 Diagram to show the causal relationships, action situations and outcomes discussed in interview 18. Relationships with clear outcomes are colour coded and highlighted as linked action situations. Grey arrows = Competing AS and outcomes. Light Purple arrows = Reduction AS and outcome. Pink arrows = Rulemaking, Deliberating and Converting As and outcomes. Yellow arrows = Lobbying AS and outcomes. Dark Green arrows = supporting AS and outcomes.

Interview 19 – The Crown Estate EIA expert

Discussion with Interviewee 19 revolved around the ecological side of offshore wind governance from a Crown Estate perspective. There was an overarching AS (green, Figure 5.13) which concerned the making of and enforcement of rules by governance entities in the area with regards to UKNS ecology and the offshore wind industry. This mostly revolved around assessments such as Environmental Impact Assessments and Habitat Regulations Assessments. In this AS, The Crown Estate, through their leasing process, and national government, mostly through the arms-length body Natural England, enforce rules onto the offshore wind industry which mitigate the negative impacts on offshore developments onto marine species (I19). To note, Natural England do this for inshore English waters, whilst the Joint Nature Conservation Committee are responsible in offshore waters in England and Wales (JNCC, 2019). The competent authorities in Scottish waters are the Marine Directorate and Nature Scot (Marine Directorate, 2024). Where Interviewee 19 described conversion of the seascape by offshore wind developments as having a weak negative (or at best neutral) effect on marine species (see converting interactions in Figure 5.13), the desired outcome of rule enforcement is that marine species are spared from some of the most adverse potential effects. In rare situations, enforcement of rules has led to reduction of wind farm site boundaries away from a marine protected area (MPA) (I19). More commonly enforcement of rules leads to design mitigations, such as changing the height of turbine blades to reduce bird collision risk, soft start piling to scare away marine species before they get hurt by noise, or more effectively burying cables to reduce electromagnetic field effects (I19).

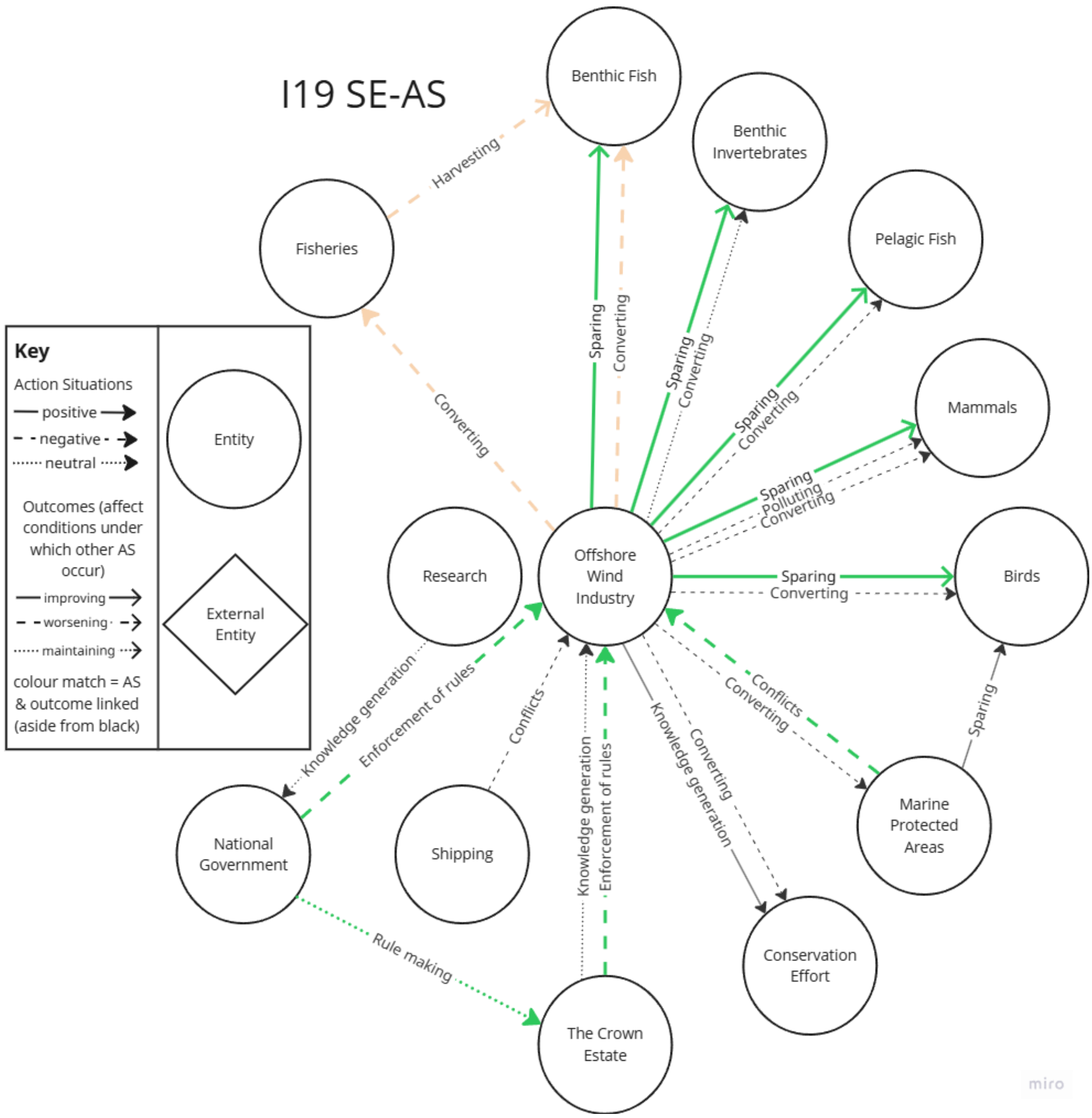


Figure 5.13 Diagram to show the causal relationships, action situations and outcomes discussed in interview 19. Relationships with clear outcomes are colour coded and highlighted as linked action situations. Green arrows = Rule making, enforcement and conflict AS and outcomes. Light orange = Converting AS and outcomes.

A second AS discussed by Interviewee 19 concerns a dynamic relationship between offshore wind, fisheries, and benthic fish (light orange, Figure 5.13). In this AS conversion of the seascape through offshore wind development causes some moderate negative effects to benthic fish species, such as through electromagnetic fields from cabling or piling activity during construction (I19). At the same time, offshore wind is detrimental to the harvester of benthic fish – fisheries, through stopping certain fishing methods such as bottom trawling from happening within a wind farms area (I19).

Interviewee 19's point was that if "the offshore wind farm displaces that trawling, then the odds are that you're going to have a stronger benthic fish community" (I19). In this sense, the outcome of this AS is a change in the ability for fisheries to harvest benthic fish. An important caveat to this predicament, as with many of the AS's that have been discussed, is that these relationships are location specific within the UKNS. If the seabed is not trawled in a specific location, then an offshore wind farm may have a net negative impact on benthic fish populations.

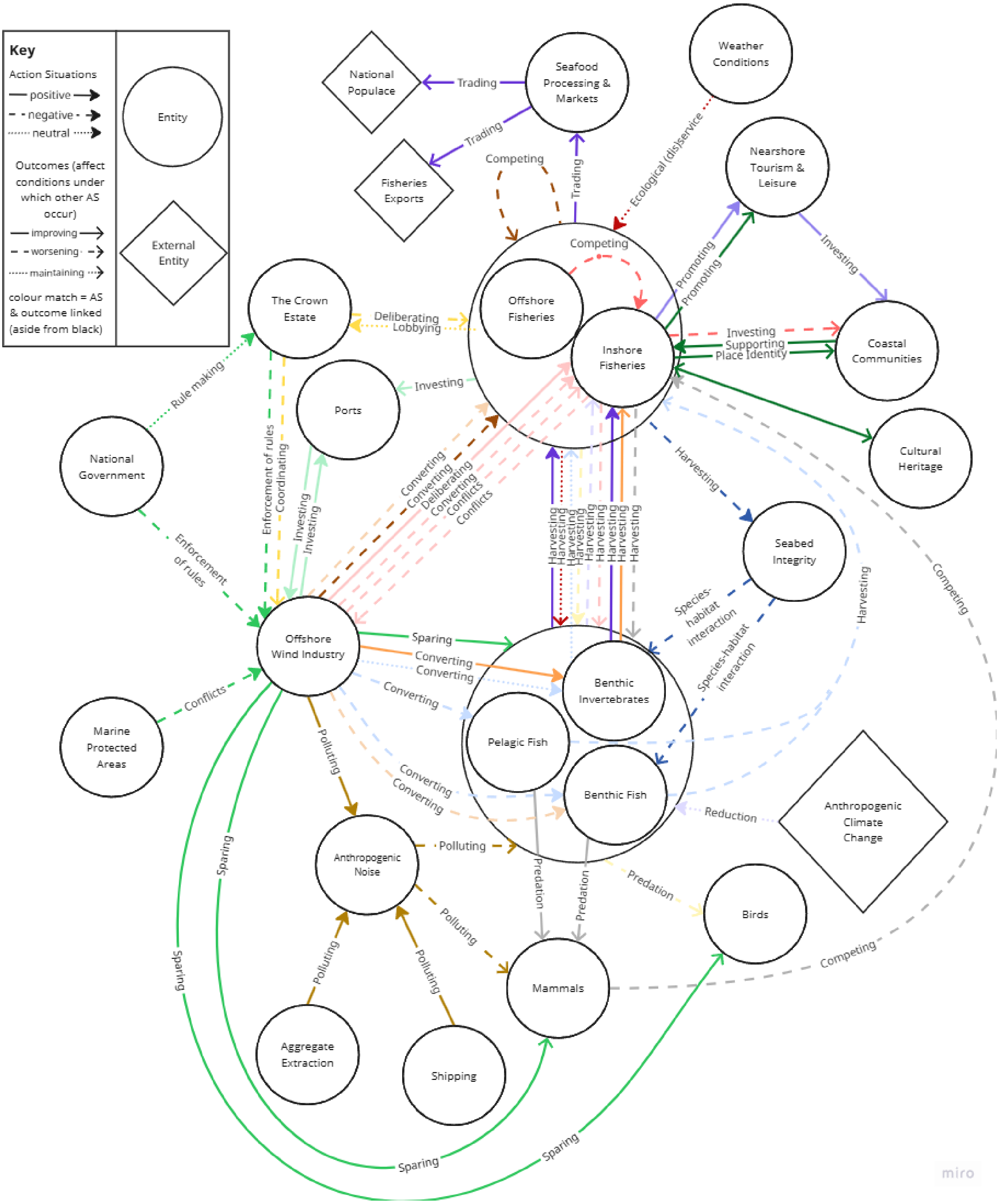
5.2.3 Combined fisheries and offshore wind SE-AS configuration

Figure 5.14 combines AS and their outcomes identified through analysis interviews 8, 10, 15, 18, and 19, and should be interpreted in conjunction with the textual descriptions of AS and outcomes in the Action Situation and Outcome tables at the end of this chapter (section 5.5). Central to this configuration, and reinforced by several interviewees, are a trio of core co-occurrent AS: the conversion of the seascape through offshore wind development having a raft of negative impacts onto inshore, and to a lesser extent all fisheries; this same seascape conversion having mixed (perceived as neutral or sometimes positive for benthic invertebrates) but overall negative impacts onto marine life; and the harvesting AS between fisheries, and fish and benthic invertebrates. Both converting AS are shown to strongly influence the harvesting AS, affecting the conditions under which it is occurring.

Other AS affect and are affected by this central trichotomy. For example, governance-based entities such as TCE and National Government endeavour to alter the conditions under which the core suite of AS occur. They leverage their power over the offshore wind industry through rule-making and enforcement of rules AS, influencing the offshore wind industry to mitigate its negative effects on marine life, thus producing "sparing" outcomes (green, Figure 5.14, textual definition in Table 5.2). To a lesser extent, TCE is beginning to coordinate with the offshore wind industry to mitigate potential negative effect of offshore wind developments onto fisheries. This outcome is due to fisheries associations lobbying TCE to better include them in the offshore wind leasing process (yellow, Figure 5.14).

Figure 5.14 also begins to paint a picture of the cumulative impacts being experienced by fish and benthic invertebrate populations within this area. Predation, reduction (migration due to anthropogenic climate change), harvesting, converting, polluting, and species habitat interactions all contribute pressure onto these species. A range of pressures are also placed onto inshore fisheries: as well as the core interactions already described, displacement through converting of seascapes to offshore wind results in increased competition amongst fisheries, increased safety risks, and lowered overall revenue due to the challenges of fishing in different grounds (I18). Additionally, competition for fish stocks between inshore fisheries and marine mammals adds to the cumulative pressure felt by inshore fisheries. Though the pressure on inshore fisheries from more richly resourced offshore fisheries was only mentioned by Interviewees 10a and 10b of this set (red AS, Figure 5.14), a similar "competing" AS was also described in Interview 14 (I14). As shown in Figure 5.14 and Figure 5.8, inshore fisheries provide place identity and conserve cultural heritage for some coastal communities, and can also act as a pulling mechanism to promote nearshore tourism and leisure.

Figure 5.14 (below) Combined SE-AS framework depiction of how different UKNS entities are perceived by six offshore wind industry and fisheries experts. Green arrows = Rule making, enforcement and conflict AS and outcomes. Light orange = Converting AS and outcomes. Grey arrows = Competing AS and outcomes. Light Purple arrows = Reduction AS and outcome. Pink arrows = Rulemaking, Deliberating and Converting As and outcomes. Yellow arrows = Lobbying AS and outcomes. Dark Green arrows = supporting AS and outcomes. Bright orange arrows = Converting AS and outcomes. Dark gold arrows = Polluting AS and outcomes. Dark blue arrows = Harvesting AS and outcomes. Lavendar arrows = Promoting AS and outcomes. Bright red arrows = Competing AS and outcome. Light blue arrows = Converting AS and outcomes. Brown arrows = Converting AS and outcomes. Light green arrows = Investing AS and outcomes. Dark purple arrows = Harvesting AS and outcomes. Dark red arrows = Ecological (dis)service AS and outcomes.


Key
Action Situations
positive
negative
neutral
Outcomes (affect conditions under which other AS occur)
improving
worsening
maintaining
colour match = AS & outcome linked (aside from black)
Entity
External Entity
National Populace
Seafood Processing & Markets
Weather Conditions
Fisheries Exports
Nearshore Tourism & Leisure
The Crown Estate
Offshore Fisheries
Inshore Fisheries
Coastal Communities
Ports
Cultural Heritage
National Government
Seabed Integrity
Offshore Wind Industry
Benthic Invertebrates
Pelagic Fish
Benthic Fish
Marine Protected Areas
Anthropogenic Climate Change
Anthropogenic Noise
Birds
Mammals
Aggregate Extraction
Shipping
Trading
Competing
Ecological (dis)service
Promoting
Investing
Deliberating
Lobbying
Supporting
Place Identity
Rule making
Enforcement of rules
Coordinating
Converting
Conflicts
Harvesting
Species-habitat interaction
Sparing
Polluting
Reduction
Predation
miro

5.3 Discussion

Strengths

Use of the SE-AS framework in this chapter has required me to distil from expert interviews the interactions of UKNS entities and how their known emergent outcomes affect the rules and conditions under which other interactions occur (Schlüter et al., 2019). Following this framework has focussed the analysis onto the actions which are co-occurring within the area, and how the dynamics of some actions are interlinked with the dynamics of others. In other words, this framework obliges the researcher into cataloguing the interconnected nature of a system.

Exploration of the interactions between coastal communities, the offshore wind industry, and other related UKNS entities through use of the SE-AS framework has allowed me to conduct a more thorough examination of the complex and interconnected nature of the UKNS SES than was possible from the FCM presented in Chapter 4. The range of AS and outcomes that have been found are described respectively in the directory in section 5.5. This methodology has exposed the nuances of complex interactions that had been previously abstracted as (in the example of offshore wind affecting coastal communities) a very weak negative effect (-0.05) by Aura CDT students (Chapter 4).

Additionally, following expert perceptions of what the most important AS are in the UKNS has helped to distil which interactions are worthy of inclusion on two final SE-AS diagrams (Figure 5.8 and Figure 5.14), including some areas which are tangential to the core relationships but still change the rules and conditions under which offshore wind, coastal community, and fishery based AS occur. These are described in results sections 5.1.3 and 5.2.3. Where the summary diagram for offshore wind and coastal communities interactions showed mostly social AS (Figure 5.8), the summary diagram for offshore wind and fisheries included a range of social-ecological and some ecological AS as well (Figure 5.14). This is due to the direct reliance of fisheries on the stocks they fish, and has meant that fish and benthic invertebrate stocks became a third core entity of the combined SE-AS diagram in Figure 5.14.

Combining the perceptions of experts also allowed me to compare their points of view and expose biases in the data. For example, where Interviewee 3 emphasised that the offshore wind industry were deliberating (Table 5.1) with fisheries to find the best ways to coexist in the marine space, Interviewees 4, 5 and 14 asserted that the offshore wind industry were directly impacting fisheries through loss of potential area for fishing (converting, Table 5.1). Whilst both interactions are true to an extent (as Interviewee 3's company had a team dedicated to managing the offshore wind and fisheries relationship (I3)), the more impactful AS is the conversion of fishing grounds by the offshore wind industry.

A strength of the SE-AS framework which overcomes a limitation of the fuzzy cognitive mapping approach used in Chapter 4 is that it can incorporate effects between UKNS entities for which flows are more difficult to describe. This helps to produce a more comprehensive representation of system dynamics, which incorporates less tangible but qualitatively important mechanisms, relating especially to governance and cultural value. The AS of rulemaking and enforcement of rules that tend to come from governance entities such as TCE and national government, as well as the AS and outcome of supporting, which was more often associated with local government, all represent important system dynamics that affect the conditions within which other AS occur (Figure 5.8). For example, TCE make rules within the leasing process which require offshore wind developers to directly benefit coastal communities, through STEM outreach and community benefit schemes. Through the lens of an FCM, the arrow from TCE to the offshore wind industry might be given a weak negative effect (of increased regulation) to fuzzily describe this rulemaking AS, but that weak negative could easily be lost within the synopsis of the overall effect between these multi-facetted entities. Furthermore, the connected interaction and outcome between TCE, the offshore wind industry, and coastal communities cannot be visually displayed with fuzzy cognitive mapping, even if it can be fuzzily incorporated into weightings.

Methodological observations

Herzog et al. (2022) collated a descriptive list of S-AS, SE-AS, and Ecological AS (E-AS), based on Pahl-Wostl et al. (2020) and the origin paper for the SE-AS framework, Schlüter et al. (2019), as well as additions from their own work. The combined list was used successfully in this study to deductively match AS observed in the UKNS to those seen in previous papers, with the possibility of adding new AS within this study if they could not be described by the current list of AS. This approach is described as “a primarily deductive approach completed by an inductive one” (Herzog et al., 2022).

A partial difference in the classification of AS between this study and of previous works was in the conversion AS. Where Schlüter et al. (2019) categorise this AS as an SE-AS, in this study it was also considered an S-AS. Specifically, addition of offshore wind infrastructure converts a seascape to a form which certain forms of fisheries (e.g. trawl fisheries) cannot function within, but which others (e.g. potting) can (Table 5.1). Fisheries inhabit a borderland between the social and social-ecological, being a social entity with a dominating presence in ocean food webs. In the first part of this chapter, which draws on the perception of marine social experts, conversion has been seen as an S-AS because of the positionality of the marine experts who were interviewed. This exhibits how positionality can affect how system dynamics are interpreted. A core takeaway of previous SE-AS works is that the proportions of social, ecological and social-ecological AS can tell us more about how SES are perceived by those who interact within them (Herzog et al., 2022). Something to be aware of for this study as well as others that follow this methodology is that what are perceived as important interactions may not fully align with the core social-ecological dynamics actually at play.

A repeated pattern seen in this study as well as in the AS configurations shown in previous SE-AS framework studies (Herzog et al., 2022; Schlüter et al., 2019) is that of one AS having multiple outcomes. An example of this is with the investment AS between offshore wind and ports, wherein outcomes of both increased offshore wind employment and regeneration of coastal communities (Figure 5.8, light green). A configuration not seen in previous studies is that of multiple chained AS leading to one identifiable outcome, such as the enforcement of rules from national government to TCE, leading to TCE enabling the offshore wind industry, which leads to the overall outcome of conversion of seascapes for offshore wind energy production (Figure 5.8, blue; Table 5.1, Table 5.2), or the planning, information sharing, coordinating and supporting AS amongst offshore wind, national government, local government and local economic partnerships which lead to outcomes of local governmental support and local economic partnership deliberation with and for the offshore wind industry (Figure 5.8, light purple; Table 5.1, Table 5.2). This pattern could be due to the distinction between AS and outcome still being somewhat unclear within the SE-AS framework, as suggested by Herzog et al. (2022). A strength of the diagrammatic configuration I use compared to other studies (as explained in Figure 5.1) is that it allows for more flexibility in the possible arrangements of AS and outcomes. It removes the necessity of AS only being linked by outcomes and allows for incorporation of situations where AS are directly linked to one another.

In addition, this representation allows the reader to see how an outcome affects the performance of other ASs, either by improving, worsening or maintaining their function. For example, in Figure 5.14 the deep purple AS harvesting is worsened by light purple harvesting outcome that is a result of the light purple reduction AS that causes fish populations and benthic invertebrates to migrate northward due to warming a warming climate.

Another benefit of the way AS and outcomes were configured for this study is the ability to more clearly incorporate directionality of AS between entities. As with the FCM approach (Chapter 4) a combined map like Figure 5.8 can show the direction of effect between different entities. Observing these directionalities can show which entities are drivers and receivers of effects and impacts within a system, which as discussed in Chapter 4 can be an allegory for variation in power across a system.

To give an example of revealed power dynamics, Figure 5.8 shows that coastal communities were broadly considered by the marine experts as receivers of effects across the system. They therefore could be considered as having low power to affect change within the system when compared with other entities. This perception was mostly upheld within the interviews, aside from by Interviewee 14, who said that coastal communities do have the potential to stop offshore wind developments, although “usually they're overridden” (I14, Figure 5.7 - conflicts). The low power that coastal communities seem to have with respect to offshore wind developments could be construed as an exclusion from decision making and governance, one of ten themes associated with ocean-based injustices by Bennett et al. (2020). Some mechanisms, such as local governance, exist to bring power to coastal communities and thus more firmly include them in this form of decision making. However, this power has limits, not being able to stop the emplacement of infrastructure along areas of the Norfolk coast which after decades of new developments are experiencing “offshore wind fatigue” (I5).

The diagrammatic exposition of AS at play in the UKNS can provide decision and policy makers with a distillation of what experts believe to be at the core of UKNS social-ecological dynamics. In this chapter, the focus has been on unpacking the dynamics between the offshore wind industry, coastal communities (Figure 5.8) and fisheries (Figure 5.14). As discovered through the interview process, this type of representation can be further used as a discussion object to posit and place the effects of new policy suggestions. In Figure 5.7 and Figure 5.8, a rule making AS is suggested by Interviewee 14 in dark blue: “the Crown Estate with the government could say this area of land that's seabed, that's being leased (by the offshore wind industry) - these are the areas of communities that you have to consider, you know, we've drawn the lines. They could do that.” As this policy does not currently exist, it is given a neutral effect on the AS network along with its potential outcome of collaborating between the offshore wind industry and coastal communities.

Limitations

Whilst the combined diagrams of Figure 5.8 and Figure 5.14 depict a network of AS and outcomes within the UKNS, it does not exhibit the full suite of interactions as discussed by the marine experts. The interactions not included are shown by black arrows in Figure 5.2, Figure 5.3, Figure 5.4, Figure 5.6, Figure 5.7, Figure 5.9, Figure 5.10, Figure 5.11, Figure 5.12 and Figure 5.13. The primary reason these are not included in the summary diagrams of Figure 5.8 and Figure 5.14 is that these interactions cannot be considered as linked ASs, because they are not associated with outcomes that affect other AS. Their inclusion onto one final figure would also greatly decrease the simplicity and readability of these figures, which is one of their core strengths, especially when compared to the aggregated fuzzy cognitive map in Chapter 4.

Figure 5.8 and Figure 5.14 also miss out on important AS that are present within the system but that are not discussed by the interviewees. A good example of this for fisheries lies with the primary producers of marine ecosystems. The offshore wind industry may have significant effects on their productivity which has knock on effects for the marine food web (Slavik et al., 2019).

A challenge felt by the interviewees in this study was evaluation of interactions at the scale of the UKNS. Whilst participants often knew interactions very well at the more local scales they worked at – for example of Grimsby, The Humber, or near to the Thames Estuary, there was a lot more uncertainty about how these interactions persisted or were different across the entire UKNS region. Particularly responses to questions concerning interactions of coastal communities were sometimes prefaced with comments such as "it's too big to answer" (I14) or "it's too complicated to do that" (I14). The place-based variety of coastal populations is such that interactions can differ a lot across the UK's eastern coastline. As such, to balance uncertainty with accuracy of social-ecological interactions, future studies should focus on smaller regional scales. Similarly, environmental impacts often vary at the species level (I15) and the wide variety of methods used by fisheries are impacted in different ways by offshore wind farms (I18).

A persistent difficulty with this style of research is that the data gathered here is limited to what known by these marine experts (Schlüter et al., 2019), which should not be considered a perfect reflection of what the most important social-ecological dynamics within the UKNS are. Future work could compare data from the literature with the AS in Figure 5.8 and Figure 5.14 to corroborate or challenge how the system is constituted.

Another difficulty with this form of research on dynamics is the difficulties of including spatial and temporal factors AS representations. Whilst the SE-AS format is excellent for displaying relationships at a fixed point, difficulties arise when trying to incorporate both the fast and slow changing processes of a system which interact to generate emergent phenomena (Levin et al., 2013). in individual SE-AS perceptions being harder to incorporate into the whole picture.

A significant proportion of the interviewees had more expert knowledge on the interactions between offshore wind and coastal communities which were based near to ports along the UKNS coast. Specifically, Interviewees 3, 6a and 6b spoke mostly on offshore interactions around the Grimsby and North-east Lincolnshire area. My impression across the interviews was that particularly in post-industrial areas such as these, it is perceived that locals tend to look more favourably on the prospect of more offshore developments, due to the direct positive impacts they have on employment prospects.

Across these interviews, there was less of a voice for coastal communities that do not rely as much on marine economies for their income. Further, and as previously mentioned in Chapter 3.8.2, a key stakeholder group which was not included through the course of these interviews were coastal community representatives. Future studies should prioritise sampling methods which more proactively engage community representatives, instead of relying on a purely purposive sampling approach which may inadvertently miss key groups.

5.4 Conclusion

This chapter has mobilised the social-ecological action situation framework to analyse aspects of the UK North Sea marine and coastal social-ecological system. Twelve marine experts across ten interviews discussed with me the offshore wind industry's interactions with coastal communities and fisheries. To best understand the system-wide dynamics at play, the outcomes of these key action situations, as well as the rules and conditions under which they are set, were also a focus of the analysis. These experts' social representations of the UK North Sea have revealed a complex social-ecological system, amidst a transformation wrought by the expanding offshore wind industry. No two areas within the system have a uniform reaction to offshore wind developments: whilst some communities actively seek and encourage them, others conflict with them, experiencing offshore wind fatigue at the disturbances that accompany their development. Where some inshore crab and lobster fisheries have been largely unaffected, many other fisheries have had their livelihood's threatened by displacement from or reduction of traditional fishing grounds. Governance plays an important role in encouraging offshore wind development whilst mitigating its potential adverse effects, with entities like The Crown Estate behaving with increasing awareness of the effects of this transformation.

5.5 Action Situation and Outcome Directory

*Table 5.1 Shows describes the Action Situations and gives examples of each. AS with a * symbol are newly identified in this study. Those without a star are seen in Herzog et al. (2022) and also found in this study.*

Action Situation	Description	Example (Herzog et al., 2022)	Example in UKNS
Competing	Aiming to do better than other actors, may involve interfering with their activities to reduce their performance; active demand by two or more actors or groups of actors for some environmental resource/s (Merriam Webster Dictionary)	Advertisement for lake tourism, campaigning for own action/achievements like reducing pesticide use or restoring shores	Competition between local governments and their associated local economic partnerships (I6) Competition between offshore fisheries and inshore fisheries for quota and stocks (I10)
Conflict resolution	Social interactions specifically designed to resolve conflicts	Legal procedures (law case), round tables (regular seminars), mediation between conflicting parties by an independent third actor	Offshore Wind Industry engaging in feedback processes with coastal communities during project construction (I3).
Converting	Changing sea or landscapes through technology (e.g. building a dam) or by restoring or converting use to protect eco- systems (e.g. protected areas/reserves)	Changing the lake level through dam construction, changing the littoral zone (landing stages), construction on the shoreline (building/ real estate),	Proliferation of offshore wind farms in habitats suitable for fishing, causing displacement of fishermen and/or adaptation to new

		hydrological manipulation	modes of fishing in response (I4).
Coordination	Social interactions specifically designed to support the coordinated development of strategies, plans, activities, instruments, monitoring processes, taking of measurement, etc.	Facilitation of meetings and communication channels by state offices or associations that accompany the specific task	The Crown Estate beginning to coordinate strategy through offshore wind leasing to mitigate the impacts of offshore wind developments on fisheries (I18)
Deliberating	Communicating, exchanging observations and views, reflections, assessing outcomes, persuading each other	Water associations informing their members, chambers of agriculture informing their members, deliberation within forums	Management of relationships between local fishing communities and offshore wind industry (I3).
Ecological (dis)service	Disservice brought by natural systems to human populations	Floods, pests, natural disasters	Poor weather conditions (strong wind, heavy rain) making it impossible to fish in the UKNS (I8)
Enabling *	To give the authority or means to do something (Oxford languages)	The Crown Estate enable offshore wind development in the UKNS by mapping energy potential and presenting viable leasing opportunities to energy companies (I4).	
Enforcement of rules	Monitoring the achievement of certain pre-defined goals, environmental targets etc. and procedures that assess the compliance with rules	State offices for the environment taking regular measurement of water quality, environmental NGOs counting species and	National government applies pressure through policy to The Crown Estate to help the UK reach net-zero by 2050 (I4).

	and their enforcement, and informal observation of others behaviour which might exert social pressure	reporting the numbers, state offices checking on technical standards (e.g. of sewage treatment plants) or controlling the sale of pesticides to agricultural actors, etc. Sanctions in case of non-compliance, reporting on compliance, self-reporting	
Evaluating	Evaluating outcomes of action situations	Reports of projects and council/ association meetings, independent evaluation of the implementation of measures/policy instruments by a consultancy	The Crown Estate evaluating how offshore wind expansion is affecting coastal communities, and considering inclusion of cultural values in future decision making (I4)
Harvesting	Harvesting natural resources such as fish, timber, grass, and livestock.	Fishing, drinking water extraction	Fishing in the UKNS (I8)
Impeding*	The presence of one industrial entity getting in the way of another.	Offshore wind and to a lesser extent fisheries vessels cause an increase in marine traffic, which can impede shipping activities (I18).	
Investing	Allocating financial resources to restore, conserve, or convert sea or landscapes	EU-financed projects to delineate reserves, national plans for renaturalisation of rivers and lakes	Offshore wind industry creating community funds to give to local communities (I3)

Knowledge generation	Produce knowledge regarding ecosystem dynamics and relevant to other governance functions and possibly also to operational activities	Information about ecosystem dynamics (e.g. pH-value, concentration of substances, residence time of water, etc.) to inform about lake's status and the potential measures to be taken to improve its status; about new techniques that clean a lake's waters	Production of knowledge by research communities and The Crown Estate, on social-ecological dynamics which is relevant to governance, management and industrial function. (I4)
Lobbying	Influencing political actors to follow one's own interests	Information campaigning (e.g. by Greenpeace, etc.), petitions, direct lobbying of interest groups at decision-making meetings (e.g. parliamentary sessions)	Local government receipt of inquiries from waste management projects seeking to develop sites (I6)
***Polluting**[8]	Introducing substances into ecosystems	Nutrients, plastics, inorganic compounds from agricultural, industrial, or water sewage treatment activities (private septic tanks, communal)	Noise generated by industrial activity in the UKNS, including the dredging, shipping, and offshore wind farm construction (I10)

[8] This is not a new AS, but for this study the description has been updated to include sensory pollutants such as light and noise pollution.

Predation	Individuals of one species prey on another	Zooplankton on phytoplankton, bream on zooplankton, pike on bream	Seabirds pprey on pelagic and benthic fish species in the UKNS (I10)
Promoting*	The presence of one industry within an area promoting the growth of another	Increased presence of inshore fishing in coastal communities causing an influx in tourism to that coastal community (I10, see also promoting outcome)	
Reduction	The presence of one ecological component (in a specific state, e.g. hotter, more abundant, …) reduces the capacities of another ecological component	A high amount of macrophytes in a lake ecosystem reduces the light climate within the lake	The warming effects of anthropogenic climate change causing a general migration northward of many pelagic and benthic fish species (I18)
Restructuring*	Changes in the formation of an industry and its workforce.	The growth of the offshore wind industry to larger structures further away from shore changing commuting requirements for engineers, meaning their homes and families can be based further afield (I3)	
Rule Making	Developing an operational rule, e.g. the level at which individuals can harvest a common pool resource; developing collective choice rules that determine who is involved in decision making	Supra-national directives (e.g. WFD), national and regional water law, sewage treatment regulation, policies	Obligations placed onto offshore wind developers by The Crown Estate, which require offshore wind to benefit coastal communities in more ways as part of a lease (I4).
Supporting*	Provision of aid/expertise from one entity to another in pursuit of mutually beneficial goals	Local authorities being supported by offshore wind industry in acquisition of funding for local infrastructural improvements (I3)	

Trading	Exchanging goods or services between two or more actors, selling products at markets	Fish selling (private business, cooperatives, patron-client), fishing licences, concessions to water extraction, boat-renting	The leasing of UK marine areas for industrial activity. For example, offshore wind farms, oil and gas pipelines, and moorings for nearshore leisure activities. (I4)

Table 5.2 Presents examples of outcomes of AS in this study.

Outcome	Example(s) in UKNS
Bycatching	An outcome of a harvesting AS – sea birds such as seagulls or guillemots occasionally being caught in fishing nets (I18).
Collaborating	The potential of the offshore wind industry to work coastal communities to co-design infrastructure and developments that align with what a community wants and needs (I14)
Competing	Competition between different local economic partnerships and local government councils across a region to attract big businesses such as offshore wind energy and oil and gas energy to invest in the local areas (I6).
Converting	Proliferation of offshore wind farms in areas suitable for fishing, causing displacement of fishermen and/or adaptation to new modes of fishing in response (I4). Separately, the changing of a community landscape caused by presence of new industry.
Deliberating	Local government putting forward strategic sites that suit potential big business investors, in order to advertise investment opportunities and persuade big business to invest (I6).
Employment	Increased levels of employment as a result of the expansion of the offshore wind industry (I5).
Harvesting	Fishing in the UKNS (I8)

Investing	A small reduction in investment to coastal communities caused by restructuring of offshore wind operations and maintenance centres (I3). The obligation of the offshore wind industry to provide jobs, community schemes, internship programmes, stem engagement to coastal communities they are impacting (I4).
Mutual Benefit	Both coastal communities and the offshore wind workforce that exist within and beyond them benefit from increased investment into coastal communities by offshore wind through support for local government funding acquisitions (I3).
Social Acceptance	The acceptability of industrial development such as that associated with the offshore wind industry, by coastal communities (I3).
Place Identity	A person's sense of belonging to a specific place, and how it shapes their identity. A complex concept that is influenced by a variety of factors such as physical surroundings, personal experiences, and cultural influences. In this case, the place identity of some coastal communities is influenced by the presence of the local fishing industry (I14).
Profits	A large proportion of the profits that The Crown Estate make go to the Treasury (I4).
Regenerating	Increased activity in the maritime sector leading to more employment and community benefit schemes for coastal communities, which leads to the regeneration of coastal areas near to ports (I5).
Social Acceptance	The extent to which a coastal community approves of and supports offshore wind developments in their area, based off how it contributes to, impacts and effects a place (I3).
Sparing	Social outcomes (e.g. a measure) that wilfully care for or ameliorate ecological component's states (Herzog et al., 2022). For example, reduction of wind farm site boundaries away from a marine protected area (MPA), changing the height of turbine blades to reduce bird collision risk, soft start piling to scare away marine species before they get hurt by noise, or more effectively burying cables to reduce electromagnetic field effects (I19). Additionally,

	increased conservation efforts for benthic invertebrates due to research presence/dissemination and increased awareness of ecological disasters (I14).
Species-habitat interaction	The integrity of the seabed affects the ability of benthic fish and invertebrates to thrive and procreate (I10).
Trading	Fish selling from inshore and offshore fisheries to seafood processors and markets, and on to exports and the national populace (I8).

Chapter 6: Modelling Offshore Wind Industry Expansion Scenarios

After a brief network structural analysis, this chapter displays the results of an offshore wind expansion scenarios analysis, which was completed using a fuzzy cognitive map (FCM) based on the UK North Sea (UKNS) social-ecological system. The FCM is based on the results presented Chapters 4 and 5 of this thesis, which gathered and mapped expert social perceptions of the interactions between different entities (synonymous with components in this chapter) in the region. Four scenarios are modelled and compared: a baseline scenario (A), in which the offshore wind industry interacts freely with other components of the system; a scenario in which offshore wind stops expanding (B); one in which offshore wind expands to a 2030 prediction from Renewable UK (EnergyPulse, 2024) (C); and one in which offshore wind expands to the government's 2050 target (ENTSO-E, 2024) (D).

6.1 Structural Comparison of Aura CDT FCM and Expert Augmented FCM

Table 6.1 shows the differences in the structural properties of the aggregated Aura CDT FCM from Chapter 4, and the marine expert augmented FCM from this chapter (see section 4.2.2.for a description of these structural properties). Thirteen new components were incorporated by the marine experts, alongside 79 new connections (Table 6.1). The density of the maps is similar (Aura CDT had a density of 0.064, which was slightly higher than the expert augmented FCM density of 0.059), suggesting that an overall low level of connectivity between UKNS components has been retained. Despite this, there is an increase in the connections per component (up to 4.04 from 3.58) (Table 6.1), which suggests that that addition of expert insights has increased the interconnectedness of the system.

The expert augmented FCM had one more driving component, and three fewer receiving components than the Aura CDT FCM (Table 6.1). This is reflected in its complexity ratio of 1.75, which suggests a lower overall complexity than the Aura CDT FCM. However, the largest disparity in components between the two FCM is in the number of ordinary components, which have both positive indegree and outdegree (section 4.2.2). The expert augmented FCM has 13 more ordinary components than the Aura CDT FCM (Table 6.1). This reflects how most of the new components incorporated to the FCM through the marine expert interview analyses were considered interconnected parts of the system i.e., both affecting and being affected by other UKNS entities.

Table 6.1 Comparison of structural properties of Aura CDT FCM (Chapter 4) and expert augmented FCM (this chapter)

Name of structural property	Aura CDT FCM value	expert augmented FCM value
Number of Components (N)	57	70
Number of Connections (L)	204	283
Density (L/N²)	0.064	0.059
Connections per component	3.58	4.04
Driving Components	7	8
Receiving Components	17	14
Ordinary Components	33	46
Complexity (receiving/driving)	2.4	1.75

The centrality of each component within the expert augmented FCM shows how connected different components are. The centrality scores of many components have changed due to the inclusion of the perceptions of UKNS experts on top of the Aura CDT data from Chapter 4 (which were originally displayed in section 4.4.2). Figure 6.1 compares the new centralities of components in the expert augmented FCM with those which were generated by just Aura CDT in Chapter 4. It reveals an overall trend of increased centrality for many UKNS entities. The most central component, the offshore wind industry, has marginally increased centrality within the system, up to 20.85 from 19.68. Inshore fisheries have become the second most central entity, up to 11.79 from 8.48, reflecting my targeting of fisheries experts for the second stage of research. For the same reason, the centrality of coastal communities in the system has increased from 5.25 to 8.26, moving from the 12th to the 7th most central component. Of the components with higher centrality, national government and anthropogenic climate change have the largest centrality decreases, dropping from 9.95 to 7.61 and 8.60 to 7.45 respectively (Figure 6.1). Both of these entities have seen reductions in their centrality due to the changes and reductions in weightings applied to them by Chapter 5's marine experts. For national government in particular, this reduction could be due to the more nuanced perceptions of the marine experts who had more awareness of certain bodies within and associated with national government, such as DEFRA, DESNZ or the MMO. Knowledge of these bodies revealed that their strategic goals (i.e. protect the environment versus expand the blue economy) were sometimes at odds with one another and could even cancel each other out when it comes to weighting of national government interactions.

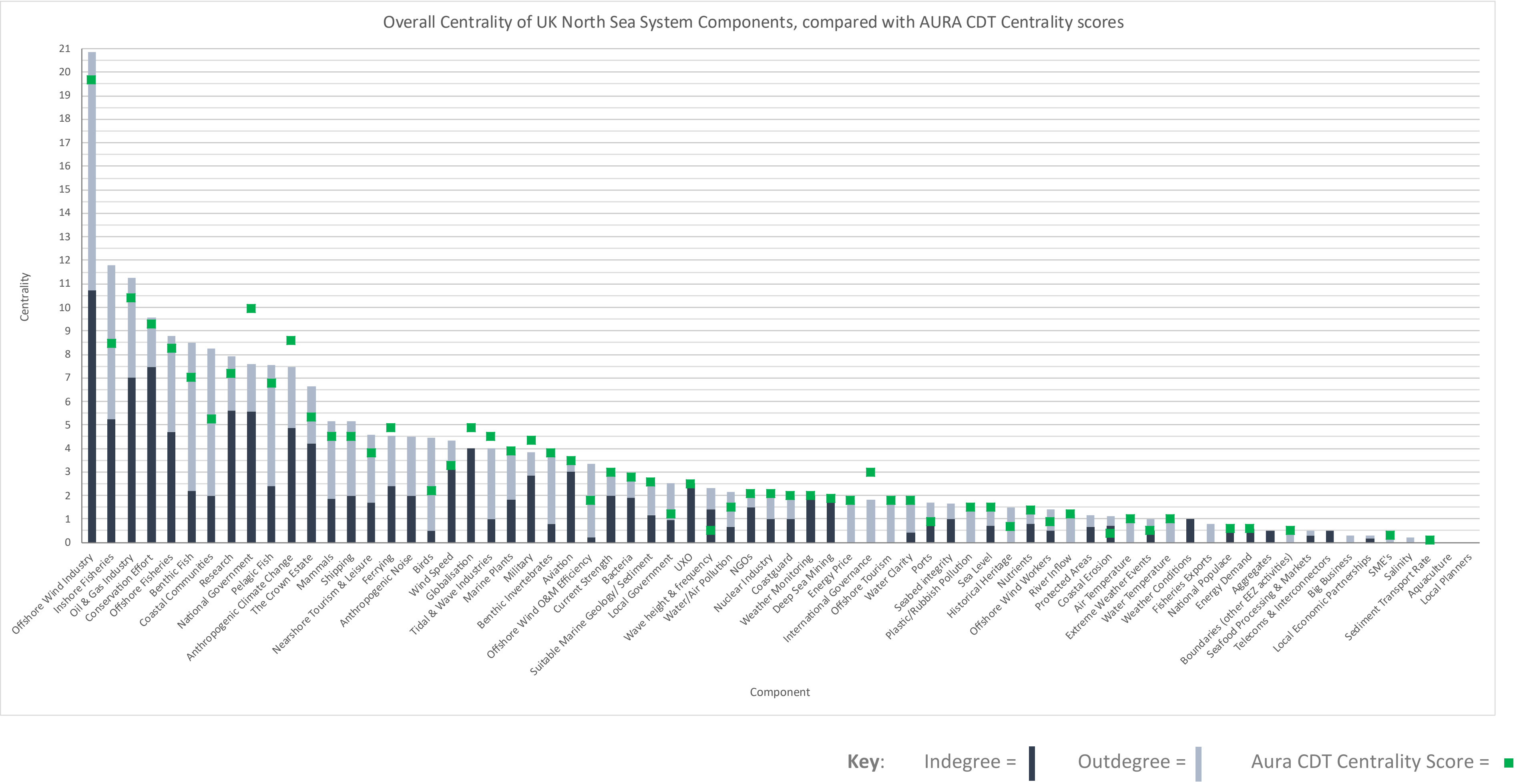


Figure 6.1 Stacked column chart to show the centrality of each UKNS component in the expert augmented fuzzy cognitive map. Green squares represent the centrality scores generated from Aura CDT data in Chapter 4, and are added as a point of comparison between the original and expert augmented datasets.

6.2 Expert Modelling Results

6.2.1 Scenario development

FCM can be used to ask what emergent properties of a system occur under different conditions (Özesmi & Özesmi, 2004). Model runs under different parameters can determine how the state of the system varies when 'what if' questions are posed to it. In this thesis, the overriding question is: 'what if offshore wind expands in the UK North Sea to its predicted and proposed levels?' As of 2024, offshore wind energy installed capacity in UK Seas was 14.7GW, with EnergyPulse, RenewableUKs market intelligence service, forecasting 41.5GW by 2030 (EnergyPulse, 2025). This falls below the UK government's 2030 target for 50GW of UK offshore wind energy (DESNZ, 2023). The non-binding goal set by the UK for 2050 is 96.9GW of offshore wind energy (ENTSO-E, 2024). These statistics have been collated and presented as four scenarios in Table 6.2.

Table 6.2 Four scenarios for future UK offshore wind capacity in GW. Different expansion scenarios refer to proportionate activation levels. In scenario A, the activation level for offshore wind energy capacity is left to evolve based on input from other entities within the UKNS system. In all other scenarios, the offshore wind energy activation level is fixed at a certain number to reflect an expansion scenario.

Scenario	GW in UK Waters	Initial Activation Level
A: Unsupervised	14.7 (initially)	0.15, allowed to vary
B: Offshore wind stagnation	14.7	0.15, static
C: Offshore wind capacity hits 2030 prediction	41.5	0.43, static
D: Ambitious offshore wind 2050 target is reached	96.9	1.00, static

6.2.2 Unsupervised scenario A

Figure 6.2 shows the unsupervised outputs of the combined FCM, which is informed by the perceptions of Aura CDT students whose results are discussed in Chapter 4, supplemented with the marine expert perceptions from Chapter 5. Unsupervised here means the model is left to interact freely, unlike in later scenarios where the offshore wind industry is given a fixed activation level. The activation levels broadly represent the abundance of each component within the system, within a range of [0,1]. Zero represents a component's minimum extent, and one represents its maximum possible extent. Initial activation levels were determined through a literature review process (see Chapter 3 Appendix X) because there was not time to discuss them in focus groups and interviews. When the scenario A model was run, component activation levels mostly stabilised by the fifth timestep, with full stability achieved by the ninth (Figure 6.2). This shows that with all activation levels and interactions weighted as they are, the system tends towards one of a multiple of possible states (Folke, 2006). The system's state is defined by the stabilised component activation levels that are the outputs of the modelled scenario. Because this is a relational model, how long this stabilisation takes cannot be specified. It can only be stated that it takes few iterations for this model to reach equilibrium.

The limits of this modelling technique in depicting a complex adaptive system (CAS) should be outlined: the FCM cannot incorporate adaptive responses to the feedbacks from interactions between its components (Preiser et al., 2018). Also, though some attempts are made to incorporate larger (typically slower) external and smaller (typically faster) nested social-ecological structures into the FCM, the model cannot be considered to incorporate cross-scale, non-linear dynamics (Preiser et al., 2018; Gunderson & Holling, 2002) – the model is focussed to the regional scale, largely summarising the individual agents that are its base constituents (Levin et al., 2013), and the larger scale interactions beyond the system that could influence its dynamics. Not being able to include these CAS qualities could explain why the system reaches equilibrium after only nine timesteps.

Seventy distinct components are displayed in Figure 6.2. Because they cannot be distinguished from one another by colour alone, lines representing components of focus for this thesis have been made bolder and dotted. These components are Fisheries, Offshore Wind, fish and invertebrates of the marine ecosystem, and Coastal Communities, which were the focus much of the marine expertise drawn upon in Chapter 5. The full dataset produced for this chapter is available in Appendix XII.

A key feature of the scenario A results is that the system is perceived to be geared towards a significant expansion of the offshore wind industry (Figure 6.2, red dotted line). By the 4th timestep, despite starting from a relatively low abundance of 0.15, offshore wind has reached an activation level of 0.91, which signifies a very high abundance of offshore wind energy in the UKNS (equivalent to 87.2GW UK seas installed offshore wind capacity, according to conversion of activation levels Appendix XI).

Of the other entities of most interest, coastal communities (pink dotted line), offshore fisheries (purple dotted line), and benthic invertebrates (green dotted line) also experience varying increases in activation level (Figure 6.2). Purely from this figure, the causes of these increases cannot be discerned, but are reliably based on the social perception of marine experts.

The activation level of inshore fisheries (Figure 6.2, orange dotted line) experiences a brief increase from 0.17 before dropping back down to 0.16 at the end of the simulation. Similarly, benthic fish (Figure 6.2, yellow dotted line) experience a temporary increase before an overall reduction in activation level, from 0.27 to 0.16 with a maximum of 0.33. Decreases in abundance of several key components (i.e. pelagic and benthic fish groups, invertebrates, inshore fisheries) between A1 and A2 timesteps in Figure 6.2 follow on from an overall increase in the average activation level across all components between A0 and A1, suggesting the presence of growth-based trade-offs within the system that limit abundances of some components.

Whilst many changes in activation level align with expected changes, several components change unexpectedly within the system, confirming gaps in the range of perceptions of some components. Examples include: Ferrying, whose abundance is based on quantity of UK domestic sea passengers per year (see Appendix XI for glossary) drops significantly from 0.88 to 0.36; and Birds, whose abundance increases from 0.71 to 0.90, despite their known current vulnerability to cumulative stressors in the marine environment (Stanbury et al., 2024).

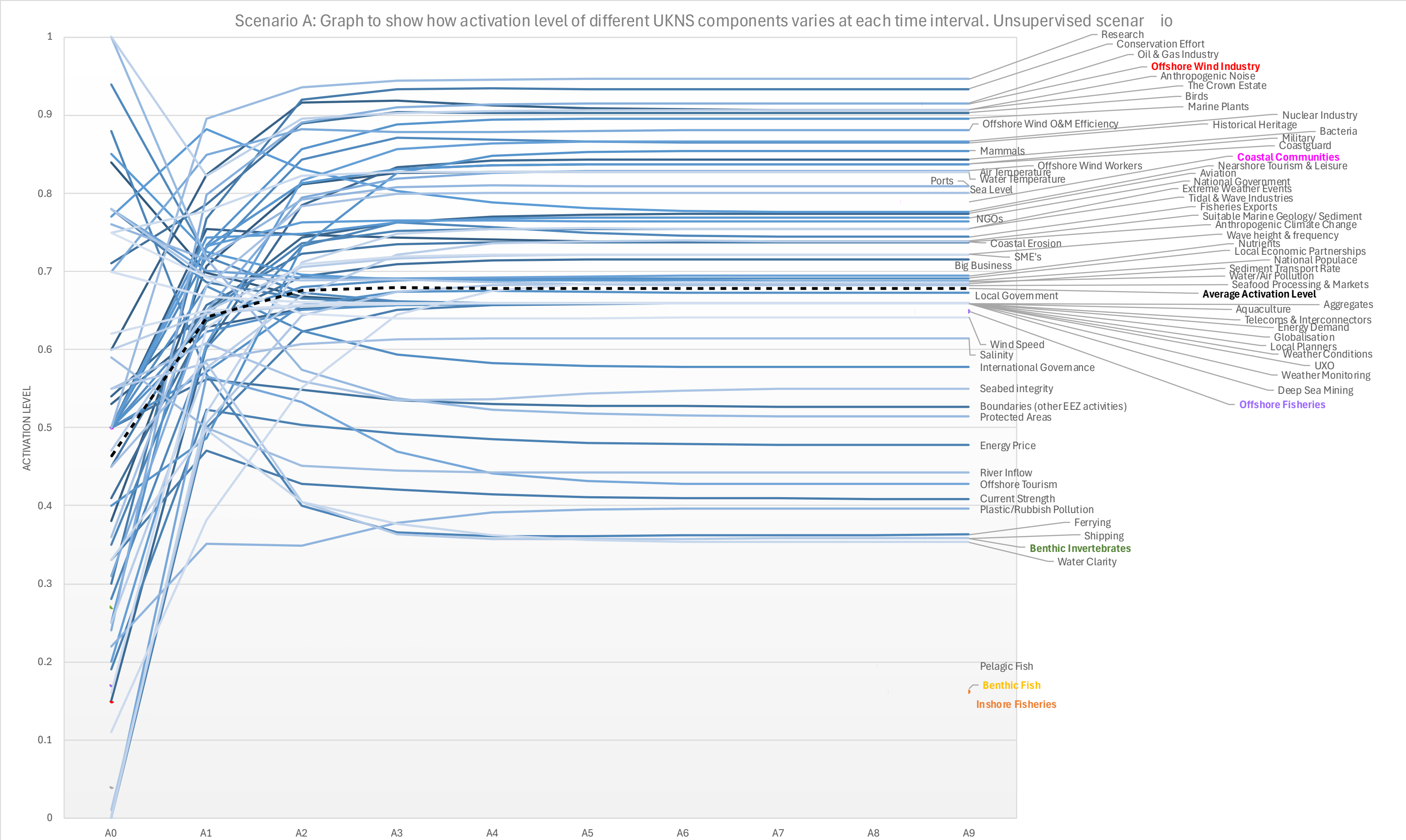


Figure 6.2 FCM outputs in a baseline run, with no activation levels altered. Shows the evolution of the UKNS towards a basin of attraction after nine timesteps. The change in activation level for most system components are shaded in blue. Components with most relevance to the discussion have been highlighted by coloured dotted lines. The average activation level is signified by a dashed black line.

6.2.3 Comparison of modelled scenarios

In unsupervised scenario A, the outcome activation level of offshore wind (0.91) is closest in value to the fixed activation level ascribed to scenario D. Comparing the outcome activation levels of all other UKNS components between scenarios A and D revealed only very small differences of no more than 0.01 in the outcome activation levels of each component. Hence, the unsupervised FCM predicts - based on socially represented interactions and entities within the UKNS system - that something approaching the largest offshore wind industry expansion in this area (scenario D) is feasible. Consequent to the similarities between scenarios A and D, I only needed to use one for more extensive inter-scenario comparison. I chose to use D because it directly represents the maximum predicted offshore wind industry expansion target, whereas A only very nearly represents this.

By comparing the activation level results of scenario B with those of scenarios C and D, the relative change in overall activation level of UKNS components under differing offshore wind expansion scenarios can be displayed (Figure 6.3). Across all components which experience change in their activation levels, scenario D shows a greater change then scenario C. This difference between scenario outputs is not directly proportional to the offshore wind industry activation level changes: the changes in component activation levels between scenarios C and D as compared with scenario B vary between -2.00 and 5.00 (Figure 6.4). This is consistent with the presence of non-linear dynamics, which are a hallmark of CAS (Preiser et al., 2018).

Figure 6.3 shows that the largest reductions due to expansions of the offshore wind industry occur in the following components: energy price (C: -0.05, D: -0.14), current strength (C: -0.05, D: -0.14), and protected areas (C: -0.05, D: -0.14). Negative relative changes as a result of offshore wind expansion were also experienced in shipping (C: -0.04, D: -0.11), offshore fisheries (C: -0.03, D: -0.11), suitable marine geology and sediment for offshore wind infrastructure (C: -0.03, D: -0.09), water clarity (C: -0.03, D: -0.09) and inshore fisheries (C: -0.03, D: -0.08). The strongest positive relative changes are in local government (C: 0.04, D: 0.12) and aviation (C: 0.04, D: 0.10) followed by ports (C: 0.03, D: 0.08), offshore wind operations and maintenance efficiency (C: 0.03, D: 0.07), offshore wind workers (C: 0.02, D: 0.06) and The Crown Estate (C: 0.02, D: 0.06).

Many components of the UKNS system that had been classed as ecological (Chapter 4) appear to show little relative change in abundance due to offshore wind expansion, with components belonging to commercially fished species (pelagic and benthic fish) changing very little. Benthic invertebrates see a small upturn (C: 0.01, D: 0.03) while marine birds see a small downturn (C: -0.01, D: -0.02). The modest effect size could be due to the complex interactions occurring between offshore wind and fisheries, which have been investigated more fully in Chapter 5.3.3.

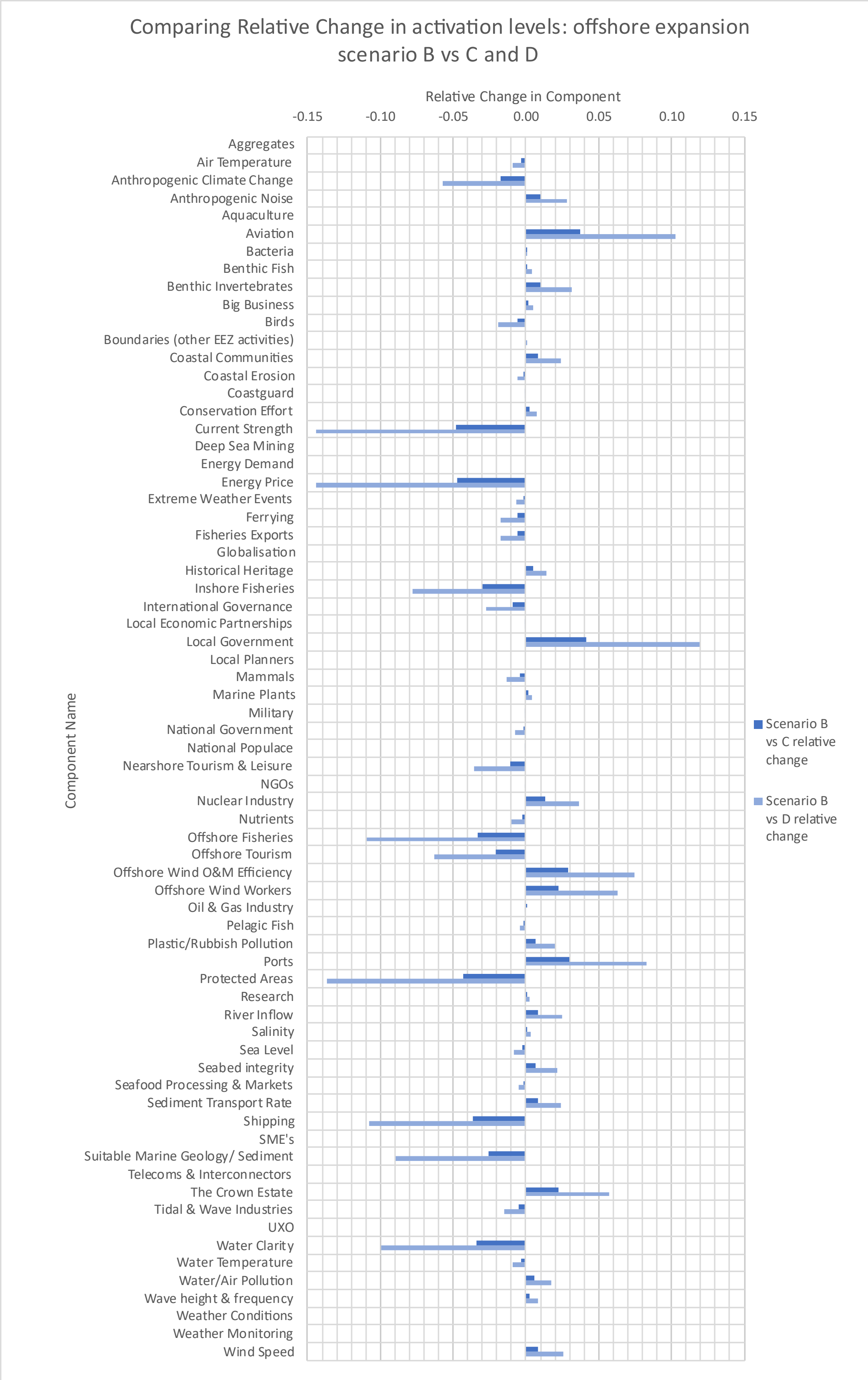


Figure 6.3 The relative change in activation level between scenarios C (2030 offshore wind expansion forecast) and D (2050 offshore wind target) as compared to scenario B (no further offshore wind expansion).

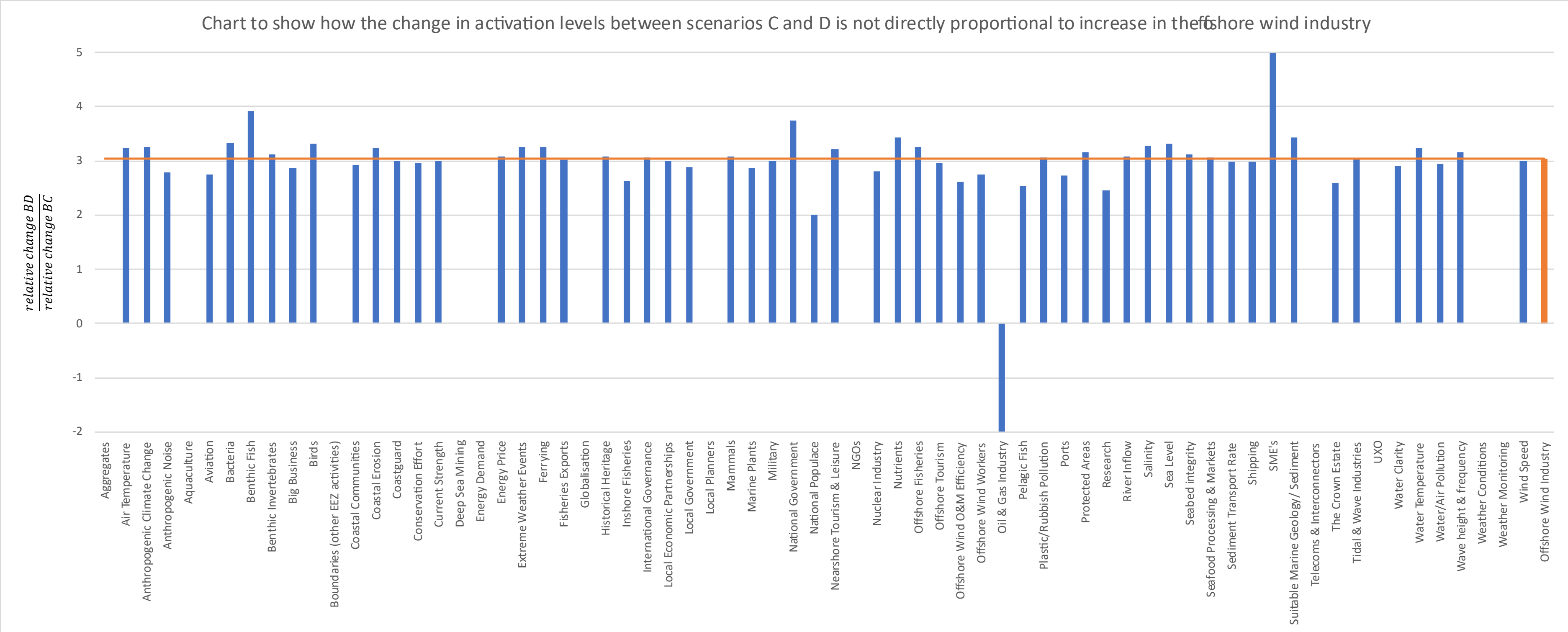


Figure 6.4 This chart shows the relative change in activation levels of each component between offshore wind expansion scenarios C and D . The orange bar and line represent the proportional increase of the offshore wind industry (3.04). To obtain all other values, the model outputs for each component as displayed in Figure 6.3 are divided by one another.

6.3 Discussion of Modelled Results

6.3.1 Structural differences between Aura CDT and expert augmented FCMs

Contrary to my expectations, the expert augmented FCM shows lower structural complexity than the Aura CDT FCM, because it has fewer receiving components, and one more driving component. Fewer receiving components indicate an FCM that considers fewer outcomes and implications that are a result of the system (Eden et al. 1992; Özesmi & Özesmi, 2004). This structural calculation for complexity is difficult to reconcile with the much broader concept of complexity itself, which is a scientific amalgam of ideas based around the word's Latin origin '*complexus*' – which means what is woven together (Preiser et al., 2021). Unlike receiving and driving components, ordinary components both affect and are affected by other entities of a system (Papageorgiou & Kontogianni, 2012). They exhibit a hallmark of complexity: interconnectivity (Preiser et al., 2021). The expert augmented FCM has more ordinary components than the Aura CDT FCM and could be considered to have more complexity based on the metric of interconnectedness. Overall, according to structural properties laid out by Özesmi & Özesmi (2004), the expert augmented FCM has lower complexity than the original Aura CDT FCM. However, I disagree with this structural evaluation of the FCMs, based on a broader understanding of complexity which is inclusive of interconnectivity, as well as my own experience of incorporating a lot of complex information into the expert augmented FCM.

To expand on interconnectivity, the augmented FCM had significantly more connections per component than the Aura CDT FCM. That the addition of more knowledge increased the connectivity of the system poses a question about how many expert perspectives should be added to an FCM before it is developed enough to inform marine decision makers. There is likely an efficiency trade-off between capturing the core dynamics of a system, and incorporating the right number of new perspectives on component interactions. In Chapter 3.5.2, following the accumulation curve method laid out by Özesmi & Özesmi (2004), I predicted that only two additional components were likely to be added to the data with inclusion of the fifth focus group's FCM. In this chapter, the predicted trend of very few new components per interview was followed: across 10 interviews, 13 new components were added to expert augmented FCM. Despite these additions, there are more connections per component, which suggests that the addition of new connections in each interview does not level off at the same rate as the addition of new components. Given that in social-ecological systems research there is an emphasis on understanding the interactions of entities over the entities themselves (Preiser et al., 2018), perhaps accumulation curves to define optimal sample size should be based on connections as opposed to components.

Another index of connectivity, the density, remains broadly the same across the two FCMs at around 0.06, which could hint that the optimal balance had already been reached after the focus group stage (Chapter 4). What the structural analysis overlooks, however, is the quality of the data captured at each stage of the research. In the first round of data capture, participants were highly educated marine science generalists with a proclivity towards offshore wind. In the second round of data collection, marine experts were challenged to distil the core interactions of entities they have a wealth of direct experience with. A strength of a multi-stage data gathering technique, such as the one used here, is that system scoping provides a skeletal structure that can be tested and built upon through a more focussed and in-depth second stage.

6.3.2 Modelling

The modelled outputs of the FCM co-created by Aura CDT and marine experts have brought together social perceptions of UKNS system dynamics, and have provided an idea of how those dynamics might unfold under four scenarios: one unsupervised, one representing offshore wind stagnation, and two portraying offshore wind expansion (Table 6.2). The FCM required little processing power to run, and although the data is geared more towards understanding the offshore wind industry's effects, it could feasibly be used to test other scenarios such as decreases in fish stocks, changes in conservation effort, or increased effects of anthropogenic climate change. Furthermore, it would be straightforward to incorporate more data into this FCM, either from further focus groups or interviews (designed around the methods specified in Chapter 3), or from other data sources, such as other academic literature or gathering of reports and data (for example, The Crown Estate (a), n.d.; Ecowind, n.d.). The social-ecological dynamics bought together for the UKNS can also be applied to other parts of the North Sea or indeed other sea basins, provided some re-evaluation of present entities, connections, weightings and activation levels occurs.

The modelled results help to answer the second RQ of this thesis, "How might these (UKNS) linkages interact together to generate emergent properties of the expansion of the offshore wind industry in the UK North Sea?" (Chapter 1). Expansion of the offshore wind industry is perceived to change several properties of the UKNS social-ecological system – changing bio-physical conditions by reducing current strength and decreasing water clarity; applying significant pressure to inshore fisheries (currently) and offshore fisheries (further into the future), as well as shipping routes and the cover of marine protected areas; increasing investment into ports and providing overall marginal benefits to coastal communities. Relative change to marine fish and invertebrate populations as a result of offshore wind expansion are low in the scenario outcomes, which masks the interplays between fisheries, offshore wind, and commercial marine species which are discussed at more length in Chapter 5. Importantly, these findings paint an overall picture of the perceived changes due to offshore wind expansion, but do not highlight the placed-based variety of effects that this expansion will cause. For example, the same offshore wind developments might affect neighbouring coastal communities in different ways depending on their associated characteristics (Devine-Wright & Howes, 2010; I14). Similarly, the variation in the size and catch methods used by inshore fisheries means that offshore wind developments impact their activities in different ways and to varying extents (I18; Hooper et al., 2018).

On the extent to which this gathering and modelling of knowledge reflects reality: Projecting the future adaptive steps entities of this real-world complex system will take is not possible through this method – data on how the type and strength of effect between different UKNS entities will change beyond the near future exists only in uncertain speculations. The complex adaptive system modelled in Figure 6.2 reaches a stable state after nine timesteps, though realistically weightings and abundances of interconnections and components would keep the system in a state of some flux. Additionally, the interactions that play out in this UKNS FCM focus on one layer of a Panarchy which is composed of several nested scales of adaptive cycle (Gunderson and Holling, 2002). 'Remember' and 'revolt' processes undoubtedly affect this complex system from both higher and lower scales, and although my methods allowed the influences of some larger-scale entities - such as anthropogenic climate change and international governance – to be incorporated, summarising small-scale effects through this process has proven challenging, especially for experts with deep and nuanced knowledge of interactions (e.g. I3, I10, I14).

Whilst many of the outputs of the comparative graph Figure 6.3 align with scientific data on offshore wind industry interactions, some component responses to offshore wind expansion are strange. Some of these could be artefacts of different interpretations of what a component symbolises within the system. For example, Figure 6.3 shows that increased offshore wind expansion leads to a reduction in anthropogenic climate change. From a scientific perspective, there is nuance here, because the production of offshore wind energy still produces some anthropogenic CO_2 emissions (Reimers et al., 2014). However, the socially perceived effects of more offshore wind energy production are a decrease in fossil fuel production and a reduction in overall greenhouse gas emissions. The plurality of ways that an increase in anthropogenic climate change has been defined in this case led to a questionable perception of what the component truly means. This inconsistency could have knock-on effects for how other components react to the offshore wind industry's expansion, namely in how marine biota respond to anthropogenic climate change if according to social perception, anthropogenic climate change is reduced by offshore wind energy. The narrative that expansion of renewable energies such as offshore wind are transitioning us away from anthropogenic climate change - as has been perceived by participants in this thesis - is being challenged by a critique of the energy transition which says that lower carbon energy sources supplement high carbon sources instead of replacing them (Fressoz, 2024). Comparing a subjective social representation of the UKNS system with objective scientific evidence of interactions that are taking place could provide opportunities for resource managers such as the MMO to compare their views of how a system is functioning with the views of stakeholders who interact within the system, as has been highlighted by (Herzog et al., 2022).

Other socially perceived component responses to offshore wind expansion are directly incongruent with scientific understanding. This study’s modelled results show wind speed marginally increasing (C: 0.02, D: 0.04) with further expansions to the offshore wind industry. This is contrary to the academic literature, which describes how wake effects caused by turbines and turbine arrays can lower local wind speeds many kilometres downstream of a windfarm (Christiansen et al., 2005; Cao et al., 2023). Importantly, this FCM has no direct link between offshore wind energy and wind speed – it was not mentioned by experts throughout the data gathering phases of this thesis. Instead, it is linked to offshore wind through current strength during the focus groups. Basing the entire model on social perceptions has its strengths, but in some cases contributes to an incompleteness of this map of social-ecological dynamics.

Additionally, the locational bias of experts is more prevalent in these results in certain nodes. For example, local governance has the largest of all relative increases to its activation level as a result of offshore wind expansion. Interviewees 6a and 6b (Chapter 5), who talked from a local governance perspective on the relationship with the marine environment, may have influenced this finding with their firsthand experience of how the presence of the offshore wind industry can benefit local governance. Grimsby, in the Humber region, is a case study for how offshore wind can positively affect local governance efforts and benefit coastal communities (Laister, 2019; Wakeling, 2024). Whilst their social perceptions are real and based on experience in some places, they are perhaps not reflective of the local governance-offshore wind interaction experienced across the UKNS seaboard. The Norfolk coast, in contrast to Grimsby, has seen strong opposition to offshore wind developments from the local parish council level, undoubtedly amounting to negative impacts onto many local governance entities (Anderson, 2021; Adams, 2021). Using relatively few expert perceptions to summarise the social-ecological interactions across a large and varied region such as the UKNS may not be a fair summation of how some interactions are socially perceived. To counteract biases introduced in this way, future studies should either work across smaller areas, or utilise a wider range of participants.

Incorporating some data from Chapters 4 and 5 into the fuzzy cognitive map for this chapter proved challenging. The way that FCM works relies on the multiplication of component weights and activation levels. More fundamentally, FCM relies on informal causal reasoning – pushing us to conceive of a system as constructed purely in terms of cause and effect (Carvalho, 2013). Through this thesis, I have found this conception of a system breaks down where important interactions are weighted neutrally. When the weight assigned to a link is neutral (i.e. 0), the interaction is completely lost to the model (as activation level multiplied by 0 = 0). In Chapter 4, some weights were given neutral scores to represent effects that participants knew existed, but were not aware of what an appropriate weighting could be because of the complex dynamics involved in the interaction. Focus group 2, for example, thought that increasing temperatures would have some effect on wind speeds in the UKNS, but assigned a neutral weighting for uncertainty on what that effect was. In Chapter 5, neutral weightings were given for action situations such as national government making rules for The Crown Estate. The action takes place, but it is not considered beneficial or detrimental to The Crown Estate because The Crown Estate works for the Treasury, and so any rules or policies set form part of the inherent obligation The Crown Estate is set up to fulfil (I4). FCM meets another limit when complex interactions are too difficult to fairly summarise through a semi-quantitative arrow between two nodes. Whilst in Chapter 5 I used the SE-AS framework to challenge this limitation by distilling interactions through the lens of the action situation, I still think there is scope for future work to more beneficially couple these methods, especially in preparation for use by marine managers.

Given the ambiguity of some of the model outputs, future studies using this approach might benefit from the higher levels of confidence in models that come with conducting a sensitivity analysis. Baker et al. (2018) highlight the exclusion of sensitivity analysis from most FCM studies as a critical issue to the FCM approach. As previously discussed, relying on expert opinion in FCM has associated drawbacks – biases and non-intuitive translation of knowledge, for example – which could necessitate sensitivity and uncertainty analyses. For this and other FCM studies, a sensitivity analysis could be conducted by generating a uniform distribution of the range of plausible initial activation levels and connection weightings of all components and connections to obtain a distribution of relative change for each of them. Then one could investigate how frequently the distributions align with model outcomes to assess confidence in the model results, which would determine how sensitive the model is to changes in its input values. A sensitivity analysis could have been a benefit to this study, by numerically displaying confidence in the FCM outputs. However, as they have so infrequently accompanied FCM in the past, I did not consider their potential benefits until late in the thesis. Additionally, they are a complex and a highly computationally intensive undertaking - a standard network modelling approach here would suggest modelling 100,000 different sets of interaction weightings (Baker et al., 2018) – which would have required time beyond the thesis limits to enact. An alternative approach which could also increase confidence in model outputs would be to utilise unsupervised or supervised learning algorithms available through the FCM Expert interface (Nápoles et al., 2018).

6.4 Conclusion

This chapter has combined the results of two rounds of data collection and analysis into one expert augmented semi-quantitative fuzzy cognitive map, which numerically summarises complex causal relationships between different entities of the UKNS social-ecological system. The expert augmented fuzzy cognitive map had 13 more entities and 79 more linkages, but broadly maintained similar structural characteristics to the Aura CDT fuzzy cognitive map - high complexity and low connectivity. The relational accuracy was improved through overwriting scoping stage model characteristics with marine expert perceptions on complex social-ecological relationships. However, some fringe properties of the SES were still shown to be inaccurately perceived when compared to the scientific literature.

Four scenarios for offshore wind expansion were modelled using FCM - one unsupervised (A) and three within which offshore wind industry abundance was fixed to: 2024 capacity (B), 2030 predicted capacity (C), and to 2050 target capacity (D). In scenario A offshore wind capacity increases to nearly the maximum possible abundance, almost mirroring scenario D. This suggests that the UKNS is perceived by participants to be arranged to encourage continued offshore wind expansion – even though factors beyond the system boundaries, such as supply chain capabilities or fluctuations in political will, may inhibit this process. By comparing the results of fixed scenarios B, C and D, emergent properties of the UKNS social-ecological system that result from offshore wind industry expansion were revealed. These changes included reductions in current strength and water clarity, as well as pressure onto inshore fisheries (currently), offshore fisheries (further into the future), shipping routes and marine protected areas. This inter-scenario comparison also predicts marginal overall benefits to coastal communities and increased port investment to accompany offshore wind expansion. The benefits of a systems-based approach to understanding marine regions are exemplified by the modelled outcomes for marine fish and invertebrates: although offshore wind developments are perceived to be directly detrimental to these groups, the overall outcome of offshore wind expansion is neutral on them because of the reduction in fishing effort that occurs in and around offshore wind developments.

Due to time limitations for Chapter 5 data, there was a paucity in marine expert data that focusses on the oil and gas industry and base elements of the marine ecosystem. To paint a more holistic picture of the effects of offshore wind expansion, future work should seek to incorporate these entities more deeply into the marine social-ecological system of the UKNS.

A challenge for this research lay in incorporating neutrally and variably effecting AS data from the SE-AS frameworks in Chapter 5 into Aura CDTs aggregated fuzzy cognitive map from Chapter 4. In some cases, this resulted in loss in depth of data. This was partially rectified by evidencing FCM weightings with transcript excerpts (Appendix XII), but future studies using FCM for SES research should look into methodological improvements which allow nodes and weightings to exhibit complex adaptive system properties, such as neutral and variable interactions, cross-scale interactions, and adaptive responses to changing properties of the system.

Chapter 7: Conclusions

This final chapter begins with a summary of how the empirical work and findings of this thesis fulfil RO2 of constructing a marine social-ecological relational model of the UK North Sea (UKNS). The remaining majority of this conclusion is then split into two parts. Firstly, I discuss the potential contribution of the thesis findings to the UK marine spatial planning (MSP) process. This is done by outlining statutory marine spatial planning mechanisms relevant to the UKNS, before applying findings from the thesis to critique the incompatibilities of some marine management objectives. I then outline the potential benefits of combining a relational social-ecological systems-based approach with The Crown Estate's established RIO tool for marine planning. In the second discussion section, I use the thesis outcomes to contribute to geographical perspectives on a sustainable blue economy, summarising how a systems-based perspective can aid the ongoing transformation towards a sustainable blue economy for offshore wind. I highlight some of the blue injustices present within the UKNS that my SES research has revealed, and how some injustices are obfuscated by a focus on regional vs. local scale interactions. Next, I outline how my offshore wind centred research lends weight to looking at the transformation to a sustainable blue economy through the lens of a blue fix. Finally, I suggest lines for future enquiry, such as the possible contributions of 'assemblage thinking' to social-ecological research via the incorporation of future novelties or inclusion of more conceptual qualities of a system.

7.1 Summary of main empirical findings

I set out in this thesis to portray the social and the ecological aspects of the UK North Sea as interwoven – as a complex adaptive system in the throes of great change wrought by a multiplicity of anthropological interventions. Amidst an ongoing transformation away from sector-based management strategies towards a whole-system view, I sought to apply interdisciplinary SES frameworks to an emergent phenomenon that is reshaping the UKNS. The offshore wind industry's expansion in this area is powered by dual threats at larger scales than the study area: the need to move away from fossil fuel-based energy to reach net zero carbon emissions, thus reducing the impacts of anthropogenic climate change; and more recently, the increasing need for national energy security exemplified by the price shock due to loss of Russian gas supply to the European energy system as a result of the war in Ukraine. Consequent to these very real threats, successive governments have incentivised and supported rapid offshore wind expansion, with little consideration for how this expansion could affect the system it is built within. This is not a thesis designed to uncover the 'dirty secrets' of an industry and thus slow its progress – global crises bought on by previous capitalist expansions and restructurings are too great a threat. Rather, this thesis has sought to analyse the system-wide effects of offshore wind expansion to provide marine managers with a picture of the trajectories arising from current interactions in the system, so that they can plan adaptively and effectively in the transformation to a sustainable blue economy.

Across three empirical chapters, I have shown that the UKNS is perceived by marine experts to be a complex, social-ecological system, whose entities are interconnected both directly and indirectly to one another across a relational network. In the systems scoping stage (Chapter 4) participants of Aura Centre for Doctoral Training (CDT) worked in focus groups to identify, categorise, map the linkages between different UKNS social-ecological entities through fuzzy cognitive mapping (FCM), and outline entities' relative power and interest in the expansion of the offshore wind industry using power-interest matrices. Because it forms a significant part of their eclectic research interests, the offshore wind industry was perceived by the focus groups to be central to interactions in this region, being consistently described as the most affected and effecting entity across the system. At the sacrifice of some holism, the bias of the focus groups guided the social-ecological analysis towards the offshore wind industry. Other industrial and political entities, such as the oil and gas industry and national government, tended to be perceived as both powerful and central to the aggregated fuzzy cognitive map. Structurally, the students produced a complex fuzzy cognitive map that had low overall connectivity. With 57 nodes and 204 connections, the aggregated map was visually indigestible, limiting its use in conveying an assemblage of relationships

There were inter-focus group disagreements on some of the linkages of the FCM, which informed the research direction for the second stage of research (Chapter 5), identifying relationships of high complexity and uncertainty which warranted deeper investigation. Only two of four of these relationships were researched further due to time constraints: I focused on the relationships of the offshore wind industry with fisheries and with coastal communities due to the quality and quantity of interviews which directly related to these themes. To structure this deeper investigation - the 'diving' stage of the thesis - the social-ecological action situations framework was used to distil key entities, interactions and outcomes in a digestible yet descriptive way.

Chapters 4 and 5 deliver RO1 by describing the linkages between offshore wind energy and other social, economic, and ecological components that act within the UK North Sea. My analysis of relational linkages is based on data generated in two related ways. The first was focus group data (Chapter 4) in the form of five transcripts and sets of fuzzy cognitive maps and power-interest matrices. These were designed to scope the range of entities and interactions at work within the system. The second dataset was 22 marine expert interview transcripts (Chapter 5). They were based on discussions focussed onto the nuances of interactions between key entities of the UKNS, and 10 of them were analysed to produce several sets of linked social-ecological action situations (SE-AS). Together, these two datasets were used to answer RQ1: "What are the linkages between different components of the UK North Sea social-ecological system, especially with relation to the offshore wind industry?" The natural bias of Aura CDT students towards the offshore wind industry helped steer the direction of inquiry in the intended direction.

All empirical chapters contributed to RO2 - to generate a unitless, relational network map of the intertwined UKNS social-ecological system. In Chapter 4, I aggregated the fuzzy cognitive maps produced by four focus groups together (after Olazbel et al., 2018), producing a signed and weighted digraph[9] with 54 entities and 207 connections, which depicts a relational network of UKNS interactions. I analysed the structure of this network and used to the most variably perceived linkages to inform the research direction of Chapter 5. In Chapter 5, I produced a series of relational networks based off expert interviews, under the structure of the social-ecological action situations framework (Schlüter et al., 2019). I linked action situations together into two summary diagrams which showed the intertwined states of coastal communities and fisheries with regards to the offshore wind industry and other relevant UKNS components. In Chapter 6, I combined all the relational data from previous empirical chapters together into one final notated fuzzy cognitive map (Appendix X).

I achieved the third objective of this research, modelling and comparing the relational effects of offshore wind expansion in the UKNS across several scenarios using the fuzzy cognitive map produced in Chapter 6. By developing an understanding of which entities would be adversely and beneficially affected across these scenarios, I have been able to predict some emergent regional-scale properties of the UKNS system due to offshore wind expansion, which are summarised in Chapter 6 (section 6.4.2). These emergent properties form the answer to my second research question.

Together, these empirical chapters provide the substance for this concluding chapter's discussions. In the next section (7.2), I discuss the potential of SES analysis for MSP in this region, thus providing an answer to RQ3. Then, to realise RO4 (and answer RQ4), the proceeding section (0) outlines how

[9] A digraph consists of a collection of nodes (components) connected by edges (effects) into a network (Kosko, 1986). The sign and weighting of the effect from one component to another represent the type and strength of effect.

my social-ecological analysis of offshore wind expansion can give weight to geographical perspectives on the transformation towards a sustainable blue economy.

7.2 Application of Findings to Marine Spatial Planning

MSP offers a set of tools to balance the management aims of economic development, social value and ecological conservation (Trouillet, 2020) - see Chapter 2 (2.2). In this section I consider how SES and the relational framework developed in my thesis may have practical use for MSP, thus forming an answer to RQ3: "How could social-ecological perspectives complement the marine spatial planning process in the UK North Sea?" (Chapter 1). While my data do not perfectly conform to any single marine plan in the UKNS, many of the social-ecological interactions outlined in Chapters 4-6 occur within all existing plan areas.

7.2.1 Incorporating interactions into MSP for offshore wind energy

The thesis findings are useful for marine planners, because they confirm the system-wide relational implications of marine objectives and plan policies for the offshore wind industry. To show this, I will focus on the East Offshore and East Inshore marine plan areas, which take up a significant part of the study area (all relevant MSP areas to the study area are detailed in Figure 1.1 and Table 1.1). Plan policies[10] related to offshore wind objectives[11] across these plan areas only suggest some interactions of offshore wind energy with other marine uses. For example, the plan policy to support proposals in the East marine plan areas which contribute to offshore wind energy generation is linked with supporting plan policies, such as the maximisation of coexistence and the protection of ports (MMO & Defra, 2014). The FCM has revealed a greater diversity of plan-scale interactions between the offshore wind industry and other UKNS entities than these linked planning policies suggest. Offshore wind expansion could, for example, result in further reductions to inshore and offshore fisheries (Chapter 6), which goes against fishing plan policies in the same marine plan, which are currently designed to allow development proposals to go ahead so long as adverse impacts to fisheries are minimised or mitigated (MMO & Defra, 2014). As well as mapping the incongruencies of plan policies, this could be used to show how objectives from one aspect of a

[10] Plan policies are often accompanied by maps to show the extent of where a given plan policy is and or will be relevant. Where there is a paucity in data, best approximations are used.

[11] Objective 3 of these plans is "to realise sustainably the potential of renewable energy, particularly offshore wind farms, which is likely to be the most significant transformational economic activity over the next 20 years in the East marine plan areas, helping to achieve the United Kingdom's energy security and carbon reduction objectives." (MMO & Defra, 2014, p.26).

given plan push against or work alongside others. For example, in the East Marine plan, Objective 8 aims “to support the objectives of Marine Protected Areas” (MMO & Defra, 2014, p.28) which according to FCM modelling results (Chapter 6), is not cohesive with Objective 3’s sustainable realisation of the potential of offshore wind farms. Objective 3 is however conducive to Objective 2 - “supporting activities that create employment at all levels” (MMO & Defra, 2014, p.26), according to moderate increases in the wellbeing of coastal communities as a result of offshore wind expansion in the modelled FCM results, alongside expert perspectives laid out through the social-ecological action situations framework in Chapter 5. New iterations of marine plans could better take account of the priority of offshore wind development by reflecting the anticipated effects of its expansion through alteration of other objectives and plan policies.

At its core, the social-ecological perspective developed throughout this thesis could serve the MSP process by incorporating relational complexity into plan level management decisions, therefore being more aware of the system-wide implications of offshore wind industry expansion in the UKNS. Specifically, use of FCM, which can model the indirect and to an extent cumulative effects of changes to the marine environment could complement established MSP tools used for UK seas. In their supporting evidence for the East marine plans, MMO (2014a, p. 205) state that “the implications of the interaction between a range of activities, and between that range of activities taken together and sustainability considerations, is integral to marine planning”. In 2014, they did endeavour to take a plurality of interactions into account, by mapping marine activities and environmental characteristics using sensitivity analyses across a few case study areas and for a few marine sectors. The current MSP process is far more rigorous. Though many groups contribute to it, The Crown Estate (TCE), who own and manage the seabed, stand out as generators and sharers of marine data which contribute to the statutory marine planning process (The Crown Estate (b), n.d.)[12]. Of specific relevance to this thesis, they have also produced their own in-house GIS-based MSP tools to inform marine planning decisions. The principal tool is a resource identification and optimisation (RIO) software tool (I1), which brings together spatial datasets from an array of different topics to identify and evaluate all constraints on the seabed (Esri UK, 2025). Through analytical hierarchical processing – where different constraint factors are given different but comparable weightings and scores (Brunelli, 2014) – TCE create heatmaps to show high and low constraint areas (1km^2 hexes) for specific sectors, such as the offshore wind industry (I1). These are combined with feasibility and cost maps to reveal the best areas for development according to different scenarios. Together, this

[12] TCE host the marine data exchange, are a competent authority for habitats and regulation assessment, and organise seabed leasing for marine activities such as offshore wind energy and aggregate extraction. They are also noted as a public authority in the UK Marine Policy Statement (Defra et al., 2011).

process constitutes TCE's "whole of seabed programme" (The Crown Estate, 2024), whose evidence is fed to statutory marine planners – MMO – to inform marine spatial plans (I1). To illustrate a use of the combined tool, an interviewee (I1) gave the example of using scenario modelling to see how costs would change if offshore wind developments were built at the lowest constraint areas (I1).

There are methodological similarities between the RIO tool and what I have achieved through this thesis. The fuzzy weighting of different constraints for RIO can be compared to the weighting of different effects that took place as the fuzzy cognitive map was being developed. Additionally, scenario modelling is used in both RIO and FCM approaches to try to predict outcomes of decisions taken in the marine environment. Though not discussed in our interview (and not researchable within the bounds of this thesis due to it being an in-house tool) I suspect that RIO specifically uses fuzzy analytical hierarchical processing (explained by de Korvin & Kleyle, 1999) in cases where the relative strength of constraints is unclear due to lack of evidence. This would mean that my approach and the RIO approach also share in the use of fuzzy logic. Beyond these similarities, the whole of seabed approach through the RIO tool and the approach taken in this thesis are compared in Table 7.1:

Table 7.1 Comparison of TCE's RIO tool to support decision making with the approach used in thesis, which incorporated the SE-AS framework into FCM. Information on RIO is gleaned from I1.

RIO tool – whole of seabed approach	Thesis approach (FCM & SE-AS framework)
• $1km^2$ spatial resolution	• No explicitly spatial data. Spatial variety of interactions acknowledged through SE-AS process
• Uses weighted feasibility, cost and constraint data from a range of sources. Focus on feasibility of and incompatibilities between marine entities	• Uses weighted relational data based on expert social perceptions. Focus on interactions of marine entities, both beneficial and detrimental
• Can inform both project (local) and plan (regional) level management decisions	• Can inform plan (regional) level management decisions
• Produces spatial recommendations for marine use through scenario modelling	• Produces emergent outcomes of anticipated offshore wind expansion through scenario modelling
• Cannot capture cumulative effects	• Can capture and bring together expert perceptions of cumulative effects
	• Does incorporate feedbacks

• Does not incorporate feedbacks • In-house tool which requires licencing, not open access, and requires expertise to use • Some difficulty in incorporating social value	• Open access, FCM digraph design easy to understand. Uses freely available software • Incorporation of social value through mechanism of data collection

This comparison highlights where the different approaches vary, but also shows where they can be complementary. For example, the RIO tool has strength in spatial resolution, while the thesis approach does not. This allows RIO to inform planning at the scale of local projects as well as the regional plan scale, whilst the thesis approach is only able to inform the overall outcomes of the marine planning objective of offshore wind energy expansion at the plan scale (MMO & Defra, 2014). The thesis approach could complement RIO is in its ability to outline interactions beyond those which would constrain other marine activities. Unlike RIO, this thesis approach can incorporate fuzzy cumulative effects of a range of interactions between marine social-ecological entities, weigh those interactions against one another and map feedbacks. It provides a means to map expert perceptions of system dynamics, and allows for more incorporation of social values to outputs, by using Likert-style scales to bring together quantitative and qualitative data into a semi-quantitative form.

One uncertainty lies in how useful FCM outputs are to decision makers and stakeholders, given their unitless dimensions of relative change. However, relative changes in component activation level can be re-aligned with data from which the initial activation level was deduced to produce more meaningful outputs to stakeholders. For example, in Chapter 6, between scenarios B (offshore wind stagnation) and D (offshore wind reaches 2050 target), the resultant relative increase in activation level of the ports component is +0.08 (from 0.76 to 0.84). By realigning this output with the data gathered in Appendix XI, it can be calculated that this equates to an additional £4 billion per year turnover in UK ports. The caveats to deductions like this lies in the quality of the data that initial activation levels have been calculated from (the data on ports, for example, is a UK wide as opposed to a UKNS specific dataset), as well as that the interaction weightings themselves are socially perceived by marine experts.

What has been achieved through FCM in this thesis has potential to complement established tools such as RIO, because it has been shown to fill certain gaps in their capabilities (Table 7.1). This must be conditioned with the fact that through this thesis, and especially in Chapter 5, there are areas of higher focus, such as coastal communities and fisheries, but also areas that in the interest of available time were not included to the extent that they should be, such as ecosystem dynamics and oil and gas industry interactions. If used by a public body like TCE, an FCM approach should seek input from a wider range of marine experts than I have been able to achieve in this thesis, to ensure a comprehensive enough balance of perspectives is achieved.

7.3 Offshore Wind Towards a Sustainable Blue Economy

Though in the last couple of years use of the term blue economy has taken precedence over blue growth, the concepts had previously been used synonymously by policymakers since their emergence in the mid-2010s (Germond-Duret et al., 2023) to represent the possible contribution aquatic and marine spaces can make to human wellbeing (Martinez-Vasquez et al., 2021). Much like blue growth (Chapter 2), blue economy's diverse interpretations allowed its co-optation by marine users of differing ideologies and visions. Both terms have their roots in sustainable development, with a core vision to unlock opportunities for economy and society whilst protecting and enhancing marine environments (Niner et al., 2022). Marine policy objectives and research is evolving rapidly[13]. Recent objectives - like blue growth and blue economy - are being eclipsed by objectives for a sustainable blue economy. This underlines a shift in tone, from blue growth and its openness to a range of interpretations by different stakeholders (Chapter 2, Eikeset et al., 2018), to something more explicitly inclusive of sustainability. Based on the European green deal and the recovery plan for Europe, the European Commission now advocates for a shift from blue growth to a *sustainable* blue economy, because "(t)he outdated notion that environmental protection conflicts with the economy is giving way to the realisation that, especially in the maritime industry, the environment and the economy are intrinsically linked" (European Commission, 2021, p.2). This indicates increasing recognition that overexploitation of oceanic resources jeopardises the oceans life-sustaining ability to provide food, economic benefits and environmental services to society (Martinez-Vasquez et al., 2021). Considering this shift in rhetoric, I discuss here how the thesis findings could complement research in geography and the wider social sciences on the transformation towards a sustainable blue economy, from the more conceptually ambiguous blue growth/ blue economy base.

[13] In June 2025 I attended the One Ocean Science Congress (OOSC) in Nice, France. There, amongst 619 other posters, I exhibited my own thesis outline, entitled "Assessing Blue Growth in the UK North Sea", with some preliminary ideas about how more of the social-ecological perspective could contribute to our understanding of the blue growth concept. I quickly learnt a lesson about the pace of change in marine research – finding that I was one of only a few delegates still using the term blue growth. In conversation about this with other academics, I was told it has dropped out of use because of growth connotations that are misaligned with the sustainable bounds of ocean use

This discussion answers the fourth RQ (see Chapter 1) by applying social-ecological systems (SES) learning from this thesis to some critical geographical debates on blue growth and the blue economy, within the context of the UK North Sea (UKNS). It begins by outlining how the SES research undertaken in this thesis shows how some blue injustices have accompanied offshore wind expansion in the UKNS, before explaining how narrowing the scale of focus has inadvertently obfuscated blue injustices. Research findings are then operationalised to lend weight to the reframing of a sustainable blue economy towards a blue fix. Finally, potential links between assemblage thinking and SES are outlined and posed as way to pursue (and extend) the whole system approach that grounds the social-ecological research field.

7.3.1 Reconfigured resource use and consequent 'blue injustices'

A systems-based perspective – as developed in this thesis - can benefit the transformation to a sustainable blue economy by revealing the effects that a reconfiguration of marine space such as offshore wind expansion can have. Blue growth was predicated on the idea that the blue economy could continue to expand without impacting planetary sustainability, by decoupling GDP from two core threats to the marine environment: resource use and greenhouse gas emissions (Ertör & Hadjimichael, 2020). It pitted resource use and environmental management as opposing forces, that could be made to co-exist within the marine realm if technological advancements could lessen or remove the negative effects of industrial development from the equation. Marine renewable energy, the vast majority of which is currently generated through offshore wind, is one of the major blue growth sectors of the European blue economy (European Commission, 2025). Its expansion is the result of an impressive series of technological advancements that have opened vast swathes of shelf sea for economic development. The offshore wind industry is also decoupled from locally extractive resource use, and partially from CO_2 emissions (Wang et al., 2019). Together, these qualities mean that offshore wind energy production is a significant step toward fulfilling the core aims of blue growth. However, in a sustainable blue economy, the marine environment is reframed as being intrinsically linked with the blue economy, being an essential unit upon which it is built.

Some of the social-ecological interconnectedness of the UKNS system is displayed through the findings of this thesis, and its inclusion in marine governance decisions is important for understanding how offshore wind expansion affects the sustainability of marine activity and resource use across other parts of this complex adaptive system. My research – using both FCM and the SE-AS framework - highlights elements of potential injustice at the heart of the blue economy, as wind energy development expands on the UKNS. I have combined expert perceptions to uncover how the offshore wind industry is altering a marine social-ecological system as it expands at the regional scale of the UKNS. Chapter 5, which summarised complex linkages between UKNS entities through the lens of the SE-AS framework, showed that the expansion of this industry is converting the seascape in ways that are detrimental to inshore fisheries, causing displacement and consequent overcrowding of adjacent fishing grounds, limiting available fishing methods, increasing subsurface and navigational hazards, increasing fuel costs and risks to safety and wellbeing of fishers (I18; I15). These impacts of offshore wind development onto fisheries both displace and undermine the livelihoods of small-scale fishers, two of ten themes of marine social injustice identified by Bennett et al. (2020). Bennett et al. (2020) call for blue justice to be at the centre of any agenda for blue growth, but suggest that this may require a complete rethinking or transformation of blue growth itself. As mentioned earlier in this discussion, the EU also aims to transform from blue growth into a sustainable blue economy. However, there are only a few incorporations of blue justice into this transformation: the promotion and support of fisheries local action groups, and use of the European Maritime Aquaculture and Fisheries Fund to adopt different fishing techniques (European Commission, 2021). Regardless of policy change, SE-AS described in Chapter 5 depict an adaptive response by fisherman to the powerlessness they felt in the face of UKNS offshore wind expansion: by lobbying TCE, who are responsible for offshore wind leasing, they have made this marine landowner increasingly aware of the effects these developments have on fisheries (I18). Consequently, the modern offshore wind leasing process is more considerate of fisheries activity (I18). Offshore wind developers have also adapted as the awareness of the detriments to fishers that their developments can cause proliferated. Larger developments now employ commercial fisheries leads, or even fisheries liaisons teams, to facilitate communication between developers and fishers and mitigate more of their adverse effects (I3; I18). These ongoing adaptations paint a picture of a system undergoing transformation by working to overcome Bennett et al.'s (2020) tenth theme of blue justice: exclusion from decision making and governance. As I18 pointed out however, many changes have come too late for inshore fishers impacted by the earlier offshore wind development rounds in the UKNS. The interactions between offshore wind and some inshore fisheries in the UKNS inadvertently wrought blue injustices to small-scale, inshore fishermen. The lessons learnt and adaptations made through this process will disproportionately favour offshore fisheries, because the spatial trajectories of future offshore wind developments are further into the offshore (Rodrigues et al., 2015).

7.3.2 Multi-scalar limits of the SE-AS framework and FCM

The presence, abundance and interactions of each entity in the linked UKNS system varies greatly at smaller scales, with interactions at the local scale contributing to emergent properties of the regional picture. These multi-scalar properties of complex adaptive systems are, however, difficult to include through use of the SE-AS framework. Through the lens of entities, interactions and outcomes, the SE-AS diagrams I produced in Chapter 5 summarise the interconnectivity of different UKNS entities, whose placed-based variety generates an array of possible ASs. This worked well to digestibly distil which complex interactions are taking place across the area, as promised by Herzog et al. (2022), but I found its capacities were limited when accommodating for scale. The thesis, which has been focussed to a regional scale, includes details of differences in interactions at the local scale, but has somewhat brushed over how local scales interconnectivities between entities such as communities, ecologies and inshore fisheries combine to produce emergent regional scale interactions.

Scale is important for understanding how CAS of interest are themselves interconnected. In Chapter 2, I reviewed how CAS are formed of nested sets of adaptive cycles that function at different scales, from individual, to group, to community, to region and upwards – thus together forming a Panarchy (Gunderson and Holling, 2002). My own research revealed some nested properties of the UKNS system, especially between the community or local scale, and the regional UKNS scale. Whilst my research methods captured the range of these properties in the SE-AS framework, it proved much more difficult to evaluate their overall effect at the regional scale with FCM. My linked SE-AS show that the socio-cultural effects of offshore wind developments onto coastal communities are diverse: from helping local government to regenerate post-industrial coastal communities through investment and job provision, thereby reinventing a place's story and identity (I6), to coastal communities experiencing "offshore wind fatigue" due to disruptions caused by cable corridors, construction and converter stations (I5). The latter experience of offshore wind development is also marked by Bennett et al. (2020) as a blue injustice – undermining access to marine resources for wellbeing. In the FCM, this variety is summarised by a single weighted value of 0.16 (a weak positive effect) – an average of five marine expert perceptions that each fuzzily evaluate how a variety of local scale interactions produce an emergent effect between two entities.

A range of local interactions contribute to the overall emergent relationships between the offshore wind industry, fisheries and marine fish species and invertebrates in the UKNS. More frequently, this interaction raises concerns of blue injustice for fisheries. Offshore wind developments affect fisheries differently depending on the fishing methods employed in a given area. Post construction, pot fishers are largely unaffected by the presence of offshore wind farms (I18; Roach & Cohen, 2017), but trawl fisheries are locally banned to protect submarine cables (I6) and bottom drifting fisheries are simply unable to carry out a fishing method because of the configuration of a turbine array relative to tidal flow directions (I18). Additional to this varied interaction, and outlined by SE-

AS framework, are further complexities between offshore wind, fisheries, and fish species. Offshore wind development causes overall declines in abundance of fish species, but effects are varied according to location and species (I15). The negative impacts of offshore wind development onto pelagic and benthic fish species can be locally outweighed by positive impacts from the prohibition of trawling in the same area (I10).

Clearly then, these social-ecological interactions vary at the scale of local interactions within the UKNS. It fell to the interviewed marine experts to draw together their knowledge of the range of interactions at the local scale to informedly assign overall interactions between entities at the regional scale. Evaluating these interactions was an exercise towards deduction of emergent properties of the UKNS system - a key feature of CAS research (Schlüter et al., 2019). By linking the properties of interactions between two entities into the wider networked system through the SE-AS framework, I have been able to display some of the regional emergent properties of the system itself. This has come at the cost of smoothing the local diversity of interactions, which could act to hide or undermine aforementioned social and environmental blue injustices that have emerged at the local scale.

7.3.3 From sustainable blue economy to the blue fix

The social-ecological, whole system approach taken in this thesis allows me to illustrate how the expansion of the offshore wind industry should be conceived as a blue fix on the route to a sustainable blue economy, as opposed to a fully realised solution for it. As reviewed in Chapter 2 (2.3.2), one reconceptualisation of blue growth is the blue fix (Brent et al., 2020). The continued expansion of the offshore wind industry in the UKNS marine environment is a reworking of the use and control of ocean space (Brent et al., 2020) – changing who has ownership of and rights over marine areas (Chapter 2.3.3) This reconfiguration of space means that more intensive forms of capital accumulation can take place in the UKNS, which carries benefits and drawbacks. In Chapter 6, I combined SE-AS framework data from Chapter 5 with FCM data from the scoping analysis in Chapter 4 to produce a semi-quantitative network model that combined the social perceptions of expert focus groups and interviewees. Running this model under different offshore wind expansion scenarios revealed which entities benefit from and are disadvantaged by this changing UKNS property – in essence identifying what is fixed and what is driven closer to breaking through offshore wind development. The model predicts that marine protected areas, fisheries (both inshore and offshore, with offshore more strongly affected in the maximum expansion scenario) and shipping will be negatively influenced by offshore wind expansion. This highlights that trade-offs are to be expected in this restructuring of capital in the UKNS, and suggests that this blue energy fix could be a contributor to emergent social crises in other parts of the social-ecological system.

7.4 Future research

There are many opportunities for future research, and here I briefly outline three: greater inclusion of larger scales than the UKNS system, the ecological knock-on effects of changing UKNS conditions, and challenging the bounds of what is included in SES with assemblage thinking. Firstly, whilst this thesis is focussed on the regional scale, one should not discount the effects from higher scales, classed in the social-ecological literature as remember effects (Figure 2.1B) – which draw on the potential and context from the system memory at larger and slower scales (Ammar, 2021). A larger scale system that fell outside the research bounds of this thesis (although it was mentioned in interviews e.g. I4) is the global supply chain associated with offshore wind, whose component construction is still based in resource extraction which contributes greenhouse gas emissions amongst other pollution (Li et al., 2022). In their bibliometric analysis of blue economy and related terms, Martinez-Vasquez et al. (2021) find that incorporation of circular economies through supply chains into blue growth sectors is key in achieving a sustainable blue economy. Because of the focus I have had on complementing MSP - which works within politically defined spatially-bounded systems – the scale of the supply chain was not included within this thesis. Future research should look at how larger scale supply chain structures influence the transformation to a sustainable blue economy. Relatedly, macroeconomic relationships that exist between UKNS industrial entities could be incorporated into linkages in future research. For example, Qu et al. (2021) find that as offshore wind expands in Scotland, it can bid away production factors from the seafood sector, thus negatively impacting fisheries.

In future related work, more attention should be given to ecological knock-on effects of changes to marine environment conditions, because they can inform us of ecological crises that emerge as a result of socio-ecological fixes (Ekers & Prudham, 2015). Changes in some UKNS physical conditions due to offshore wind expansion are shown through the modelled results, such as anticipated reductions to current strength and water clarity. However, the knock-on effects of these changing qualities onto marine ecosystems were not discussed in focus groups, or in the interviews that were analysed. Consequently, they are not factored into the FCM or SE-AS frameworks. With regards to changes in currents and circulation, Dorrell et al. (2022) show that offshore wind infrastructure affects mixing in seasonally stratified shelf seas which are present in the northern North Sea, and suggest that this may affect primary production – the basis of marine food webs. To similar effect, Opdal et al. (2019) have shown that North Sea water clarity has been declining during the 20th century, which has strongly delayed the timings of phytoplankton blooms. Offshore wind infrastructure causes increased sediment suspension, potentially causing further reductions in water clarity, and the cumulative effects of these phenomena on primary producers are unknown.

The SES methods and frameworks used in this thesis have been used to describe and combine an array of socio-spatial relations, providing a means to understand how UKNS components are assembled around an expanding offshore wind industry. There are similarities between thinking in terms of SES and assemblage thinking[14], with the latter challenging the bounds of what could and should be included within SES studies. Winder and Le Heron (2017) challenged the geographical community to apply assemblage thinking to the blue economy, based on "the planetary reality that every economic project is axiomatically a biological project, with some economic aspects" (Winder & Le Heron, 2017, p.1), which follows a similar line of logic to the sustainable blue economy – i.e., recognition that overexploitation of oceanic resources jeopardises the ocean's life-sustaining ability to provide food, economic benefits and environmental services to society (Martinez-Vasquez et al., 2021). Conceptualising the UKNS system as an assemblage can help to challenge the bounds of the SES approach I have followed in this thesis, but for future work, there is a trade-off between what could and what should possibly be included in the assemblage. First, FCM modelling – a widely used SES method – shies away from consideration of imagined futures, despite a core factor of CAS being adaptive capacity – adaptation over time in response to feedbacks between system elements (Preiser et al., 2018). FCM cannot effectively factor in projects that are only now being formulated, especially those which involve technological advancements. For example, an original entity in the Aura CDT FCMs from Chapter 4 is Tidal & Wave Industries. Although not formally removed, some interviewees (I15, I10) expressed doubts at these technologically immature industries being active in the UKNS. Despite this, the European Commission (2021) expect tidal, wave, thermal and floating offshore wind energy to reach commercial maturity in the early 2030s. Assemblage thinking challenges its users to look beyond current interactions to imagined future interactions (Winder & Le Heron, 2017), whereas FCM encourages participants to describe current social-ecological configurations, leaving no space for informed speculation. This did not stop some interviewees from speculating about which trends might evolve – for example, as wind energy moves further offshore, I3 suggested that coastal communities will receive fewer direct economic benefits, whilst I18 posited that offshore fisheries will more frequently come into conflict with offshore wind developers.

[14] A diversely used descriptor, ethos and concept used to aid in the analysis of socio-spatial relations, whose broad purpose is to understand assembling as a process whereby heterogeneous elements form and reform into emergent, non-homogeneous groupings (Anderson and McFarlane, 2011)

Another push for FCM and SE-AS to think more in terms of assemblage is in embracing the conceptual aspects of systems alongside the social-ecological entities that inhabit them, thus increasing their conceptual fluidity and compositional diversity (Winder & Le Heron, 2017). In FCM, this is limited by the fact that entities within the network must be able to rise and fall in value in some way in response to receiving effects from other entities – which is a requisite because of the basis of causality in FCM (Napoles et al., 2017). Consequently, important concepts are tacked onto FCM with their complex relationships to the rest of the system undermined. In Chapter 4, Historical Heritage and Research were two conceptual system elements which embodied this difficulty – whose inclusion was important to focus group participants, but whose incorporation into a fuzzy cognitive map format was challenging. The SE-AS framework (Chapter 5) allowed for greater conceptual fluidity, by allowing descriptive representations of interactions in graphical form which explain the complexity of an interaction between concepts and entities without having to assign a value for strength of effect. This allowed for a synopsis of a complex social-ecological system, with the caveat that scenario modelling using the SE-AS framework was not possible as it was through FCM.

Finding ways to incorporate assemblage thinking into SES methods could help to further widen the conceptual pool that SES draws from, and could prove to be a fruitful avenue for future research in marine SESs. However, trade-offs are likely to exist between how much compositional diversity can be included in SES, and how much effort is required by researchers to include it.

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Appendices

The range of resources developed and used for data gathering and analysis in this thesis can be found in the Durham Collections data repository by following this link: https://doi.org/10.15128/r2wd375w388

Each appendix is associated with one or more files within the above store. Appendix I is associated with the file that begins “App_01”, and so on.

Appendix I

Focus Group Structure (for Facilitator use)

Appendix II

Focus Group Participant Information Sheet

Appendix III

Focus Group Consent Form

Appendix IV

Aura Focus Group Powerpoint

Appendix V

Combined Focus Group Component Homogenisation Spreadsheet

Appendix VI

Aura FCM Component Glossary

Appendix VII

R Code for Building and Collapsing Combined Matrix Data

Based on Olazbel et al. (2018). Compatible with R version 4.3.3 (2024-02-29 ucrt) -- "Angel Food Cake". 64-bit. FCM matrices must be combined into 1 excel workbook to be read and used by this code, such as in file ‘App_7 FCMmatrices’ .

Appendix VIII

Generic Structure for Marine Expert Interview

Appendix IX

Transcript Analysis Examples

Appendix X

MentalModeler Fuzzy Cognitive Maps

Start with instruction file: ‘App_10 Begin Here’.

Appendix XI

Expert Augmented FCM Component Glossary

This glossary contains the names and associated abbreviations of the components of the combined FCM used in Chapter 6, as well as activation levels as calculated by minimum, maximum and current/average scores. Each activation level has been calculated based on associated references, which were found following web-based literature searches with research assistance using ChatGPT.

Appendix XII

Expert Augmented FCM Model Outputs