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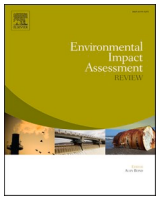

Cumulative effects of offshore renewables: From pragmatic policies to holistic marine spatial planning tools

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ABSTRACT

To alleviate climate change consequences, the UK government is pioneering offshore renewable energy developments at an ever-increasing pace. The North Sea is a dynamic ecosystem with strong bottom-up/top-down natural and anthropogenic drivers facing rapid climate change impacts. To ensure the compatibility of such large-scale developments with nature conservation obligations, regulatory processes set out that all effects need to be evaluated through cumulative impact assessments (CIA). However, by excluding climate change impacts and bottom-up effects of renewable developments, the CIA lacks spatio-temporal baselines linking oceanic ecosystem indicators to population dynamics, leading to uncertain predictions at population levels. CIA is currently required in Europe under the Strategic Environmental Assessment and the Marine Strategy Framework Directive (MSFD), suggesting that these two policy areas should be more closely aligned. This study presents an overview of the current CIA policy framework, enabling an ecosystem-based approach linking lower ecosystem components to top-predator populations using the UK as a case study. At the UK level, CIA requirements mirror the EU ones under the Marine and Coastal Access Act, the UK Marine Policy Statement, and the UK National Policy Statement. Firstly, we show how CIA and MSFD requirements are integrated into the UK licensing and maritime planning frameworks. Secondly, we provide policy pathways embedding the MSFD as a baseline for CIAs with European and UK regulations. Thirdly, we propose a framework encompassing a shared monitoring effort, an ecosystem modelling approach connected with two existing online databases supported with funds from Contracts for Difference. This integrated approach will enable a holistic and pragmatic ecosystem-based framework for more accurate and rapid methods for producing CIAs for offshore renewable energy developments.

1. Introduction

European and United Kingdom (UK) governments are pioneering rapid large-scale offshore wind (OW) energy developments to mitigate climate change consequences. Almost 20 Gigawatts (GW) of OW are produced in the North Sea across nations sharing it, representing almost 79% of European OW capacities. Today, the UK delivers 10.5 GW of OW energy in the North Sea (Europe, 2020). By 2030, European governments aim to produce 99 GW of OW, including the UK government delivering 50 GW using fixed OW and 1 GW of floating OW (HM Department for Business Energy and Industrial Strategy, 2021).

The North Sea is a dynamic ecosystem facing rapid climate change (Mahaffey et al., 2020). This ecosystem is driven by strong bottom-up forces defined by climatic effects (e.g. temperatures affecting plankton and fish population dynamics) and top-down control induced by anthropogenic pressures (e.g. fisheries removing large predators, e.g. cod, *Gadus morhua*) (Mahaffey et al., 2020; Lynam et al., 2017). As species are redistributed across longitudes and latitudes, ecosystem baselines are temporally and spatially shifting through administrative boundaries (Sadykova et al., 2018; McLean et al., 2018). Sadykova et al., 2020 (Sadykova et al., 2018) predicted a redistribution of population interactions at a scale of 75 km to 164 km for prey species (e.g. sandeels and herrings) and top predators (e.g. birds and marine mammals) respectively, in the North Sea by 2050. To ensure the compatibility of large-scale marine renewable energy developments (MREDs) with nature conservation obligations and the need for a sustainable energy

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production system, the intended MREDs must be carefully planned to avoid unacceptable levels of environmental harm. Therefore cumulative effects need to be assessed (Willsteed et al., 2018a). At a European level, the Cumulative Impact Assessment (CIA) is required under both the Strategic Environmental Assessment (SEA) (Directive 2001/42/EC) and the amended Environmental Impact Assessment (EIA) (Directive 2014/52/EU). The Marine Strategy Framework Directive (MSFD, Directive 2008/56/EC) also assesses cumulative and synergetic effects using an ecosystem approach (Cavallo et al., 2017). Although the Habitat Directive (EC Directive 92/43/EEC) is not explicit about MREDs, the Directive prescribes that cumulative effects emerging from plans or projects likely to significantly impact an N2000 site (including habitats and species) must be assessed (Le Lièvre, 2019). At the UK level, CIA requirements are under the Marine and Coastal Access Act 2009 (MCAA), the UK Marine Policy Statement (UK-MPS) and the UK National Policy Statement (UK-NPS) as stated in the Planning Act 2008. The MCAA, UK-MPS and UK-NPS are nationally planning policies translated at regional levels to enable regional CIA under SEA obligations. These regional SEA and CIA assessments will provide regional scoping frameworks for developers to assess CIA under EIA requirements at project scales.

However, EIA and post-consent conditions are not designed to address larger-scale ecosystem shifts. As they stand, licensing conditions, EIA, and post-consent processes lack accuracy in linking populations to ecosystem spatio-temporal changes from local to ecosystem scales (Busch and Garthe, 2018; Sinclair et al., 2017). Furthermore, EIA scoping processes tend to over-simplify ecosystem complexities and neglect climate change baselines by excluding hydrology and primary producer components driving higher trophic level distributions (Willsteed et al., 2018a; Fox et al., 2018; Gissi et al., 2018).

MREDs are thought to have several effects on physics and marine populations, although the extent to which these are significant remains uncertain (Gasparatos et al., 2017; Platis et al., 2018). Impacts on seabirds are often cited as critical concerns, with the main effects being collision mortality, displacement from crucial foraging areas and barrier effects leading to increased movement costs such as commuting or migration (Dierschke et al., 2016). In addition, marine mammals, fish and benthic communities may be impacted by activities during construction, operation or decommissioning (Gill et al., 2020; Graham et al., 2019). However, it is now known that OW farms generate atmospheric wake effects, where the wind speed above the surface can be reduced up to 40% close to the farm site, covering up to 70 km (Platis et al., 2018). Extracting wind reduces wind speed, likely changing the strength of stratification in shelf seas which may affect the base of the food chain by altering levels of primary production (Gill et al., 2020; Graham et al., 2019; Floeter et al., 2017). The significance of such effects at population scales is difficult to ascertain. However, evidence is becoming clearer that MREDs affect birds, marine mammals and fish when considering multiple regional developments (Joy et al., 2018; Skov et al., 2018).

Despite having detrimental impacts, MREDs have positive effects. For example, creating reef effects and excluding fisheries may have a positive impact on ecosystem functionalities (e.g. creating foraging opportunities for birds and marine mammals) (van Hal et al., 2017; Kafas, 2012; Russell et al., 2014).

These direct and indirect effects ultimately lead to uncertainties emerging from combined climate change and MRED impacts on ecosystem changes from physics and primary producers up to top predator population levels, leading to a lack of efficient compensatory measures (Elliott et al., 2015a; Lonsdale et al., 2017; Willsteed et al., 2017).

Even though MREDs reduce CO_2 emissions, their combined impacts with climate change must be understood (Woolley, 2015). As they stand, SEA and EIA procedures are not robust enough to identify interconnectivity between pressures and cross-ecosystem components, triggering high uncertainties (Borja et al., 2016; Sinclair et al., 2018). This might lead to an uncertain ecosystem assessment with a limited understanding of ecosystem-scale impacts to inform the next leasing rounds (Therivel and González, 2019; Tweddle et al., 2018).

Developing consistent CIA methodologies and shared tools led by a partnership between decision-making bodies, stakeholders, and developers have been recognised as essential to determining MREDs' impacts (Willsteed et al., 2018b). Available tools are insufficient to implement an ecosystem approach to manage marine waters (Willsteed et al., 2017). There is currently no centralised UK-wide pathway for accessing data across various stakeholders, MREDs and other marine industries involved in CIA processes (Willsteed et al., 2018a; Sinclair et al., 2017). This might be due to turn-overs between different industry teams, commercial sensitivity concerns, and a lack of a standard format/framework to ensure comparability and compatibility across datasets (Willsteed et al., 2018a; Durning et al., 2019). Creating a UK-wide online database and tools providing the required data in a consistent format whilst addressing sensitivity could contribute to streamlining consistent and transparent CIAs. This would integrate data across sectors by encouraging broad stakeholder involvement (e.g. including fisheries and data related to their activities) at the beginning of CIA processes (Lonsdale et al., 2017; Elliott et al., 2018a; González and Campo, 2017).

Addressing CIA gaps necessitates an inclusive, holistic and pragmatic inter-disciplinary approach linking academic research, policymakers, industries, licensing governmental bodies and public engagement (Fox et al., 2018; Willsteed et al., 2018b). Therefore, this study presents an overview of a CIA policy framework, enabling a bottom-up-top-down ecosystem-based approach linking physics and primary producers up to top-predator populations. We use the UK as a case study due to its current global leader status in OW developments. Our approach is embedded in EU policies (MSFD being replaced by the UK Marine Strategy Directive) and encompasses the needs of devolved governments. Therefore our framework mirrors many countries around the world signed up to international environmental directives while having different state-level legislations to contend with. We propose a policy framework integrating ecosystem and climate change indicators as CIA baselines to identify pressure pathways and keystone components. This ecosystem-based approach will be implemented with a monitoring and modelling scheme as well as the use of the Contracts for Difference (CfDs) as a collaborative tool for an interdisciplinary CIA.

Firstly, we show how the CIA and the MSFD requirements are integrated into the UK licensing and maritime planning framework and how CfDs are connected to this scheme. Secondly, we provide potential policy pathways embedding the MSFD as a baseline for CIA requirements at the European and UK levels enabling an ecosystem-based approach. Thirdly, our study explores solutions addressing remaining gaps and integrating MRED industries into our ecosystem-based approach. We suggest using a fine-scale shared monitoring effort, Bayesian ecosystem modelling, and already available online tools such as Marine Environment Information Network[1] (MEDIN) and the Marine Data Exchange[2] (MDE). We also highlight how these pragmatic tools are connected to CfDs.

2. Existing policy framework

This section presents all the policies setting an ecosystem-based cumulative impact assessment pathway from an international to a UK national level. Moreover, it highlights marine renewables energies licensing frameworks in the UK. All the policies mentioned in this section are briefly described in Table 1, and their connections are illustrated in the figures.

[1] https://medin.org.uk/.
[2] https://www.marinedataexchange.co.uk/.

Table 1
Brief description of international, European, UK national policies and tools mentioned in our proposed ecosystem-based framework for the cumulative impact assessment. The policies are organised in alphabetical order.

Policies, Licensing bodies and Tools	Focus	Description
Contracts for Difference (CfDs)	UK government subsidising tools	CfDs are private legal contracts between a developer with a capacity of at least 300 MW and the UK government.
Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention)	Marine environment	OSPAR recommends an ecosystem-based approach to assess cumulative effects using high-level descriptors translated at the European level by the MSFD. The OSPAR strategy aims to develop a repeatable, transparent, standardised risk-based approach to assess cumulative effects.
Electricity Act 1989	Energy production	MMO, Marine Scotland, Natural Ressources Wales and DAERA determine applications under s.36 and s.36A of the Act 1989 for developments in their respective waters.
Energy White Papers	Energy Production	Under the Energy White Papers, the EIR defines CfDs supply chain requirements regarding EIA data release. One key commitment is building a world-leading digital infrastructure supporting the energy system.
Environmental Impact Assessment Directive (EIA Directive)	Environmental assessment	It determines potential adverse or beneficial environmental effects of developments while also considering scientific, political, social and economic factors prior to and informing the consent process. It also requires that the report considers protected sites designated under the HBD. It emphasises public input into decision processes.
Environmental Information Regulation 1998/Environmental Information (Scotland) Regulation 2004 (EIRS)	Environmental data release tool	It sets the obligation to release environmental data publicly. It included any data on the state of ecosystem components and any interactions between them (from water to air, biodiversity (flora and fauna, alive or dead), state (physical, chemical and biological conditions), built structures, emissions (including noise or vibrations), effects (direct or indirect), measures (linked to development permits, environmental management programs or administrative measures).
EU Renewable Energy Directive	Renewable Energy Production	It establishes the target of achieving at least 32% renewable energy consumption by 2030.
Habitat and Birds Directives (HBD)	Environmental/ Nature and Biodiversity	The Habitats Directive ensures the conservation of a wide range of rare, threatened or endemic animal and plant species. The Birds Directive protects all the 500 wild bird species in the European Union.
Integrated Maritime Policy (IMP)	Marine spatial planning	The IMP connects the MSFD and the MSPD, providing a more coherent approach to maritime issues, and increasing coordination between policy areas.
Marine and Coastal Access Act 2009 (MCAA)	Marine spatial planning	It meets international marine initiatives, including the MSFD and the MSPD. The MCAA sets the UK-MPS and prescribes that all marine plans must be subjected to a SA.
Marine Strategy Framework Directive (MSFD)	Environmental/ Marine and Coastal	The MSFD aims to achieve good environmental status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend.
Maritime Spatial Planning Directive (MSPD)	Marine spatial planning	MSPD supports sustainable development and growth in the maritime sectors, applying an ecosystem-based approach and promoting the coexistence of relevant activities and uses
Strategic Environmental Assessment Directive (SEA Directive)	EU Directive	It requires authorities to undertake an environmental assessment of public sector plans and programmes likely to affect the environment significantly. The SEA report considers the protected sites designated under the HBD.
Supply chain	Economic tool	The Supply chain has to be submitted by the generators producing more than 300 MW to the Department for Business, Energy and Industrial Strategy for assessment before receiving CfD payments.
Sustainability Appraisal (SA)/Appraisal of Sustainability (AoS)	Spatial planning	SA and AoS integrate economic, social and environmental impacts, the three dimensions of a plan's sustainable development. Both integrate the requirements of the SEA Directive.
UK Climate Change Act 2008	Climate Change	The Act sets the target for reducing greenhouse gas emissions by 2050. It also requires UK governments to undertake a UK Climate Change Risk Assessment updated every five years.
UK Energy Act 2013	Electricity production	It enables investment in safe, decarbonised and accessible electricity generation for consumers through the two main mechanisms of energy market reform: the Capacity Market and the CfDs.
UK marine policy statement (UK-MPS)	Marine spatial planning	It ensures that developments avoid harming marine ecology, biodiversity, and geological conservation interests using an AoS

(*continued on next page*)

Table 1 (*continued*)

Policies, Licensing bodies and Tools	Focus	Description
		incorporating SEA requirements.
UK National Policy Statement (UK-NPS)	Spatial planning	It realises UK climate change commitments, contributes to the UK market competitiveness, and improves health and well-being via securing affordable energy supplies. UK-NPS is subject to an AoS fulfilling the SEA Directive requirements.

2.1. MSFD, MSPD and CIA

This section presents how the CIA is embedded in ecosystem-based policies from an international level, including OSPAR, the MSFD and the MSPD, to a UK national and regional one. In line with the International Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), the EU's Marine Strategy Framework Directive (MSFD, Directive 2008/56/EC) requires an ecosystem approach to manage anthropogenic activities affecting the marine environment including main cumulative and synergetic effects assessments blending environmental protection and sustainable concepts to progress towards GES (Cavallo et al., 2017) (green arrows in Fig. 1). The MSFD will be reviewed in 2023 to ensure that collective pressures of activities remain within levels of achieving GES (Macdonald, 2018). However, the MSFD does not provide operational frameworks to manage anthropogenic activities, and member states need to develop their own programs of measures to reach those targets (Altvater et al., 2019). Based on the MSFD measures and environmental targets, the Maritime Spatial Planning Directive (MSPD, Directive 2014/89/EU) balances marine human activities to maintain the sustainable use of marine and coastal resources (green arrows in Fig. 1) (Fatima Castro Moreira; Barbara Magalhaes Bravo, 2019).

Before leaving the European Union on the 1st of January 2021, the EU DEFRA created the Environment Bill defining post-Brexit marine environmental policies and how MSFD requirements integrated into the UK-MPS will continue to apply after Brexit. The bill sets methodologies and guidelines regarding risk management techniques regulating activities to achieve marine environmental policy objectives (Dbouk, 2022).

2.2. From the European level to the UK national level: the MSFD pathway towards the SEA

This section highlights the MSFD ecosystem approach pathway (green arrows in Fig. 2) under the Marine and Coastal Access Act 2009 (MCAA) and the UK Marine Policy Statement (UK-MPS).

The UK-MPS acknowledges that increasing needs for marine space should be addressed using an ecosystem-based approach, ensuring the coexistence of activities and incorporating terrestrial planning (Macdonald, 2018; Calado et al., 2019). Thus, the UK-MPS must integrate economic, social and environmental considerations accounting for different European Union Directives and recognise marine planning processes as critical tools for determining UK-wide targets and measures to implement the MSFD (Slater and Claydon, 2020). The UK-MPS *section 2.5* aims to achieve MSFD (green arrow in Fig. 2) and WFD (Water Framework Directive 2000/60/EC) targets, more precisely, any measures related to the spatial dimensions of these Directives. Authorities should then plan activities while supporting MSFD and WFD objectives in coordination with countries sharing the same regional seas. Consequently, the UK-MPS stipulates that human activities should be managed using an ecosystem-based approach, ensuring that activities are kept at a level suitable to GES accomplishment and do not compromise ecosystem capacities to adapt to human-induced changes.

However, UK-wide, the MPS splits the UK marine area into marine planning regions associated with regional plan authorities in charge of preparing their specific marine plan (green arrows in Fig. 2) (Slater and Claydon, 2020). Although the UK-MPS allows regional approaches, it unifies the administrations of England, Northern Ireland, Scotland and Wales (illustrated by yellow, green, navy blue and red boxes, respectively, in Fig. 2) in one holistic marine management regime contributing to the sustainable development of the overall UK's marine area (Slater and Claydon, 2020; HM Government, 2011).

2.3. The UK-MPS, SEA and cumulative effects

This section shows how the MCAA and UK-MPS integrate SEA and CIA requirements (green arrows in Fig. 2). The UK-MPS states that developments should avoid harming marine ecology, biodiversity, and geological conservation interests by using location planning, mitigation, and considering reasonable alternatives. Additionally, the UK-MPS acknowledges that developments may benefit the marine environment by providing opportunities to enhance marine ecology and biodiversity.

As stated in the UK-MPS *section 2.4*, benefit, adverse and cumulative effects are assessed by an Appraisal of Sustainability (AoS) incorporating SEA requirements. The AoS assesses the MPS alternatives against a panel of sustainability goals defined in the SEA Directive. The UK-MPS *section 1.2.3* recommends data sharing and consultation with concerned authorities or Member States following SEA Directive requirements to understand potential effects fully.

The UK-MPS sets obligations for decision-making bodies to manage potential cumulative effects by setting targets or limiting developments. The UK-MPS defines cumulative impacts of activities as:

- "The cumulative impact of activities, either by themselves over time or in conjunction with others, outweighs the benefits.
- A series of low-impact activities would have a significant cumulative impact that outweighs the benefit.
- An activity may preclude using the same area/resource for another potentially beneficial activity." (MMO, 2014)

To assess potential effects, UK-MPS *section 2.6* states that authorities should apply a risk-based approach without providing methodological guidelines. When evidence is inconclusive or risks cannot be assessed, the MSP applies precautionary principles without giving indications other than taking "preventive measures" (Woolley, 2015).

2.4. UK-NPS, SEA and the cumulative effect

This section explores how the UK-NPS framework integrates the SEA and the CIA. Similar to the UK-MPS, the UK-NPS is subject to an Appraisal of Sustainability (AoS) (pink arrow in Fig. 2), fulfilling SEA requirements by identifying, describing and evaluating any significant effects of a plan as well as its reasonable alternatives.

The UK-NPS recognises potential cumulative effects on ecology (including subtidal and intertidal habitats and species) and fisheries depending on the environment's sensitivity, locations and designs of infrastructures. It explicitly recognises high levels of uncertainties due to the AoS strategic level leading to uncertainties regarding mitigation measures efficiencies (UK Government, 2010). Despite cumulative impact uncertainties arising from the number and location of projects at this strategic stage, the UK-NPS requires the IPC (Infrastructure Planning Commission) to consider cumulative effects regarding individual applications. Developers must conduct project-level assessments, including EIA and CIA.

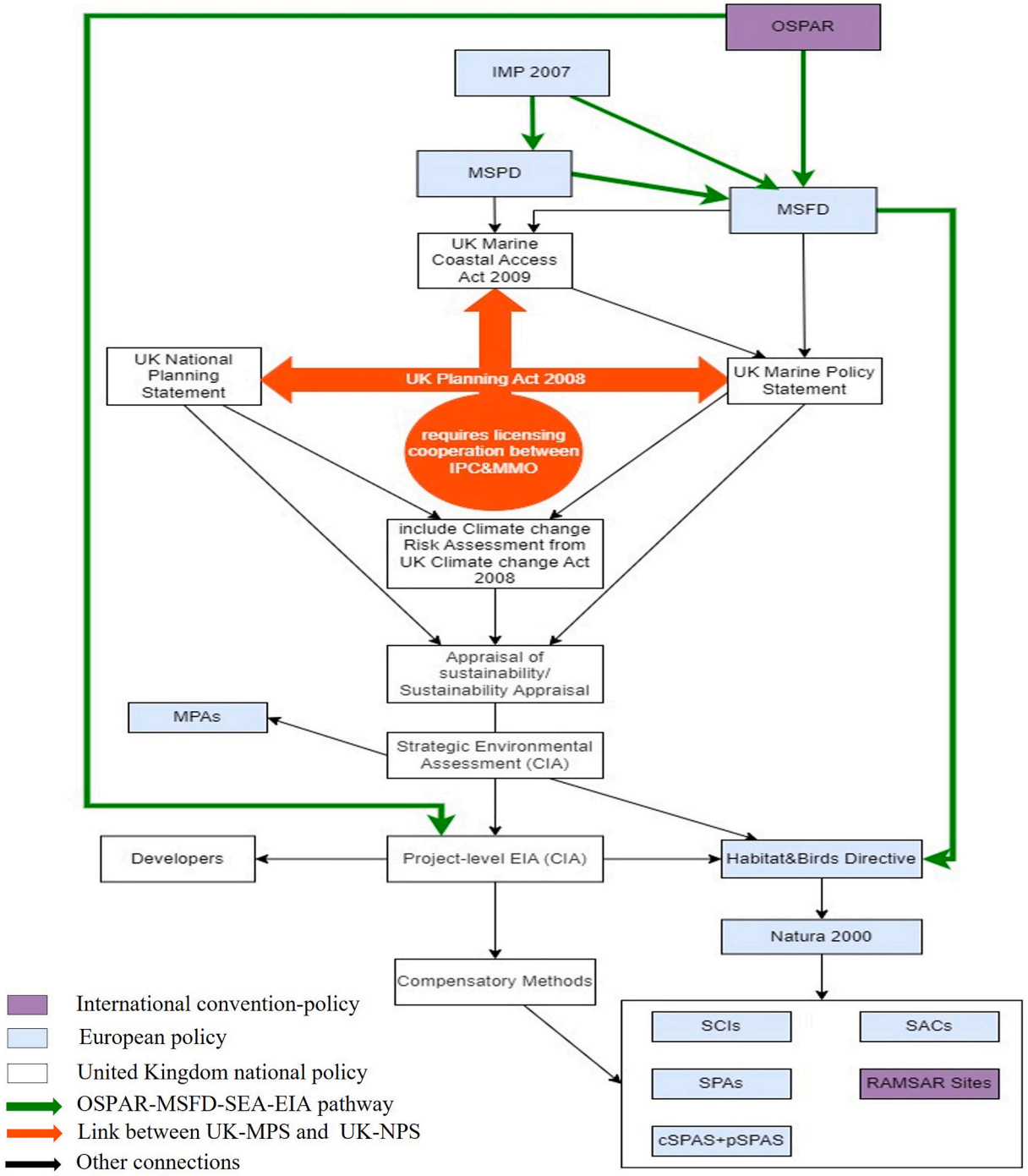

Fig. 1. Ecosystem-based policy framework integrating the Cumulative Impact Assessment (CIA) from an international and European level to a UK national level. Green arrows represent how OSPAR, the MSFD and the MSPD are linked and connected to the SEA and the EIA, requiring the CIA. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.5. Climate change pathways: UK-MPS and UK-NPS

The section explores how climate change effects are integrated into the UK-MPS and the UK-NPS (blue arrows in Fig. 2). The UK-MPS underlines climate change influences on current and future sea uses and identifies its assessment as crucial to conserving the marine environment's resilience. When developing marine plans, authorities should assess likely and potential impacts of climate change and their implications for the location or timing of projects over and beyond the plan period. The UK-MPS also states that climate change advantages (e.g. temperatures, sea-level rise, marine currents shifts) should be considered and recognised needs for mitigation measures. Consequently, planning bodies should use the Marine Climate Change Impacts Partnership (MCCIP, the latest published in 2020). Moreover, under the Climate Change Act 2008, UK Administrations must conduct, update, and include the most recent UK Climate Change Risk Assessment, as well as use significant national programs and other relevant research.

The IPC under the UK-NPS should consider climate change effects for any projects, using the latest UK Climate Change Risk Assessment alongside emission scenarios suggested by the Independent Committee on Climate Change. Even if the EIA does not require climate change assessments, the UK-NPS states that the IPC will need the information

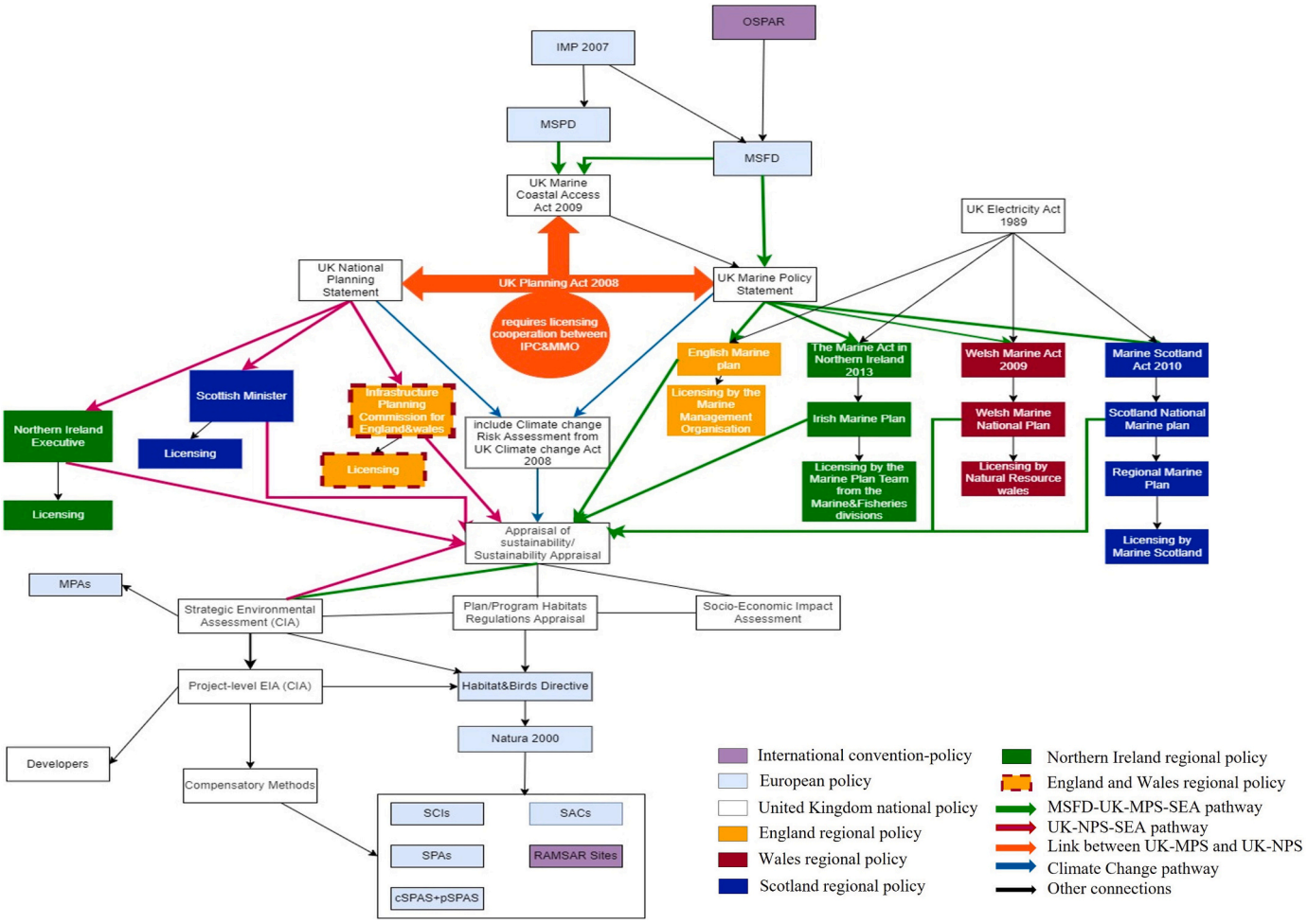

Fig. 2. Ecosystem-based approach and the licensing framework for MREDs from international and European levels to UK national and regional levels. Green arrows represent the MSFD and the licensing pathways under the UK Marine Policy Statement (UK-MPS) integrating CIA requirements. Pink arrows show licensing pathways under the UK National Planning Statement (UK-NPS) integrating CIA requirements. Blue arrows show how climate change effects are integrated into the licensing and CIA framework. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and can require further information if updates of UK Climate Projections become accessible after the proposal application. This way, any applicant should demonstrate how infrastructures account for projected climate change effects, including location, design, build, operations, and decommissioning impacts.

2.6. The Planning Act 2008: the UK national cornerstone linking the MCAA, UK-MPS and UK-NPS

This section shows the Planning Act 2008 (orange arrows in Fig. 2) as the cornerstone connecting the MCAA, the UK-MPS and UK-NPS, requiring collaborations between licensing authorities. The UK-NPS and the UK-MPS are divided under the Planning Act 2008, setting production thresholds for licensing procedures.

The Planning Act 2008 sets up the capacity threshold (between 1 MW and 100 MW) for application under the MCAA and the MMO (Marine Management Organisation) located in waters adjacent to England and Wales or the Renewable Energy Zone (except any part concerning Scottish waters in which Scottish Ministers have functions). The Act 2008 requires the IPC to grant consent under the UK-NPS to projects producing more than 100 MW.

If conflicts arise between the UK-NPS, the MCAA and the UK-MPS, the UK-NPS will apply because the IPC has the national authority on MRED appraisals. The UK-NPS recommends close cooperation between the IPC and MMO, assuring that developments are licensed under European directives and national environmental legislation. Moreover, the UK-NPS requires applicants to consult the MMO regarding nationally significant projects since, under the UK-MPS, the MMO may be implicated in setting other projects, possibly causing related impacts. This guarantees that applications assess all relevant environmental factors and that regulators provide timely advice and assurances to the IPC.

The UK-MPS states that potential adverse impacts (e.g. noise, displacements, barrier effect) and any other direct or indirect impacts on other sea users (e.g. fisheries displacement), as well as mitigation measures, are considered in the UK-NPS for renewable energy infrastructure. Therefore UK-MPS marine plan authorities should consider the UK-NPS when developing plans, advising stakeholders and granting consent.

2.7. Existing tools: contracts for difference (CfDs) and the supply chain

This section defines how CfDs are connected to the policy framework and how they are used as incentivising tools for data sharing via the Supply Chain. Fig. 3 illustrates the international, European and UK national policies framework embedding CfDs and the Supply chain requirements.

Before receiving government CfDs payments, generators must submit their supply chain plan to the Department for Business, Energy and Industrial Strategy (BEIS) for assessment (DRAFT SUPPLY CHAIN PLAN, 2020). Under the Environmental Information Regulation (EIR) and the

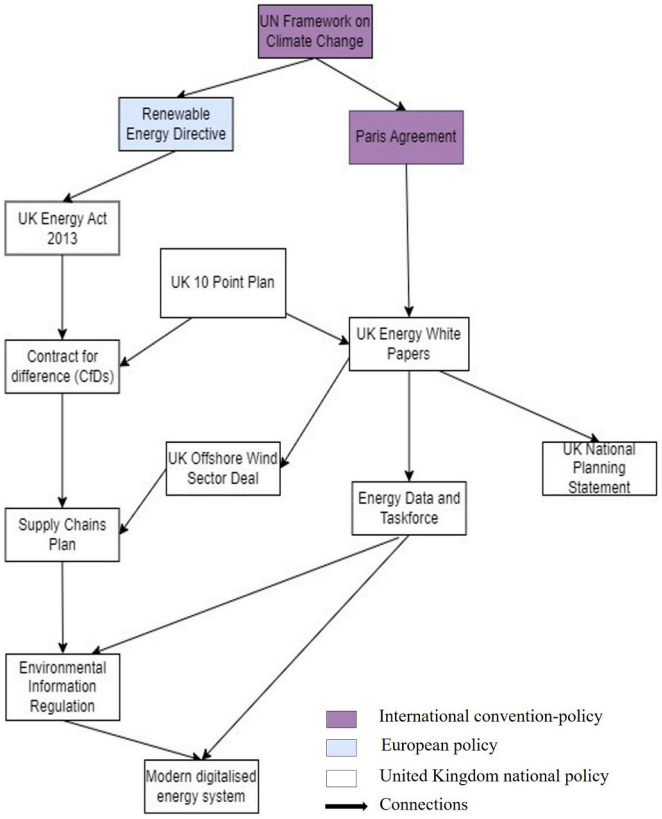

Fig. 3. Policy framework embedding CfDs and the Supply chain requirements from the international, European, to UK national level.

EISR in Scotland, BEIS or a "public authority" must publish approved supply chain reports, including EIA data, within three months of approval with consideration of commercially sensitive data, but marking sensitive data being generators' responsibilities *(*Scotland. Environment and Rural Affairs Department. Environment Group, *2004)*.

Under the Energy White Papers, the Energy Data Taskforce[3] (Fig. 3) recommends using licence conditions and identifies the Electricity Act 1989 and the EIR (Fig. 3) as robust mechanisms to proactively facilitate data release on request (Sandys, 2019). Therefore, the EIR requirements under the CfDs supply chain are tools enabling EIA environmental data accessibility while addressing commercially sensitive data concerns (González et al., 2019). Using standardised shared tools to access data and a synchronised monitoring effort between the MRED sectors and ocean monitoring communities could enhance multi-disciplinary collaborative work, as presented in the discussion.

3. Solutions for better integrating existing policies

Maritime planning should manage competing demands using an ecosystem-based approach, facilitate activities and incorporate best-practice (Macdonald, 2018; Calado et al., 2019). This way, the UK-MPS states that economic, social and environmental factors need to be considered, as well as requirements including EU Directives, such as the MSPD, the MSFD, and the WFD involving river basin planning extending to marine areas (Fatima Castro Moreira; Barbara Magalhaes Bravo, 2019).

3.1. Solution 1: European level for SEA & MSFD

This section explores how the ecosystem-based approach defined under OSPAR and the MSFD will be embedded in the SEA and EIA to enable our proposed holistic CIA framework at the European level (light green arrows in Fig. 4). Based on the precautionary principle, new activities should only be allowed if no impact is shown on GES or OSPAR targets after undergoing a SEA and EIA (Elliott et al., 2018b). At a European level, the SEA Directive is one of the MSPD tools for minimising anthropogenic impacts on the marine environment (Altvater et al., 2019). Thus, integrating the MSFD into the SEA process will be done by using the MSPD (light green arrows in Fig. 4). The MSFD focuses on ecosystem functions and responses using its 11 descriptors. Therefore, the SEA will integrate ecosystem function as a baseline (Boyes and Elliott, 2014). The following MSFD descriptors will be implemented as ecosystem and climate change indicators as SEA baselines: D7 Hydrographical conditions, D11 Energy and underwater noise, D6 Seafloor integrity, all place-specific with spatial characteristics directly impacted by marine spatial planning (Altvater et al., 2019). Although climate change is not explicitly included in the MSFD, D7 and D6 address its physical effects (Elliott et al., 2015b). To expressly reflect cumulative effects and aggregate ecosystem properties, Altvater et al., 2019 (Altvater et al., 2019) recommend D1 Biodiversity, D4 Marine Food Webs, and D6. However, even if D1, D4, and D6 assess ecosystem component states, they do not assess the causes of changes (Altvater et al., 2019). Therefore many challenges need to be addressed to better account for climate change variability and "climate proofing" the GES (Elliott et al., 2015b).

Under MSFD Art 8, Member States have the flexibility to select criteria and associated indicators to assess significant impacts and threats to a specific marine ecosystem. However, this implies using comparable methods and aggregation rules to ensure minimum standards when reporting GES across Member States and subregions to enable an integrated assessment and avoid transboundary biases (Borja et al., 2013).

However, the marine ecosystem comprises water bodies interconnected at different spatial and temporal scales, from European to local coastal communities. Therefore, using one management method is not relevant to the range of scales. That is why carrying out the GES assessment at a sub-regional scale (or even at a water body level) is necessary, as the sub-region characteristics result in impact levels depending on pressures (Borja et al., 2010). The principal task for incorporating the MSFD into an integrative assessment framework is to define how many criteria/indicators should be used (Borja et al., 2013) Linking the SEA regional framework to the MSFD will provide guidelines addressing this gap by highlighting which descriptors are affected by activities and which criteria/indicators are relevant at a regional ecosystem scale (Cavallo et al., 2017; Elliott et al., 2020).

The MSFD program of measures implementing management strategies will define and address far-field effects and degrees of perturbation of ecosystem components caused by the overall pressure of marine activities. Such impact assessments are outside developers' scopes, and licensing authorities (Elliott et al., 2020). The list of indicators of previously cited descriptors will be implemented using Regional Seas Conventions. Each Regional Seas Convention has developed or is developing its own list of core indicators in line with those of the MSFD (light green arrow on Fig. 4) (Cavallo et al., 2019). For example, using the OSPAR Biodiversity Common Indicators correlated with the MSFD as a list of core indicators will input transboundary indicators linking OSPAR and the MSFD to the SEA.

This will inform decision-making bodies on the performance of plans and if measures are necessary from Regional Seas Conventions, MSFD to SEA scales. It will also address gaps linked to analyses of the reasonable alternatives from the UK-MPS and UK-NPS SEA processes only accounting for "the objectives and the geographical scope of the plan" (UK Government, 2010). The temporal perspective of the plan will also be

[3] https://es.catapult.org.uk/news/energy-digitalisation-taskforce-launches/.

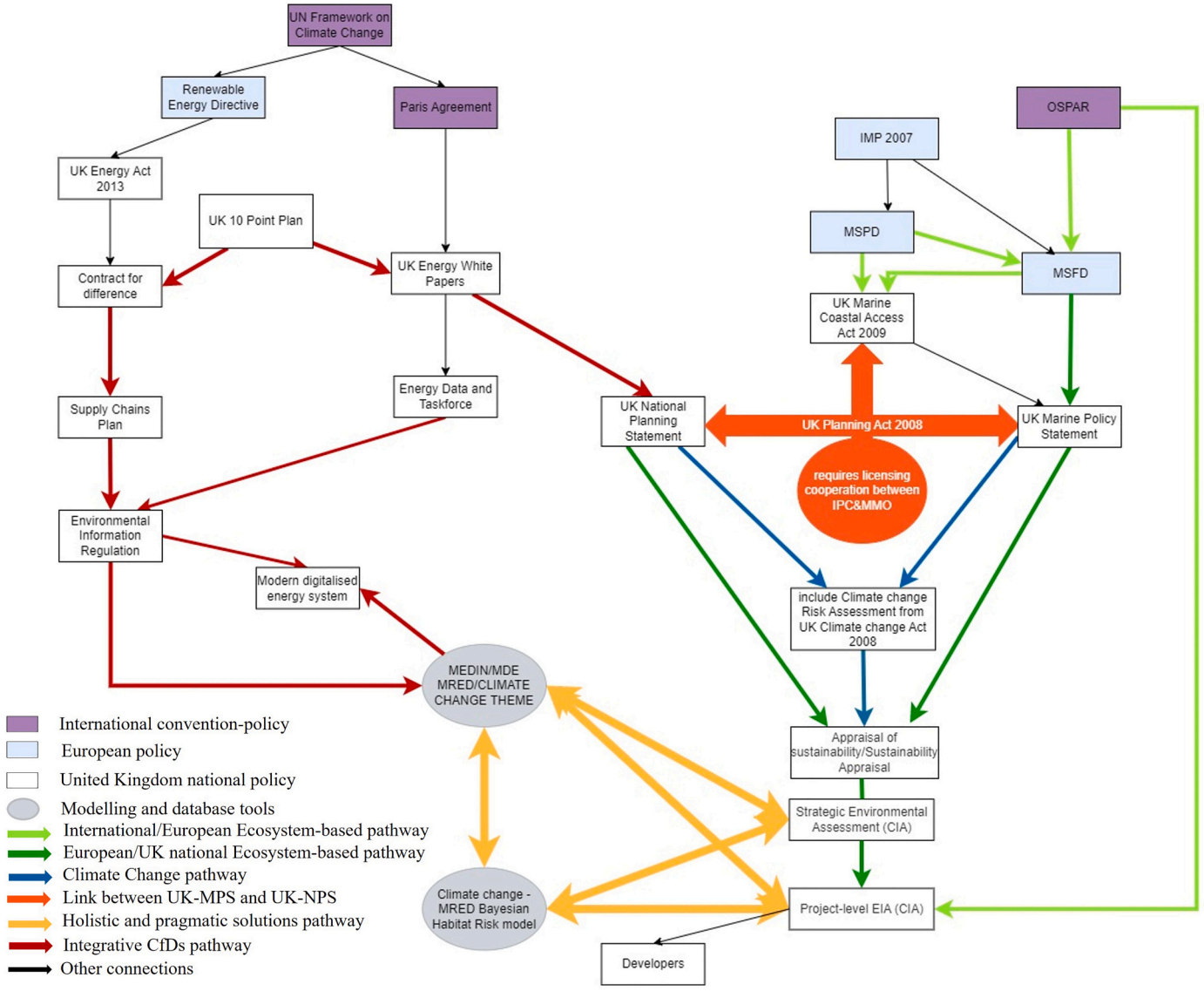

Fig. 4. The proposed holistic and pragmatic framework integrates the OSPAR/MSFD ecosystem-based approach to the MREDs CIA processes under the SEA and EIA at international (light green arrows) and UK national levels (dark green arrows). This framework includes the CfDs (red arrows) as an integrative tool, a database and a modelling approach as pragmatic tools (grey bubbles integrated using yellow arrows). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

included since the MSFD is defined by six years of reporting cycles (Elliott et al., 2015b). However, each Member State or region created its own list of indicators resulting in more than 600 indicators; therefore, a generic list needs to be created, which requires better top-down control (Cavallo et al., 2019).

3.2. Solution 2: National UK scale for SEA & MSFD

This section explores how the MSFD ecosystem approach could be embedded in the SEA at a UK national scale using the UK-MPS as a merging point. As explained in section 2.1.2, the MCAA and the UK-MPS give effect to the MSPD and the MSFD objectives (dark green arrows in Fig. 4) while specifying that marine anthropogenic activities must be assessed under SEA requirements. However, UK-MPS recommends using an ecosystem-based approach to manage human activities, to ensure that activities are kept at a level compatible with the GES achievements (Macdonald, 2018). Even if the MSFD and SEA are currently disconnected processes in the UK policy framework, the UK-MPS is the most suitable merging point compared to the MCAA due to its high-level nature limiting its utility to decision-makers (Macdonald, 2018). The MSFD GES and the SEA should be connected following the Netherland National Water Act strategy setting the MSFD GES as the SEA baseline (de Vrees, n.d.). The following UK-MPS statement: "*the use of the marine environment is spatially planned when based on an ecosystem-based approach which takes account of climate change and recognises the protection and management needs of marine cultural heritage according to its significance*" should be utilised to integrate the MSFD as a SEA baseline (Altvater et al., 2019). Setting the MSFD as a baseline for SEA processes will allow adaptive management to consider all activities and integrate new ones concurrently rather than separately (Elliott et al., 2018b). It will, then, address the need for proactive measures assessing ecosystems beyond marine planning schemes and enhance collaborative Joint Monitoring Programmes using existing data sets (Slater and Claydon, 2020; Shephard et al., 2015).

Due to environmental concerns, exclusion and restriction zones for wind energy are already happening in Germany, and licenses have been refused for ecological reasons due to species under European protections (Lüdeke, 2017; Phylip-Jones and Fischer, 2015). Therefore, integrating

the MSFD approach as a SEA baseline in Germany will prevent high licensing refusal rates and strengthen the maritime planning process. In the Belgium's marine spatial planning, the Master Plan addresses European Directives and needs for nature conservation and renewable energies (Pecceu et al., 2016). This way, the Master Plan is the connecting point between the MSFD and the SEA for a Belgium ecosystem approach. As all countries sharing the North Sea face challenges in assessing CIAs, integrating the MSFD into the SEA framework will create a transboundary approach defined by similar ecosystem baselines and GES objectives (Gușatu et al., 2021; Díaz and Guedes Soares, 2020).

3.3. Solution 3: connections between the UK-MPS and the UK-NPS for holistic MSFD ecosystem-based assessment

This section highlights how the MSFD and the UK-MPS ecosystem approach should be integrated into the MREDs licensing process under the UK-NPS via the Planning Act 2008 (orange arrow in Fig. 4). Using the MCAA and UK-MPS to integrate the MSFD as a baseline for the SEA and the EIA will create a holistic ecosystem assessment. However, the licensing process under the UK-MPS only applies to projects generating between 1 and 100 MW. Therefore, the following section explores links between UK-MPS and UK-NPS to integrate the previously explained ecosystem approach.

The UK-MPS and the UK-NPS are connected via the Planning Act 2008 (orange arrow in Fig. 4). Additionally, collaborations between the IPC, the MMO and applicants ensure that environmental European Directives are not breached, as stated in the UK-MPS and the UK-NPS. Due to these links, the MSFD will be implemented in the UK-NPS licensing process and its environmental regulatory regime. Therefore, the MSFD approach could be implemented through a hierarchical feedback loop. The top-to-bottom part is pathways from the UK-MPS to the UK-NPS, with the MMO, Marine Scotland and the IPC advising applicants and granting licenses based on SEA outputs integrating GES requirements as a baseline.

The bottom-up feedback loop is applicants integrating MSFD descriptors requirements in their EIA data collections and submitting data to the IPC, the MMO or Marine Scotland for licensing approval.

3.4. Solution 4: from international to a national scale for EIA & MSFD

In order to create the bottom-up feedback loop from a local scale to the North Sea level, the MSFD should be linked to the EIA process. Internationally, the EIA Directive already integrates the OSPAR list of threatened and/or declining species and habitats (light green arrow in Fig. 4). Consequently, the Scottish marine licensing process includes the OSPAR list in EIA processes but without including the ecosystem-based approach defined by OSPAR or MSFD indicators (The Scottish Government, 2012). As discussed by Soria-Rodríguez 2020, (Soria-Rodríguez, 2020) implementing the MSFD into the EIA Directive should consist of a minor amendment requiring legal coordination between both Directives, similar to existing coordination between the EIA Directive and the Habitats and Birds Directives. The EIA Directive Article 1 was amended in 2014 to assess and describe direct and indirect significant effects of a project on “biodiversity”, to include species and habitats protected under the Habitats and Birds Directives (Soria-Rodríguez, 2020). Connecting the MSFD to the EIA Directive should be done the same way, but instead of “biodiversity”, the amendment should state “GES”. At a UK scale, the Marine Works (EIA) Regulations 2007, transposing the EIA Directive for marine projects, should be modified to integrate the OSPAR/MSFD ecosystem approach. It should also be worth considering that before the MCAA, licensing decisions were frequently made primarily based on EIA (Slater and Claydon, 2020). Therefore, the MCAA should link the OSPAR/MSFD and the EIA procedure since the Act gives effect to the UK-MPS requiring the MSFD GES assessment and the SEA process.

3.5. Remaining gaps: harmonising spatio-temporal policies scales at a European level

Even though the MSFD is a robust legal EU and national tool (Cavallo et al., 2017), which should be implemented into the SEA and EIA process, its ecosystem approach has some gaps. The MSFD overlaps with the WFD in coastal areas as the latter applies to 1 NM from the coastline (Borja et al., 2010). Moreover, timescales for the MSFD and the WFD national implementations led to limited harmonisation of approaches at regional levels (Borja et al., 2010). The MSFD also spatially overlaps with the Habitats Directive, the Integrated Coastal Management Directive, and the Common Fisheries Policy. Thus, there is a need to examine which Directive will apply to considered areas and which status or indicators will apply. The WFD prevails in the nearshore area, while the Habitats Directive has authority in designated areas of conservation. However, marine areas falling under GES and not yet given Special Protection Areas or Special Areas for Conservation status will likely cause spatial inconsistencies under the Habitats and Birds Directives in our proposed system (Borja et al., 2013).

4. Recommendations for a holistic CIA framework

Given the previously highlighted issues, this section suggests a way forward enabling our proposed holistic CIA framework by integrating various tools that link OSPAR and MSFD ecosystem-level approaches to the SEA and EIA at international, European and UK scales. First, it will show how a collaborative monitoring effort will enable a fine-scale CIA assessment addressing MSFD, SEA and EIA caveats. Following this, a Bayesian habitat risk model connected with MEDIN and MDE databases (all represented by grey bubbles and yellow arrows in Fig. 4) will be discussed. Finally, we will show how MEDIN and MDE are linked to the CfDs (red arrows in Fig. 4). However, our recommendations need to be led by an inter-disciplinary group unifying licensing bodies such as IPC, the MMO and Marine Scotland, and any other national and regional decision-making bodies acting under the UK-NPS and the UK-MPS as well as relevant stakeholders and academic researchers in order to oversee ecologically sustainable MREDs. Furthermore, given Brexit, challenges must be addressed to strengthen data sharing across European countries and the UK at MSFD and MSPD European levels.

In conclusion, we will suggest using the European Marine Observation and Data Network (EMODnet)[4] as a platform that can be used for data sharing across regional, national and international members for a more inclusive CIA integrating local EIA scales up to European and North Atlantic ones.

4.1. Tool 1: a shared monitoring effort addressing policies caveats

Ecosystem approaches under the MSFD and OSPAR are fragmented between descriptors and receptors determined by the Member States individually. This turns into a lack of information on ecosystem connectivity (Elliott et al., 2015b). Similar fragmentation occurs in SEA and EIA processes as each species or habitat is studied separately (Willsteed et al., 2017), leading to significant uncertainties regarding cumulative impacts. Moreover, climate-affected baselines must be revised during the MSFD six-year cycle. This will require additional spatial and temporal monitoring to detect and differentiate between climate change-induced ecosystem changes and those caused by anthropogenic activities (Elliott et al., 2015b). To better understand interactions between climate change effects, habitat and species, displacement, disturbance and death (due to collisions) at population levels, as explained by Scott., 2021 (Scott, 2021), we recommend using a fine-scale, temporally continuous shared monitoring effort that is overseen by a collaboration of statutory groups and enacted by industry by integrating

[4] https://emodnet.ec.europa.eu/en/.

environmental monitoring equipment into the infrastructure of offshore arrays.

Assessing habitat change, species habitat use and prey-predator interactions at high spatial and temporal resolution above and below the water requires combining new technological approaches collecting continuous and concurrent information from physical processes through all trophic levels. This could be done using networks of distributed ocean observatories interconnected at the regional and shelf scales of planned OW as well as within wind farms (Whitt et al., 2020). Shared monitoring efforts can be simultaneously using devices such as remote sensing, drones, autonomous upward-facing multi-acoustic platforms, uncrewed surface vessels and underwater gliders coupled with tagging programs (Russell et al., 2014; Whitt et al., 2020; Lieber et al., 2019; Slingsby et al., 2021; Williamson et al., 2021; Medina-Lopez et al., 2021). By recording concurrent data on physics, plankton production, fish, marine mammals and seabirds (distributions and behaviours), the proposed monitoring effort would better enable predictions on potential effects of changes in oceanic variables on local food chains, top predator behaviours, and habitat uses around and within MREDs. A complimentary review paper we are currently creating (Isaksson et al., (in prep)) gives guidance on technical and spatial-temporal uses of the range of devices for this type of monitoring effort. This type of monitoring could also be complemented with environment surveillance technologies embedded directly in renewable structures, such as Thermal Animal Detection Systems mounted on turbines, as is seen already in the assessment of bird flight and behaviour around wind turbines in Denmark (Kaldellis et al., 2016). The data gathered using such monitoring set-ups will then be fed into tool 2; Ecosystem Modelling Framework, and made available using tool 3; A holistic database to address MSFD, SEA and EIA gaps regarding CIA.

4.2. Tool 2: ecosystem modelling framework

Currently, standard species-specific models such as iPCoD (interim Population Consequences of Disturbance for marine mammals), DEPONS (Disturbance effects on the harbour porpoise) and SeaBord (seabird displacement and collision effects) are used to predict if a project or an activity will affect populations during the licensing process (Stephanie et al., 2015; Nabe-Nielsen et al., 2018; Searle et al., 2023). Having only species-specific models with no interactions between trophic levels, especially the assumptions that prey (fish) species stay static in either distribution or population level (or both), makes it impossible to account for bottom-up effects of climate change or MREDs. This study recommends that ecosystem models need to play a much more prominent role in assessing and more accurately predicting the cumulative effects of MREDs. Trophic web modelling approaches (i.e. Ecopath with Ecosim) have recently been used to address CIA and marine spatial needs towards MREDs, they have shown that habitat type is a critical factor (Pezy et al., 2020). However, such models do not yet assess the bottom-up hydrodynamic changes caused both by MREDs structures and the effects of wind energy extraction and their consequences on the base of the food chain (i.e. primary production) (Floeter et al., 2017; Dorrell et al., 2022). Moreover, the MSFD and the UK-MPS recommend using a risk-based approach.

Therefore, this study recommends a combination of using the outputs from a data-driven Bayesian network ecosystem model identifying "best" physical and biological ecosystem indicators with associated confidence levels at different large habitat types (Dorrell et al., 2022). That creates the inputs for a fine-scale spatial analysis of choice species linking predator-prey species (e.g. seabird and fish (Sadykova et al., 2017)) to be used in a Habitat Risk Assessment model (HRA) highlighted in (Declerck et al., 2021; Trifonova et al., 2021) (see grey bubbles in Fig. 4).The HRA of choice is one of the InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) models created by Stanford University in the context of the Natural Capital Project[5] (Declerck et al., 2021; Trifonova et al., 2021). The model will quantify the cumulative risk induced by climate change stressors and MRED activities on critical physical and biological indicators from EIA scales (e.g. development scale between 1 and 10 km), SEA (e.g. regional scales around 100 km) up to ecosystem scale (e.g. the whole North Sea) (Trifonova et al., 2021; Arkema et al., 2014; Caro et al., 2020; Wyatt et al., 2017; Piet et al., 2021). This coupled modelling approach will enable the assessment of near, mid and far-field effects, including climate change using recommendations from population distribution studies (Sadykova et al., 2018; Seagreen Project, 2018; Scottish Government, 2019; Waggitt et al., 2020). Our finer-scale modelling approach will also predict CIA risks by 2050 under climate scenarios and predict changes in species distributions (Sadykova et al., 2018). To input the latest climate change predictions as stated under the UK-MPS and UK-NPS, we will use the Shared Socioeconomic Pathway data (Riahi et al., 2017). By including key physical and biological ecosystem indicators, and climate change stressors under MREDs scenarios, our CIA risk approach will contribute to "climate proofing"" the marine spatial planning process. Moreover, such a modelling approach will highlight which MSFD descriptors are more ecologically significant when assessing overall GES and CIA (Elliott et al., 2015b). The larger ecosystem modelling will also contribute to a better understanding of ecosystem services and their socio-economic implications on other activities, such as fisheries likely to be displaced under MREDs and climate change scenarios (Kafas, 2018; Trifonova et al., 2022; Van de Pol et al., 2023). However, our proposed holistic approach integrating the MSFD into the SEA and EIA processes requires using an open-source national scheme for data sharing of ecosystem modelling outputs and needs to link MEDIN and MDE (grey bubbles and yellow arrows in Fig. 4).

4.3. Tool 3: a holistic database

This section discusses the advantages of using MEDIN[6] and the MDE[7] (grey bubble in Fig. 4) as a central database and how both tools are connected to the CfDs (red arrows in Fig. 4). As an example of good practice, the German government created MARLIN[8] (Marine Life Investigator), a large-scale/high-resolution web portal combining data on lower ecosystem components up to top predators from EIA and research-based monitoring. This tool has improved monitoring and ecosystem-based marine spatial management (Von Halem et al., 2023). The UK created MEDIN, an open-access metadata portal, gathering marine datasets on geophysics, primary producers, fish and fisheries activities, top predators from the MSFD, industrial actors, decision-making bodies, stakeholders and academics. Although MARLIN and MEDIN share similar objectives, some sectors remain unwilling to upload their data on MEDIN due to commercial data sensitivity concerns, but none yet contain outputs from ecosystem models (Wolf et al., 2022).

The MDE data portal, established by The Crown Estate (TCE) in 2013, shares most of the EIA-related monitoring data during pre-construction, construction and post-construction stages collected by MRED industries in the UK (yellow arrow in Fig. 4). Similarly to MEDIN, the MDE stores ecological data but also data related to engineering design. The MDE and MEDIN are connected (yellow arrow in Fig. 4), via the MEDIN Metadata Discovery Standard data.[9] Data such as ScotMER[10] have been used during scoping stages when identifying potential leasing grounds or SEA. To prevent prejudice against a project's activity when

[5] https://naturalcapitalproject.stanford.edu/.
[6] https://medin.org.uk/.
[7] https://www.marinedataexchange.co.uk/.
[8] https://www.geoseaportal.de/.
[9] https://www.marinedataexchange.co.uk/.
[10] https://portal.medin.org.uk/portal/ScotMER.

securing a CfD and adverse effects caused by public data release, TCE is acting under EIR requirements setting the MDE "confidentiality review" process (Edmonds et al., 2015) (red arrow on Fig. 4).

Using links between MEDIN to the MDE will create a CIA-MSFD theme potentially led by a working group dedicated to data management addressing sensitive data concerns. In the longer term, data related to ecosystem services, natural capital, economic benefits, and social welfare should be added to enhance CIA sustainability (Trifonova et al., 2022).

4.4. Tool 4: CfDs as integrative tools

We propose using CfDs as a tool for integrating MREDs into our framework. Under the Energy Act 2013, CfDs are funded by public money. Thus, arguably these funds should be used to fill evidence needs such as environmental impact monitoring and regulating commercially sensitive data release supporting the sector (E. and I. S. Department for Business, 2021). The existing supply chain requirements setting CfDs payments will encourage developers to release their environmental data via the proposed CIA-MSFD theme. Under the Energy White Papers, the supply chain and the EIR are used as incentivising and robust mechanisms for developers to release EIA data (red arrows in Fig. 4). Both are also already structuring the MDE and the existing connections between the MDE and MEDIN. The Energy White Papers are connected to the UK-NPS. Thus, a holistic MDE-MEDIN tool will be linked to the UK-MPS via the Planning Act 2008 (orange arrow in Fig. 4). Moreover, the Energy White Papers aims to create an inter-ministerial delivery group bringing together relevant departments overseeing renewable energy developments in the UK, and we suggest this group could manage the proposed one-stop-shop database merging UK-NPS and UK-MPS SEA, EIA and MSFD requirements to maintain a biologically diverse marine environment while supporting MREDs.

5. Conclusion

In conclusion, our proposed pragmatic monitoring efforts, modelling framework and CIA-MSFD one-stop-shop integrating the MRED industries supported with funds from CfDs provide a holistic approach to producing more strategic, accurate and dynamic cumulative effects of MREDs and can be integrated into the European processes. Data and model outputs generated by these tools could be accessed at a European level via the European Marine Observation and Data Network (EMODnet)[11] using connections from the proposed policy framework (Fig. 1). The EU created EMODnet, under the Integrated Maritime Policy connecting the MSFD to the MSPD (Fig. 4, Table 1). European countries use this open-access data portal to share and report data collected under OSPAR, MSFD, MSPD and Habitats and Birds Directive requirements using themes such as biology, physics or human activities to benefit policymakers, scientists, and industries. The EMODnet Human Activities theme holds data regarding MREDs, fisheries and Natura 2000. The CIA datasets emerging from the proposed policy scheme and tools in this study (Figs. 2 & 4) would fit into the Human Activities theme. This would strengthen data sharing between local EIA scales, regional SEA, MSFD-OSPAR as well as connections to the MSPD at international scales for a more holistic and pragmatic CIA framework.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

[11] https://emodnet.ec.europa.eu/en/.

Data availability

No data was used for the research described in the article.

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