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Obligations and aspirations: A critical evaluation of offshore wind farm cumulative impact assessments

Edward A. Willsteed[a,b,*], Simon Jude[a,**], Andrew B. Gill[a,c], Silvana N.R. Birchenough[b]

[a] School of Water, Energy and Environment, Cranfield University, Cranfield, Bedfordshire MK43 0AL, UK
[b] The Centre for Environment, Fisheries and Aquaculture Science (Cefas), Pakefield Road, Lowestoft, Suffolk NR33 OHT, UK
[c] Cape Eleuthera Institute, Queens Highway, Eleuthera, Bahamas

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ABSTRACT

Proponents of marine renewable energy worldwide highlight that regulatory and consenting procedures are a significant barrier to the upscaling of infrastructure required to transform the energy generation sector. Uncertainties about the cumulative effects of marine renewable energy developments cause substantial delays during the consenting process, which are exacerbated by the lack of clarity about how to assess cumulative effects. These obstacles have contributed to perceptions that this essential emerging industry receives disproportionate scrutiny relative to established maritime activities. However, alongside legislated targets to reduce carbon emissions, there are legal obligations to protect, maintain and improve the condition of the marine environment. As the imperative to halt the decline in the condition of the environment increases, so expectations of cumulative impact assessments grow and the risk of consenting delays persists. To investigate how robust current cumulative impact assessment practise is, a novel evaluation framework was developed and applied to Environmental Statements of the world's largest offshore wind farms, currently in United Kingdom waters. The framework was designed to evaluate cumulative impact assessments relative to the information needs of decision-makers tasked with managing cumulative effects. We found that current practise does not meet those needs, that there is dissonance between science and practise, and problematic variability between assessments was observed. Straightforward recommendations for improved practise are provided, which if implemented may ease the perceived regulatory burden by clarifying practise. We also highlight additional steps that could enable project-led cumulative impact assessments to better support regional marine management. The results and recommendations will be of interest to countries worldwide where marine renewable energy is emerging alongside ecosystem-approach and marine spatial planning aspirations.

1. Introduction

Governments worldwide are looking to secure future energy supplies and to mitigate climate change through generating electricity from renewable energy sources [1]. Of these sources, wind energy is a mature technology that has seen consistent growth in capacity [2–4]. This growth is likely to continue as wind energy is envisaged as a key component of future low carbon energy generation sectors in numerous areas of the globe, for example, Brazil, China, the European Union, India, and the USA [2]. For wind energy to meaningfully contribute to a 'green' transformation of the electricity generation sector requires significant upscaling of wind energy infrastructure [5–7]. Large-scale deployment also enables scale economies to take effect, further increasing the financial attractiveness of investing in wind energy developments [7,8].

Upscaling wind farm developments onshore is increasingly difficult, as locations with sufficient exposure and size become scarce, and due to societal objections to expansion on land [2,4,5]. Thus the benefits of locating wind farms offshore become more apparent, particularly as technological and economic barriers are overcome [7,8]. However, the expansion of offshore wind farms (OWF) has not been straightforward. In various jurisdictions, regulatory and consenting procedures are consistently highlighted as a brake on development [9]. Developers have identified delays during the consenting process as a significant

Abbreviations: CEA, Cumulative Effects Assessment; CIA, Cumulative Impact Assessment; EIA, Environmental Impact Assessment; GEnS, Good Environmental Status; OWF, Offshore Wind Farm; VEC, Valued Ecosystem Component

* Corresponding author at: School of Water, Energy and Environment, Cranfield University, Cranfield, Bedfordshire MK43 0AL, UK.
** Corresponding author.
E-mail addresses: e.a.willsteed@cranfield.ac.uk (E.A. Willsteed), s.jude@cranfield.ac.uk (S. Jude), andygill@ceibahamas.org (A.B. Gill), silvana.birchenough@cefas.co.uk (S.N.R. Birchenough).

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financial and administrative burden [9–11], burdens that also apply to emerging marine renewable energy technologies, such as wave and tidal energy [12,13], adding an additional barrier to attracting necessary capital investment. Understanding why such delays arise in established marine renewable energy markets is key to enabling improvements in existing regulatory and consenting procedures, to facilitate the development of better guidance for developers and investors, and to provide insights that may assist nations in earlier stages of deployment.

The uncertainties surrounding the environmental consequences of marine renewable energy developments and how to assess them have been identified as significant contributing factors to delays [9,14]. While the potential for environmental effects to arise is well documented [3–5,15,16], the significance of the effects remains unknown [16,17]. Regulators are thus unsure how best to discharge their legal obligation to protect the marine environment [18]. Despite this uncertainty being well documented, there are perceptions that the marine renewable energy sector receives disproportionate regulatory scrutiny [19] and that many environmental impacts are “myths” [2]. These perceptions should be reappraised taking into account i) advances in our understanding of how human activities accumulate to effect significant environmental change [20–23]; and ii) how legislation is evolving to require management of cumulative effects [18,24].

Cumulative effects drive the most pressing environmental challenges, including climate change, biodiversity loss, air pollution, marine plastic contamination, declining fish stocks, for example. Cumulative effects, defined here as effects of human activities that accumulate or otherwise interact to drive change in the condition of the environment, are a focal point for marine managers and increasingly feature in marine management legislation and legislation driving the assessment of environmental effects of development [18,25,26]. The nature of cumulative effects is such that marine management procedures have had to evolve from a siloed, sectoral approach towards a holistic approach that, in theory, manages and accounts for the entirety of human activities taking place in a given area [27–30]. But while there is consensus that assessing and managing cumulative effects is a good idea, application is problematic [18,22,26].

Managing and reversing the incremental erosion of environmental condition caused by a continuum of effects occurring over broad spatial and temporal scales is, arguably, the greatest challenge marine management has yet faced. Addressing the challenge is made more difficult by the lack of agreement about what cumulative effects are and how to assess them [18,20,31]. Legislative intent is further undermined by significant knowledge gaps relating to cumulative effects assessment in general [20,25,31], and to the cumulative effects of offshore wind farms specifically [14,17,32–35], leaving regulators, developers, investors and societal discourse steeped in uncertainty. Heeding the call from developers and regulators to clarify expectations of cumulative impact assessments (CIAs – see Table 1 for definitions of terms used in this paper) and to ease perceived burdens [9,13,19], we sought to constructively critique CIAs associated with large-scale offshore wind farms (OWF) to identify where CIAs do and do not meet the information needs of marine managers. The paper provides insights into why evolution of project-led CIAs is necessary to provide fit-for-purpose assessments of potential cumulative effects, identifies areas where short-term improvements can be made to existing practise, and provides recommendations for further research required to clarify expectations of project-led CIA relative to broader marine management aspirations.

2. Materials and methods

2.1. Rationale

The evaluation focussed on CIAs completed for the most recent, largest OWFs in United Kingdom (UK) waters. The UK has experienced rapid growth in the deployment of OWF and UK waters now contain the world's largest offshore wind projects, with 28 wind farms comprising approximately 40% of the 12,631 MW of installed capacity in European waters as of the end of 2016 [41]. In the UK, areas of seabed have been made available for lease by The Crown Estate to developers in leasing ‘rounds’. The most recent round, ‘Round 3’, includes nine zones that are of much greater area that preceding rounds (see Fig. 1 and Table 2), which will enable large-scale OWFs that will make a significant contribution to meeting the UK's renewable energy targets for 2020 [42].

As the size of the OWFs increase, the risk of significant cumulative effects arising also increases [14,17,24,35]. Concerns over potential cumulative effects caused one OWF planning application to be refused, possibly due to overly precautionary assessment [43] and uncertainties about CIA have led to delays of up to 42 months during the consenting process for some OWF [11]. The adoption of the UK Marine Policy Statement in 2011, prepared and adopted under section 44 of the Marine and Coastal Access Act 2009, makes explicit the requirement to implement holistic marine management [44]. Expectations of and aspirations for CIA in UK waters are therefore likely to increase, not decrease. Hence the UK experience with CIAs completed for OWFs provides a valuable case study from which to evaluate the strengths and weaknesses of CIAs relative to emerging marine management information needs.

2.2. Materials

Environmental Statements for nine developments were accessible via the National Infrastructure Planning portal (http://infrastructure.planninginspectorate.gov.uk/). For each Environmental Statement, chapters with information about the CIA presented were downloaded, including introductory chapters, method statement chapters and, where present, specific CIA chapters. To evaluate how the stated CIA methodologies were implemented, the benthic ecology chapter and fish and shellfish ecology chapters were also downloaded. These two ecological components were selected, as both are critical to the healthy structure and functioning of marine ecosystems [45], are sensitive to environmental disturbance at various levels of biological organisation [46], yet the effects offshore renewable energy developments may have on these components remain steeped in uncertainty [47]. Significant effects on these ecosystem components are of increasing legislative concern, as marine legislation moves towards implementing the ecosystem approach to marine management [27]. In the European Union, for example, the revised EIA Directive (2014/52/EU) requires the effects of development on biodiversity to be assessed, and the Marine Strategy Framework Directive (2008/56/EC) requires human activities to be managed while prioritising Good Environmental Status [see [27]].

2.3. Methodology

The purpose of the evaluation was to constructively critique OWF Environmental Statements to identify where CIAs were adequate and where they were less adequate in context of the need to identify, assess and manage potential cumulative effects. To do so, a novel evaluation framework was developed applying evaluation principles developed to assess the quality of risk assessments in a variety of fields [49,50]. The procedure followed to prepare and implement the framework is shown in Fig. 3. Preparation of the framework involved the identification of attributes against which CIAs would be evaluated and the development of a supporting evidence table that enabled CIAs to be scored against each attribute based on the completeness of evidence found in the CIA (see Table 3).

The attributes were selected following a review of: i) European Union legislation relevant to the protection and sustainable develop-

Table 1
Terminology and definitions used in this paper.

Term	Definition	Source
Activity	Individual action that introduces pressures into the environment	[36]
Cumulative effect	Effects of an additive, interactive, synergistic, or irregular (surprise) nature, caused by individually minor, but collectively significant actions that accumulate over time and space	[37]
Cumulative environmental change	Environmental change caused by the temporal and spatial accumulation and interaction of changes stemming from multiple sources	[38]
Cumulative impact assessment (CIA)	An assessment of potential cumulative impacts arising from a proposed development or activity, usually completed as part of an EIA	[11]
Effect	A change that is the consequence of an action, stressor or other cause	[16]
Impact	Effects of sufficient intensity, duration and/or severity cause significant change within a receptor	[16]
Pathway	Route through which receptors are exposed to pressures/stressors enabling an interaction and effect	[18]
Pressure	External abiotic or biotic factor exerted by an activity or other source that causes an effect	[18]
Receptor	Entity or system that receives and responds to pressures/stressors. Sensitivity to and recovery from effects is determined by the traits and properties of the receptor	[39]
Stressor	External abiotic or biotic factor introduced by an activity or other source that move systems out of normal operating ranges.	[18,39]
Valued ecosystem component (VEC)	Ecological components included in an assessment (EIA and CIA) selected for the ecological significance, public value or due to regulatory requirements	[40]

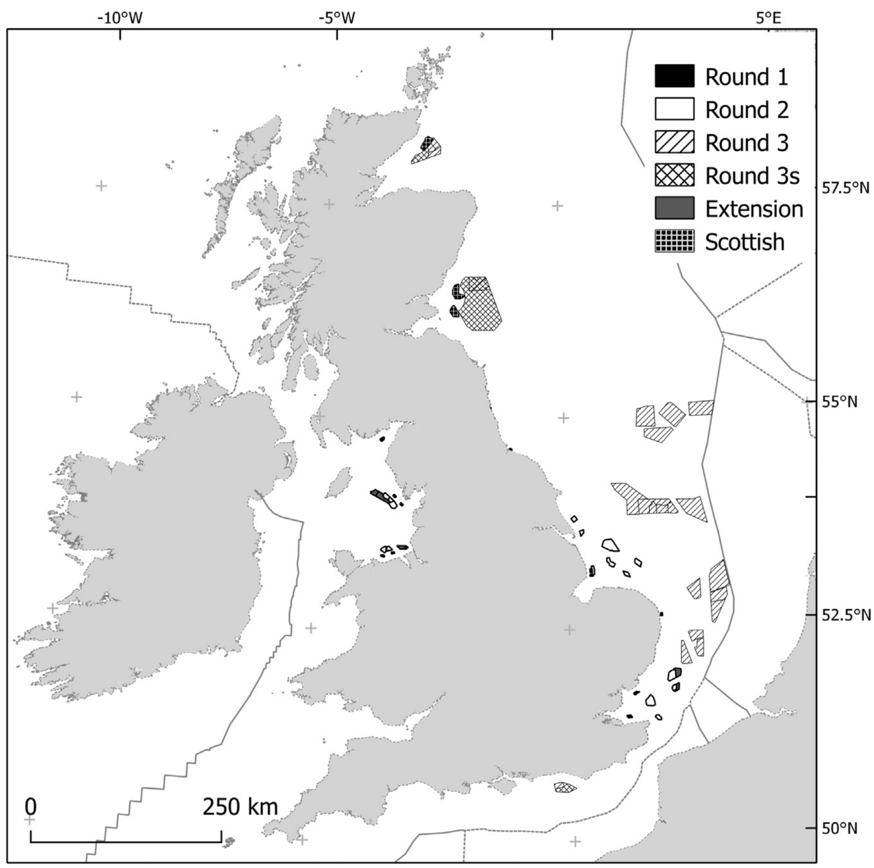

Fig. 1. Offshore wind farm developments in UK waters. Round 1, 2 and 3 developments are differentiated, indicating the much increased scale of round 3 projects in comparison with existing offshore wind farms. Data from Department for Environment, Food and Rural Affairs.

Table 2
Increasing size and capacity of offshore wind farm developments in UK waters, from the first to the most recent development 'round', indicating the significant upscaling of round 3 developments.

Development round	Number of projects	Total capacity	Status	Maximum project capacity	Example turbine capacity	Example project area
Round 1	13	1.2 GW	Operational	194 MW	3.6 MW	20 km^2
Round 2	16	~ 6 GW	Operational/construction/pre-construction	900 MW	3.6 MW	140 km^2
Round 3	9	Up to 33 GW	Consenting/pre-construction	4000 MW	8.0 MW +	> 2000 km^2

Table 3
Cumulative impact assessment evaluation framework comprising 21 attributes aggregated into 4 categories: (i) Procedure; (ii) Space & time; (iii); Pathways & receptors; and (iv) Cumulative effects. Adjacent columns set out the scoring system, which defines the evidence required to be found in the offshore wind farm Environmental Statements relative to each attribute for a score of 1 (very weak) to 4 (very strong) to be ascribed. Att = attribute.

Att. category	Att. number	Attribute description	Supporting evidence required to record score 1 (very weak) to 4 (very strong)			
			Very weak (1)	Weak (2)	Strong (3)	Very strong (4)
Procedure	**1**	The CIA explicitly defines cumulative in context of the CIA, reflecting the three components of cumulative environmental change	Cumulative not defined	Cumulative' implicitly defined for the CIA	Cumulative' explicitly defined for the CIA	Cumulative explicitly defined for the CIA. Definition recognises the three attributes of cumulative environmental change.
Procedure	**2**	The purpose and scope of the CIA specifically are clearly set out in the supporting documentation	CIA purpose and scope not defined	CIA purpose and scope not explicitly defined, but can be inferred from EIA/ CIA methodology	Explicit CIA purpose and scope documented	Explicit CIA purpose and scope documented. Expanded spatial and temporal boundaries and interaction of effects between activities referenced.
Procedure	**3**	The CIA documents and applies a clear, systematic CIA methodology, from scoping through to mitigation	Assessment methodology is not clear or systematic	Assessment methodology is systematic but the processes within each step are not clear	Assessment methodology is systematic and processes within each step are clear	Assessment methodology is systematic and processes within each step are clear. Time, space and activity components of CIA are clearly accounted for.
Procedure	**4**	The assessment makes use of appropriate data, tools and analytical methods, makes use of quantitative and qualitative methods where data allows. Assumptions and uncertainties are clearly stated and incorporated into the assessment.	The assessment is purely qualitative and lacks transparency. Linkages between data presented and the assessment outcomes are not clear.	Assessment process is qualitative and makes use of appropriate data where available. Assessment outcomes are not transparent.	Assessment process is qualitative and quantitative based on appropriate data. Analytical tools are used and described resulting in a transparent assessment process.	The assessment makes use of appropriate data, tools and analytical methods, makes use of quantitative and qualitative methods where data allows. Assumptions and uncertainties are explicitly stated.
Procedure	**5**	The conclusions of the CIA are accessible and are compiled in a document that clearly states predicted impacts before and after proposed mitigation measures, assumptions and uncertainties.	The conclusions of the CIA are difficult to access and supporting assumptions are unstated	The conclusions of the CIA are scattered and supporting assumptions are unstated or are unclear	The conclusions of the CIA are compiled and easy to access. Supporting assumptions and uncertainties are partly addressed or are unclear in the conclusion section.	The conclusions of the CIA are compiled and easy to access. Supporting assumptions and uncertainties are explicitly addressed and are presented within the conclusion section.
Space & time	**6**	The temporal extent of pressures predicted to arise from the proposed activity are identified by a scoping process and documented.	Temporal extent of proposed project activities or pressures are not documented	Temporal extent of proposed project activities leading to pressures are described without a clear process to scope/screen which are described	Temporal extent of **pressures** arising from proposed project activities are described	Temporal extent of **pressures** arising from proposed project activities are described following a clear scoping/ screening process to identify pressures to take forward in the EIA/CIA.
Space & time	**7**	The temporal extent of pressures associated with other activities included in the CIA are identified by a scoping process and documented.	Temporal extent of 'other' activities or pressures are not documented	Temporal extent of 'other' activities leading to pressures are described without a clear process to scope/screen which 'other' activities are described	Temporal extent of **pressures** arising from 'other' activities are described	Temporal extent of **pressures** arising from 'other' activities are described following a clear scoping/screening process to identify pressures to take forward in the EIA/CIA
Space & time	**8**	The spatial extent of pressures predicted to arise from the proposed activity are identified by a scoping process and documented.	Spatial extent of proposed project activities or pressures are not documented	Spatial extent of proposed project activities leading to pressures are described without a clear process to scope/screen which are described	Spatial extent of **pressures** arising from proposed project activities are described	Spatial extent of **pressures** arising from proposed project are described following a clear scoping/screening process to identify pressures to take forward in the EIA/CIA.
Space & time	**9**	The spatial extent of pressures associated with other activities included in the CIA are identified by a scoping process and documented.	Spatial extent of 'other' activities or pressures are not documented	Spatial extent of 'other' activities leading to pressures are described without a clear process to scope/screen which 'other' activities are described	Spatial extent of **pressures** arising from 'other' activities are described	Spatial extent of **pressures** arising 'other' activities are described following a clear scoping/screening process to identify pressures to take forward in the EIA/CIA.
Space & time	**10**	The CIA applies appropriate temporal boundaries relative to the VECs selected for assessment in the CIA	Temporal boundaries not defined	Temporal boundaries defined but relate to duration of activity or sub-activity, not to VEC	Temporal boundaries defined and supported by rationale for decision relative to VECs	Temporal boundaries defined, supported by rationale for decision and clearly relate to temporal pressures relative to the VECs
Space & time	**11**	The CIA applies appropriate spatial boundaries relative to the VECs selected for assessment in the CIA	Spatial boundaries not defined	Spatial boundaries defined but not supported by rationale for decision	Spatial boundaries defined and supported by rationale for decision	Spatial boundaries defined, supported by rationale for decision and clearly relate to spatial pressures relative to the VECs

(continued on next page)

Table 3 *(continued)*

Att. category	**Att. number**	**Attribute description**	**Supporting evidence required to record score 1 (very weak) to 4 (very strong)**			
			Very weak (1)	**Weak (2)**	**Strong (3)**	**Very strong (4)**
Pathways & receptors	**12**	The source-pressure-receptor pathways for the proposed activity are identified by a scoping process and documented, including potential interactions between pathways	Pathways between sources, pressures and receptors are not identified	Source-pressure-receptor pathways are documented without clear process of scoping and screening pathways	Source-pressure-receptor pathways are documented and supported by a clear process of scoping and screening pathways	The source-pressure-receptor pathways for the proposed activity are documented, including potential interactions between pathways. Assumptions about interactions are clearly stated
Pathways & receptors	**13**	The source-pressure-receptor pathways for the proposed activity and other activities are identified by a scoping process and documented, including potential interactions between pathways	Pathways between sources, pressures and receptors are not identified	Source-pressure-receptor pathways are documented without clear process of scoping and screening pathways	Source-pressure-receptor pathways are documented and supported by a clear process of scoping and screening pathways	The source-pressure-receptor pathways for the proposed activity and other activities are documented, including potential interactions between pathways. Assumptions about interactions are clearly stated
Pathways & receptors	**14**	A clear rationale is documented for selecting receptors for inclusion in the CIA (VECs) based on source-pressure-receptor pathways, likelihood to exposure and sensitivity of the VEC to pressure	No evidence of a systematic process to identify receptors for assessment found	Process of identifying receptors documented but is not transparent and rationale for receptors assessed is unclear	Systematic process of identifying receptors documented including source-pressure-pathway-receptor analysis	Systematic process of identifying receptors documented including source-pressure-pathway-receptor analysis. Receptors included in assessment are those at highest risk of adverse effects based on pathway analysis.
Pathways & receptors	**15**	The current condition of VECs is documented based on appropriate data and referencing the historical condition of the VEC	Current condition of VECs not documented	Current condition of VECs documented based on qualitative description without reference to condition relative to historical condition of VEC	Current condition of VECs documented based on appropriate use of data but does not reference condition relative to historical condition of VEC	Current condition of VECs documented based on appropriate use of data and referencing condition relative to historical condition of VEC
Pathways & receptors	**16**	The future condition of VECs without the proposed activity is predicted based on appropriate analytical methods. Assumptions are clearly stated	Future condition of VECs not documented	Future condition of VECs documented based on qualitative description	Future condition of VECs documented based on appropriate use of data but assumptions are unclear	Future condition of VECs documented based on appropriate use of data. Description is supported by clear statement of assumptions
Cumulative effects	**17**	The effects of multiple stressors from the proposed activity on VECs are assessed	Effects of multiple stressors not considered	Effects of multiple stressors from proposed activity on VECs are assessed, but rationale for combination of stressors not clear	Effects of multiple stressors from proposed activity on VECs assessed supported by clear rationale for selection of stressors relative to VECs	Effects of multiple stressors from proposed activity on VECs assessed supported by clear rationale for selection of stressors relative to VECs. Assumptions and uncertainties clearly stated.
Cumulative effects	**18**	The effects of multiple stressors from the proposed activity and other activities on VECs are assessed	Effects of multiple stressors not considered	Effects of multiple stressors from proposed activity and other activities on VECs are assessed, but rationale for combination of stressors not clear	Effects of multiple stressors from proposed activity and other activities on VECs assessed supported by clear rationale for selection of stressors relative to VECs	Effects of multiple stressors from proposed activity and other activities on VECs assessed supported by clear rationale for selection of stressors relative to VECs. Assumptions and uncertainties clearly stated.
Cumulative effects	**19**	The cumulative effect of the proposed activity and other activities on ecological connectivity is explicitly considered	Effects on ecological components not considered	Individual project pressures identified and effects on ecological components assessed	Combined project pressures identified and effects on ecological components assessed	Combined project pressures identified and incremental effects on ecological components assessed
Cumulative effects	**20**	A clear rationale for determining impact significance is presented and conclusions clearly relate to predicted change against an appropriate measure of population change	Method used to determine impact significance unclear	Method to determine impact significance is clear, however relies on qualitative decision making and/or without reference to measure of population change (threshold, PBR, etc)	Quantitative and/or qualitative methods used to determine impact significance supported by appropriate use of tools and with reference to a measure of population change.	Quantitative methods used to determine impact significance supported by tools and with clear reference to thresholds, PBR or other measure of population change
Cumulative effects	**21**	Uncertainty is explicitly considered and clearly identified	Uncertainty not explicitly considered	Uncertainty referenced in the CIA methodology but not defined. The process of considering uncertainty is not clear.	Uncertainty referenced in the CIA methodology and is defined. The process of considering uncertainty is clear.	Uncertainty referenced in the CIA methodology and is defined. Uncertainty clearly included in assessment sections.

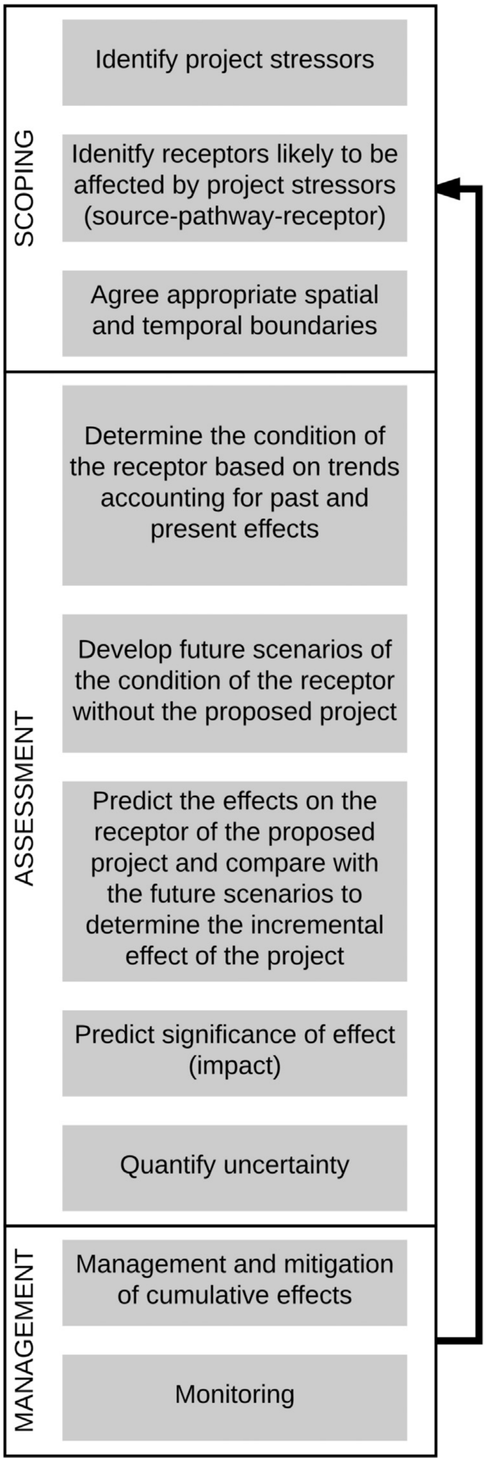

Fig. 2. Procedure to be applied to produce a meaningful cumulative impact assessment, adapted from [11,21,54]. There is currently no agreed standard for cumulative impact assessment, hence the figure presents a broad brush approach adapted from the cited studies. The arrow represents where feedback could occur to improve future practise.

ment of the marine environment and where the assessment of cumulative effects is explicitly or implicitly required (including: Directive 2008/56/EC of the European Parliament and of the Council (MSFD), Council Directive 92/43/EEC (Habitats Directive); Directive 2014/52/EU of the European Parliament and of the Council (EIA Directive); and Directive 2001/42/EC of the European Parliament and Council (SEA Directive)); ii) of key literature on the principles of cumulative effects assessment and cumulative environmental change theory e.g. [18,20,21,51], including the general steps required to complete CIAs (Fig. 2); and iii) key literature on the principles of marine ecosystem management e.g. [29,52,53]. Gathered literature and legal documentation was reviewed and criteria extracted that relate to legal obligations to conduct CIA, to principles of marine ecosystem approach management, and to key principles of assessing cumulative effects. Criteria that were amenable to translation into CIA evaluation attributes were condensed into a set of 21 attributes, listed in Table 3. The attributes focused on testing the performance of CIAs as meaningful sources of information about the likelihood of cumulative environmental change *sensu* [38] occurring due to a proposed development, and taking into account recent literature emphasising the importance of identifying effect pathways and interactions [18], and dealing with uncertainty [14].

The 21 attributes were subsequently grouped into four categories. Attributes in category 'Procedure' sought to identify strengths and weaknesses in the procedural aspects of the CIA. Attributes in category 'Space & time' investigated how CIAs identify and describe the spatial and temporal aspects of pressures arising from the proposed project and from proximal activities, and how these were applied to valued ecosystem components (VEC, see Table 1 for definitions). Attributes in category 'Pathways & receptors' address the process by which VECs were selected and whether pathways between pressures and VECs were documented. Attributes in category 'Cumulative effects' investigated how CIAs addressed the assessment of multiple stressors effecting VECs, how significance determinations were derived, and whether uncertainty (which is an intrinsic characteristic of CIA [14,18]) is explicitly accounted for. Attributes were considered to have equal weighting. To score the completeness of evidence found in Environmental Statements relative to the CIA attributes, a linear scoring system from 1 (very weak) to 4 (very strong) was developed. Each attribute was supported by a definition together with descriptions of the evidence expected to be found within an Environmental Statement to indicate how completely the CIA addressed each attribute (Table 3).

The framework was piloted by evaluating two Environmental Statements, to determine how well the attributes could be applied in practise and to validate the scale system. Following a review of the results from the pilot, attributes were revised to improve clarity and purpose, and to improve consistency of the scale applied. During the pilot, variability within Environmental Statements became apparent. For example, an Environmental Statement may include a detailed description of the spatial extent of one pressure, typically underwater sound, warranting a score of 3 (strong), but weak descriptions of other pressures, warranting a score of 2 (weak). To record where evidence was observed of better practise within an Environmental Statement, which pointed to the potential for CIA practise to improve, a mid-point between scores was deemed appropriate (e.g. 2.5 in the preceding example).

Following the evaluation, the draft evaluation tables for the nine Environmental Statements were validated by convening an expert panel (n = 6) of regulatory and ecological experts at the Centre for Environment, Fisheries and Aquaculture Science (Cefas) Laboratories in Lowestoft, UK, which is a statutory advisor to the UK government. Documentation detailing the rationale and approach to the evaluation was distributed to panel members prior to the review. The review commenced with an examination of and discussion about the attributes and the strength of evidence specified to assign an attribute score. Following this, a review of the evaluation outcomes was completed, firstly by repeating the evaluation of one Environmental Statement against the 21 attributes, and secondly by the expert panel randomly selecting attribute outcomes recorded in the evaluation tables and repeating the step-wise approach outlined in Fig. 3 to test whether draft attribute scores were a fair reflection of the evidence identified within ESs and CIAs therein. The expert panel review concluded with a discussion of the preliminary results and of the implications of the

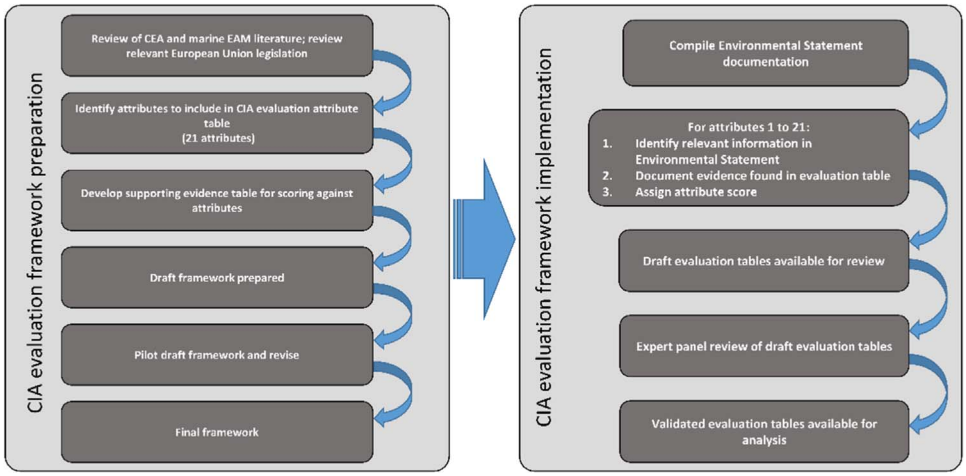

Fig. 3. Process applied to develop and implement the CIA evaluation framework, which was applied to Environmental Statements of Round 3 offshore wind farms in UK waters.

results, including where improvements to CIA guidance and practise could be made.

Following the expert panel review, validated evaluation outcomes were taken forward for analysis. The analysis sought to identify and present a representation of the strengths and weaknesses of the ESs as a group, thus outcomes recorded were averaged across the sample set. The results were presented using radar plots, one for each of the four attribute categories. To investigate the consistency of the approach and practise applied to CIAs in the Environmental Statements, attribute scores were compared between Environmental Statements. To investigate patterns in strengths and weaknesses both across the group and between Environmental Statements, average attribute scores from across the group were ranked from high to low and a note taken of the variance from the average attribute score to further consider variance between Environmental Statements. Results are anonymised to prevent identification of individual ESs.

3. Results

Radar plots showing the attribute scores averaged across the Environmental Statements evaluated using the evaluation framework are presented in Fig. 4, providing a graphical representation of the strengths and weaknesses of the Environmental Statements relative to the 21 attributes described in Table 3. Environmental Statements were strongest in relation to attributes linked to the procedural aspects of CIA (Fig. 4a) including the provision of a definition for 'cumulative', provision of a scope for the CIA, provision of a systematic methodology, evidence of appropriate use of data and tools, and the presentation of CIA conclusions. Variability between Environmental Statements was commonly observed (Fig. 5 and Table 4) thus while the average indicates the trend across Environmental Statements, some performed markedly better than others. Six Environmental Statements included an explicit definition of cumulative impacts (attribute 1), but no definition explicitly recognised the key components of cumulative environmental change. Most Environmental Statements included a clear purpose and scope clarifying the CIAs (attribute 2), with four Environmental Statements scoring 4 (very strong). A systematic methodology was described and applied in all but one Environmental Statements and CIA methodologies tended to be an extension of the EIA methodology. In Environmental Statements with strong or very strong method statements, the application of the methodology was less robust, perhaps indicating the challenges of translating CIA theory into practise.

Evidence of the use of appropriate data from baseline surveys and literature reviews was identified in all but one Environmental Statements, and all applied a mixture of qualitative and quantitative analytical tools. The use of analytical tools varied, for example modelling methods were widely applied to create underwater noise contours but only rarely were quantitative assessments of the percentage loss of particular habitat types applied. Qualitative methods, specifically expert judgement, were invariably used to determine how significant the impact of pressures identified would be regardless of whether the assessment process involved quantitative or qualitative analysis. The presentation of CIA results varied, but all but one of the Environmental Statements presented CIA results clearly. However, to obtain detail about how CIA conclusions were derived required delving into the main CIA chapter or the benthic ecology and fish and shellfish ecology chapters.

Evaluating how pressures or the activities that create pressures were identified and described, both for individual MREDs and for other nearby activities, such as aggregate dredging or proximal OWFs, highlighted a marked difference between the consideration of spatial and temporal components of potential effects (Fig. 4b). The spatial aspect of activities and pressures tended to be dealt with more comprehensively than the temporal aspect. All but two Environmental Statements clearly documented how spatial pressures were identified (attribute 9), resulting in spatial boundaries being applied that were straightforward to understand and apply relative to valued receptors included in the assessment (attribute 11). By contrast all Environmental Statements scored weak or very weak regarding the identification and documentation of temporal pressures (attributes 6 and 7). A common assumption appeared to be that temporal pressures exist for the duration of an activity rather than demonstrating consideration of the temporal aspects of pressures relative to valued receptors. Thus temporal boundaries (attribute 8) scored less well on average.

In general, Environmental Statements included a clear process documenting how valued receptors were identified (attribute 14), however, consideration of pathways (attributes 12 and 13) and consideration of the current and future, without development, conditions of the valued receptors (attributes 15 and 16) were on average weak (Fig. 4c). Notable variation between Environmental Statements was observed (Table 4). Valued receptors in the chapters evaluated were the same as those included in the EIA section of the chapters and broadly align with receptors of conservation/legislative interest. Examples of better practise were observed whereby potential pathways were subject to a scoping process and potentially significant pathways scoped in were clearly set out and the likelihood of a receptor being disturbed was discussed. In Environmental Statements that scored less well, pathways could generally be inferred through the text within the Environmental Statements chapters, and by working backwards to link the assessed impact on a receptor back to the receptor sensitivity

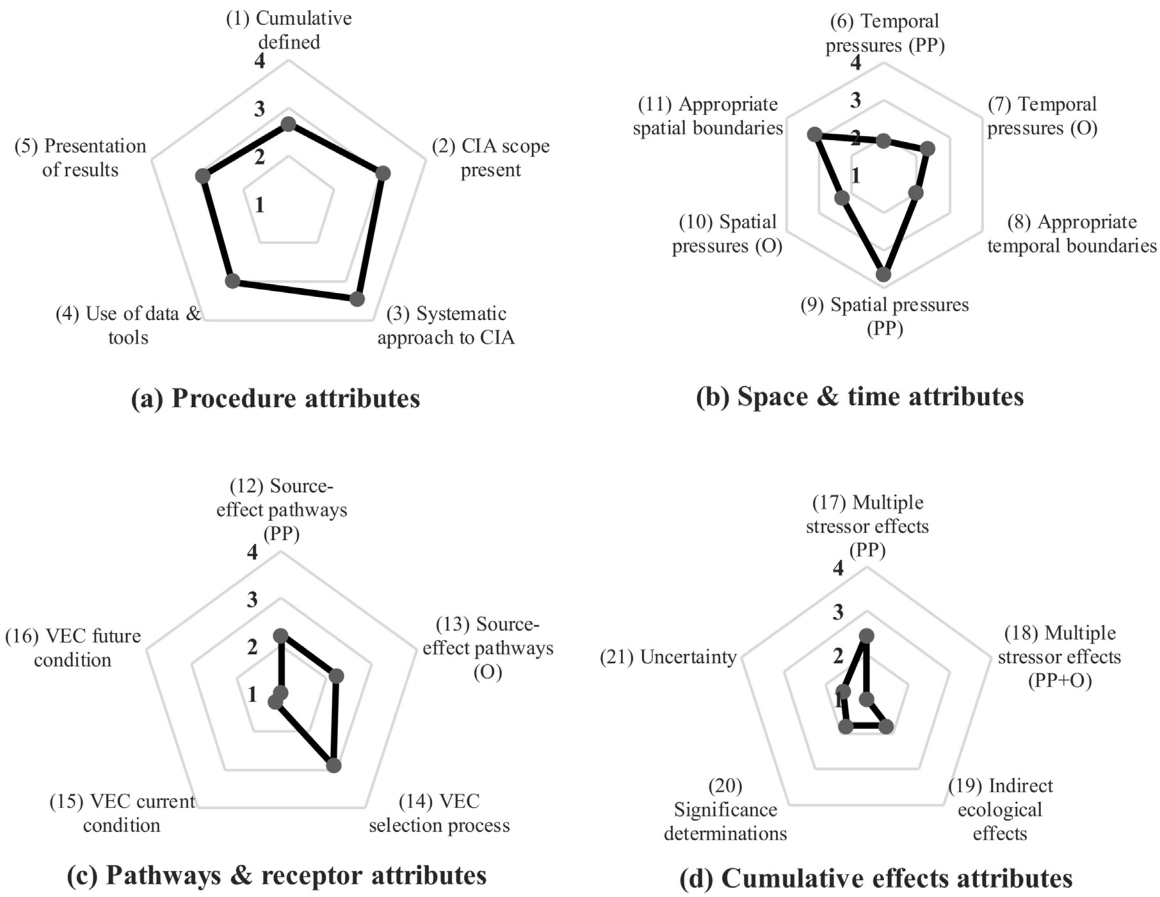

Fig. 4. Radar plots presenting the attribute score averaged across all Environmental Statements evaluated (n = 9), aggregated into Procedure; Space & time; Pathways & receptors; and Cumulative effects categories. 'PP' = proposed project. 'O' = other activities. 'PP+O' = proposed project and other activities. 'VEC' = valued ecosystem component.

matrix and impact magnitude matrix. However, this is not an intuitive process. Environmental Statements that included graphical representations of pathways were far clearer to interpret.

A consistent weakness identified was the consideration of the condition of valued receptors included in the assessments. Unless a valued receptor was of conservation interest, the current condition of the receptor (attribute 15) tended not to be assessed with all Environmental Statements recording scores of 1 or 2. The trajectory of valued receptor condition without the proposed project (attribute 16) was invariably not considered, reducing confidence in the impact significance determinations due to the difficulty this poses when attempting to understand the consequences of an incremental change to the condition or abundance of a valued receptor.

The most striking results were observed in the final attribute

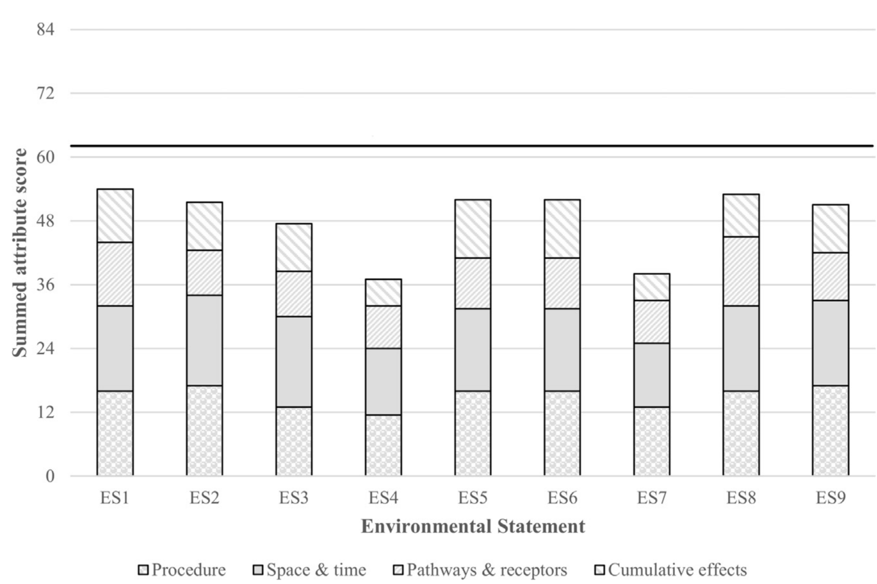

Fig. 5. Variance in scores between Environmental Statements evaluated (n = 9). The four components of each bar correlate with the attribute categories presented in Fig. 4. The horizontal black line indicates the expected height of the bar if an Environmental Statement scored 3 for each attribute ('strong').

Table 4
Evaluation attributes ranked by averaged outcome level across all Environmental Statements (n = 9). The maximum outcome level recorded and minimum outcome level recorded are also presented to provide an indication of variance between Environmental Statements. Att. = attribute.

Att. rank	Attribute category	Attribute description	AVG score (n = 9)	Max score	Min score
1	**Space & time**	Spatial extent of pressures of proposed project described	3.7	4	2
2	**Procedure**	Systematic CIA methodology applied	3.4	4	2
3	**Space & time**	Spatial boundaries applied are appropriate relative to VECs	3.1	4	2
4	**Procedure**	Clear CIA scope present	3.1	4	1
5	**Procedure**	Appropriate use of data & tools	3.0	4	2
6	**Procedure**	Clear presentation of CIA results	2.9	3	2
7	**Pathways & receptors**	Clear rationale for selecting VECs	2.9	4	2
8	**Procedure**	Explicit definition of cumulative impact	2.7	3	2
9	**Cumulative effects**	Multiple stressor effects assessed (proposed project only)	2.4	3	1
10	**Space & time**	Temporal extent of pressures of 'other' activities described	2.3	2.5	1
11	**Space & time**	Spatial extent of pressures of 'other' activities described	2.3	2.5	1.5
12	**Pathways & receptors**	Source-pressure-receptor pathways of proposed project described	2.2	3	2
13	**Pathways & receptors**	Source-pressure-receptor pathways of 'other'; activities described	2.2	3	2
14	**Space & time**	Temporal boundaries applied are appropriate relative to VECs	2.0	2	2
15	**Space & time**	Temporal extent of pressures of proposed project described	1.9	2	1
16	**Cumulative effects**	Indirect effects on ecosystem components considered	1.8	2	1
17	**Cumulative effects**	Significance determinations follow clear process	1.8	2	1
18	**Cumulative effects**	Uncertainty explicitly considered	1.6	3	1
19	**Pathways & receptors**	Existing VEC condition documented	1.2	2	1
20	**Pathways & receptors**	VEC future condition without proposed project documented	1.0	1	1
21	**Cumulative effects**	Multiple stressor effects assessed (project and other activities)	1.0	1	1

category, 'Cumulative effects', which sought to evaluate how CIAs assessed multiple stressor effects on receptors, how impact significance determinations were derived, and how uncertainty was incorporated into the CIA. From a perspective of wanting to understand the cumulative effect of a development on the environment, all Environmental Statements provided incomplete information (Fig. 4d) and there were clear differences between Environmental Statements (Table 4). Environmental Statements tended to include a chapter on interrelationships, within which the effects of different stressors arising from the OWF on valued receptors were considered. Significance determinations in the interrelationship chapters were qualitative and based on significance determinations associated with individual stressors being combined. An unstated assumption appeared to be that minor stressor effects could not interact to have a greater effect on a receptor, contrary to cumulative effects theory [37,55,56].

The specific CIA components of the Environmental Statements (as distinct from the interrelationships chapter or section) considered the potential accumulation of effects arising from the OWF and proximal activities. However, the CIAs consistently assessed stressors in isolation, i.e. assessed the potential for accumulation of like-for-like pressures, for example, overlapping sound contours from temporally coincident percussive piling. As with the interrelationships chapters, the CIA chapters used significance determinations transposed from the main EIA chapters. The unstated assumption observed in the interrelationships chapter also appeared to apply to the CIA chapters, i.e. individual, seemingly insignificant effects could not interact to have a greater effect on a receptor.

The average score associated with the consideration of uncertainty (attribute 21) was low (1.6, see Table 4). Better practise was observed in some Environmental Statements that included a description of and approach to dealing with uncertainty in the CIA methodology. As with the CIA methodology, a discrepancy between the stated methodology for dealing with uncertainty and application in the CIA was observed in some cases. It was difficult to establish how uncertainties associated with, for example, cause-effect relationships were incorporated into the EIA or CIA.

Significance determinations tended to be based on qualitative, expert opinion. Information about how pressures from other activities could interact with pressures from the proposed development to affect a valued receptor was typically qualitative and assessed that cumulative effects could occur where temporally coincident, spatially overlapping activities were identified. In context of the fish and shellfish ecology and benthic ecology chapters, it was difficult to interpret how the potential for pressures to accumulate were assessed. Whether it is reasonable to expect individual developments to obtain detail about other activities to enable an adequate CIA is moot, however uncertainties and assumptions related to other activities were rarely cited. Thus significance determinations (attribute 20) scored low, resulting in an average recorded score of 1.8 (see Table 4). Examples of better practise were observed in more recent Environmental Statements that applied a tier system to define the likelihood of pressures from the OWF overlapping with future activities or developments.

The variance between Environmental Statements was considered in more detail by ranking the attributes by outcome, from high to low (Table 4) and by presenting the sum scores of the attribute categories (Fig. 5). This indicated patterns in the strengths and weaknesses of the ESs: for example, attributes relating to the procedural aspects of CIA tended to have higher average outcomes than attributes relating to assessing cumulative effects; spatial aspects of the pressures are generally considered more comprehensively than temporal aspects. Maximum and minimum scores recorded, along with the average score across all Environmental Statements are presented in Table 4, further indicating where variation between Environmental Statements exists and providing insights into where better practise could be achieved. For example, scores recorded for attribute 2 (the inclusion of a clear scope to guide the CIA) varied between 1 and 4. Aspects of better CIA practise (rather than procedure) were also observed, such as a clearer and more comprehensive scoping process, suggesting that elaboration and dissemination of better practise could improve CIA practise for little cost.

Investigating the average sum of scores provides further evidence of the strength of Environmental Statements at meeting procedural attributes of CIAs and the need to improve CIA practise. The average sum score for the 'Procedure' category (5 attributes) was 12 versus an average sum score of 8.5 for the 5 attributes included in the 'Cumulative effects' category. Fig. 5 provides a clear visual representation of the variance observed between Environmental Statements, with total evaluation scores recorded varying from 37 to 54.

4. Discussion

4.1. Implications

This is, to our knowledge, the first evaluation of published cumulative impact assessments against attributes that would inform regulators and managers of the marine environment about the scale and significance of potential cumulative effects. The results of this study adds to recent research highlighting the need to improve CIA practise [25,31] by providing specific evidence of the dissonance between CIAs completed for the foremost emerging maritime industry in the North Sea and the expectations of what CIA should be (e.g. [18,20,57]). CIAs invariably assessed single stressor-types, e.g. habitat loss, arising from different developments and activities on receptors. The interrelationships chapters considered multiple stressors arising from the proposed development only acting on receptors. The CIA and interrelationships chapters each present partial assessments of cumulative effects. While highlighting an issue relating to terminology, clarification of which remains a pressing need [18,20,31], the interrelationships chapters were conceptually closer to an assessment of cumulative effects than the CIA chapters. As receptors integrate effects arising from multiple stressors from multiple sources [20,39], future CIAs would be more effective if the single stressor assessment approach applied in the CIA sections were integrated with the interrelationships chapter and transboundary chapter using a common methodology to a provide a combined assessment of the cumulative effects of a proposed development on receptors. Understanding the cumulative effect of a development on the environment requires, by definition, consideration of the sum total of effects on the environment to date and the incremental effect that a proposed development will have on that baseline [51]. The Environmental Statements evaluated here do this partially and relying primarily on qualitative methods. This may provide some insight into why delays in the decision-making process exist relative to CIA; decision-makers are not supported by robust CIAs.

Cumulative impact assessments are a recognised weakness when conducted using standard EIA approaches [58,59]. Yet CIA is regarded as the most meaningful analysis within an EIA [20] by providing, in theory, a more complete understanding of the consequences of development. While improvements, such as those suggested here, would improve consistency and the quality of information provided to decision-makers, a question arises about the usefulness of single stressor EIA assessments if they are not combined to provide a more complete analysis of how a proposed development will effect change in the environment. Thus a deeper question arises about the role of CIA within EIAs, particularly in light of holistic marine management and sustainable development ambitions.

The driving principle of modern marine management is to protect, maintain and where possible enhance and/or restore natural ecological characteristics while delivering the services and benefits required by society [27]. This evaluation suggests that current EIA-led CIAs do not provide a meaningful assessment of potential cumulative effects, as required by the recently revised EIA Directive (Directive 2014/52/EU), or as required by the Marine Strategy Framework Directive (Directive 2008/56/EC). An argument can also be made that the ESs do not provide marine managers with an adequate assessment of the likely effect of a development on the status of the environment, posing a problem for those tasked with achieving 'Good Environmental Status' [48] by 2020, and who are faced with climate change effects adding a further layer of complexity [60]. Placed in the context of evolving legislation to consider effects of development on biodiversity and to include climate change in an assessment, EIA-led CIA practise needs to evolve if it is to comply with legislated expectations of CIA (Table 5). Further to the question raised previously about the role of CIA within EIA, a more radical approach may be warranted where CIA is placed above EIA, with EIA contributing to higher level, regional assessments where cumulative effects can be better quantified [20,21,26,35].

4.2. Strengthening EIA-led cumulative impact assessment

The weaknesses identified by the evaluation indicate that project-led CIA shortcomings expounded by, for example [20,57,61], also apply to CIAs submitted within Environmental Statements for OWF in UK waters. Such shortcomings have been cited as reasons for widespread implementation of strategic or regional approaches, which being independent of individual projects are in theory better placed to assess cumulative effects [21,62]. However strategic environmental assessments (SEAs) and regional assessments suffer from many of the issues that limit project-driven CIA, including, among others, the lack of consensus on the nature of cumulative effects and the complexity of assessing cumulative effects [62–64]. Further, SEAs tend to apply an "EIA-plus" [21] approach and maintain focus on the effects of a proposed action on receptors, be they ecological or social, rather than providing the more complete picture required that assesses how a receptor is being impacted by the multitude of actions effecting change in the receptor (Fig. 6). Also problematic is the weak relationship between regional or strategic CIA and project-level EIA: regional CIAs tend to apply approaches more in keeping with cumulative environmental change theory (such as consideration of greater spatial scales, e.g. [65]), but associated decision making processes tend to be weak; project-level CIAs in contrast are associated with stronger decision making processes [20]. Given that the majority of CIAs are completed in relation to individual activities and developments, project-level CIAs are likely to remain a vital source of information for regulators, marine managers and their statutory advisors. Hence, strengthening project-level CIA practise is highly desirable.

4.2.1. Improving consistency and improving practise

Calls to clarify expectations regarding project-driven cumulative effects assessments [10] were partially answered by the publication of recent industry-led guidelines for UK developers [11]. Such guidelines provide greater clarity about expectations and how to improve consistency and seek to enable meaningful CIAs. Notably, aspects of the guidelines were not observed in the CIAs evaluated, for example to include valued receptor trends in assessments to provide a more robust analysis of the effects of development on the valued receptor ([11]; p.6). This suggests the guidelines have not yet been fully adopted. This study indicates that further clarification and guidance is necessary if expectations of CIA associated with broader marine management objectives are to be met.

The production and application of revised guidelines to improve the consistency and quality of CIAs would be a relatively simple action that would aid developers and EIA practitioners to have clarity about the expectations of a CIA relative to a proposed project. Given the evolution of marine management towards the ecosystem approach, the novelty of the MRE industry and the size of planned developments

Table 5
Examples of increasing demands placed on cumulative impact assessments (CIAs) as a result of evolving legislation, and qualitative assessment of CIA compliance based on evaluation results.

Emerging information requirements demanded of CIAs as a result of evolving legislation	Example legislative instrument
Is the cumulative effect of a proposed development or activity on biodiversity assessed?	EIA Directive (Directive 2014/52/EU)
Is climate change considered with the assessment, as a receptor and as a risk to infrastructure?	
Does the assessment support the ongoing marine region assessment of cumulative effects on human pressures and impacts?	MSFD (Directive 2008/56/EC)
Does the assessment provide information to manage pressures and impacts relative to good environmental status targets?	

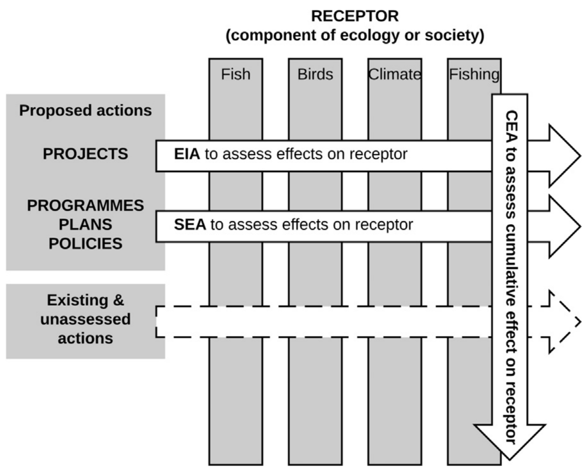

Fig. 6. Relationship between EIA and SEA, and the theoretical role of cumulative effects assessment in cutting across the various assessment levels to provide a comprehensive understanding of how a receptor is impacted by the many actions effecting change. The dashed arrow indicates actions that are not subject to assessment, but which contribute to incremental change in receptor condition. Example of ecological and/or societal receptors are shown. Adapted from [21].

in UK and adjacent waters suggests that the challenges the marine renewable energy industry has experienced during consenting may be a sign of things to come for other industries. From a positive perspective, this provides the marine renewable energy industry with an opportunity to contribute to the development and application of best (or better) practise that could be transposed to other sectors.

From an ecological perspective, revised guidelines would benefit from defining what is expected of project-led CIAs, including:

- Requiring CIAs to include a complete definition of cumulative effects, accounting for the characteristics of cumulative environmental change;
- Requiring CIAs to include a scope that sets out what the CIAs intends to achieve;
- Requiring CIAs to include a clear CIA methodology that is applied in practise;
- Setting out best practise for the structure and content of an adequate scoping process to include clear analyses of source-pressure-pathways and a means of focussing the assessment on key pressures relative to valued receptors;
- Setting out best practise for identifying and applying appropriate spatial and temporal boundaries;
- Clarifying how the baseline condition of valued receptors should be derived, considering population trends (distribution, abundance and variability);
- An approach to deriving significance determinations, which includes the incremental effect of multiple stressors acting on valued receptors;
- A requirement to explicitly deal with uncertainty to enable CIA reviewers to identify where uncertainties result in increased risk of adverse environmental impacts.

Examples of better practise were observed suggesting that research is warranted to identify and clarify what is possible at the present time, and to provide examples in revised guidance. Step-wise frameworks for cumulative effects assessments outlining the integral components of an assessment, e.g. [18], are a useful reference from which project-level CIA guidance could be developed. Scoping in particular is an area where increased attention would reap benefits for CIA practitioners and decision-makers, as in theory strengthening the scoping process could validate a focus on fewer receptors, which could be more ecologically meaningful and which could support regulatory requirements to consider the bigger picture (i.e. the effect on the status of the environment). By identifying receptors most sensitive to pressures predicted to arise from proposed developments, the number of receptors included in the assessment could be reduced and baseline and monitoring data collection focussed to provide for more robust analyses of effects on valued receptors. If an appropriate methodology for scoping could be designed that provides a robust means of determining which stressors, pressures and receptors to include in a CIA, e.g. [66,67], EIAs as well as CIAs could benefit in the longer term, by encouraging consistency and thus comparability between assessments, to improve the regional picture. Logically the methodology could be extended to apply across maritime activities submitting CIAs/EIAs in a given area, which would further aid the identification and resolution of key knowledge gaps through pooling effort and monitoring data. Whether there are meaningful regional indicator species, processes or functional groups that could be incorporated into assessments and transposed across activities with analogous pressures would require research [68].

The treatment of receptors within an assessment warrants further discussion. CIAs evaluated were observed to have a greater focus on spatial considerations than temporal considerations. This highlights a weakness of the CIAs, as the capacity to identify significant environmental change arising through incremental changes that accumulate and interact over time is greatly reduced [21,36]. Thus the inclusion in CIAs and in EIAs of receptor trends and trajectories, e.g. [69], is important to determine the condition of the receptors at the current time and to provide more robust context from which to derive significance determinations. Environmental Statements evaluated here commonly stated that valued receptors have adapted to past and existing activities, implying that the current condition of valued receptors is normal. This approach enables a gradual accommodation of the incremental decline in the condition of the environment, known as the shifting baseline syndrome [70]. The OWF Environmental Statements described already installed infrastructure, practiced licenced activities and implemented measures as part of the existing environment to which receptors have already adapted. Including existing activities within the EIA or CIA is referred to within ESs as a potential risk of “double-counting”. However, Annex IV 5(e) of the EIA Directive requires that existing environmental problems within an area are considered (Directive 2014/52/EU). Excluding existing activities from the assessment is therefore not appropriate [61,70,71]. That said, establishing an appropriate baseline is problematic, leading into debates about historical states and the appropriateness of seeking a return to what no longer exists [72]. However, agreeing a common baseline in a given area is critical if interventions are to be evaluated [73], hence the recommendation that trends and trajectories are specified in the guidelines for inclusion in a CIA.

Given the many uncertainties associated with OWF environmental effects, with CIA and with the marine environment in general [18,74], explicit consideration of uncertainty is crucial [14]. The term ‘uncertainty’ observed within Environmental Statements evaluated more frequently referred to uncertainty about the likelihood of ‘other future activities’ occurring and thus whether or not to include these activities in the CIA. This presents an opportunity for improvement as the explicit consideration of uncertainties associated with, among others, the availability of data, of cause-effect relationships and of analytical methods, would support decision-makers in making determinations of environmental risk [14]. The variability observed in ESs indicates better practise exists, thus the inclusion in revised guidelines making explicit expectations of the inclusion and treatment of uncertainty would be beneficial and could be supported by recent reviews of dealing with uncertainty, e.g. [75]. At a minimum, improved consistency of CIAs completed in Environmental Statements should be achieved before the perceived EIA burden is reduced (Fig. 7).

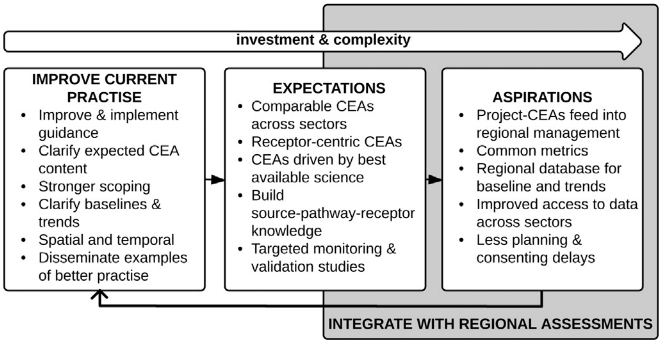

Fig. 7. Schematic outlining improvements to project-led cumulative impact assessments leading to increased support for regional marine management and marine spatial planning objectives. Actions moving from left to right increase in complexity and required investment to achieve. A feedback loop is shown to demonstrate that as higher level improvements are made, project-led assessments should be revisited and potentially streamlined in light of reduced uncertainty.

4.2.2. *Clarifying expectations*

The recommendations for the guidelines included in the preceded section (Section 4.2.1) should be possible to develop and apply without adding to the growing complexity of the EIA process. Further improvements to project-led CIA practise in light of the evolving need for CIA would require additional study, as determining what is reasonable to expect of project-led CIA is tricky when the prevailing view is that meaningful assessments of cumulative effects requires a regional assessment, e.g. [20,61].

Cumulative impact assessments for individual developments or activities typically apply narrow spatio-temporal boundaries relative to project-related stressors [21,57,61,76], but assessing the likelihood, magnitude and thus significance of probably environmental change as a result of a proposed development requires the predicted effects to be placed in context of a receptor or the receiving environment more broadly [20]. The timescales, spatial extent and range of pressures that collectively effect change may not lend themselves to assessment by individual projects [21] where obtaining information on other activities and developments is often problematic [10].

A move towards an effects-based assessment approach, as is recommended by numerous proponents of cumulative effects assessment, raises a challenging question, as EIAs invariably focus on stressors associated with the proposed development. This is the bread and butter of EIA practise [37,77] and a movement towards effects-based approaches would require a significant shift in thinking among EIA practitioners, away from a comparatively narrow, easier to assess approach, towards a broader approach with greater uncertainties attached, and thus potential for greater confusion rather than clarification of expectations

A shared regional baseline, supplemented by the focussed, site-specific studies conducted by developers, would seem a logical development to support CIA practise [26]. The scoping and screening processes would benefit, by enabling a common frame of reference for regulators, regulatory advisors and developers to work from, to identify which VECs are most sensitive to the expected pressures, what the condition of the receptors is now and what their condition is likely to be based on current trends. Assuming access to data can be encouraged in the UK (or legislated for), as occurs in other European Union Member States such as Germany, revisiting data with a set of revised questions and novel analytical tools may yield valuable information without requiring additional, costly at sea data collection. Examples of data-sharing and joint research exist in the UK within the aggregate dredging industry, which pools resources and applies a regional, multi-operator approach to assessing environmental effects [78]. The advantages of such an approach are better ecological decision-making, cost benefits for the industry through streamlined monitoring over time and improved decision-making capacity for faster consenting/licensing process [79].

4.2.3. *Aspirations: realising the potential*

Realising the potential of project-led CIA requires challenging questions to be addressed, such as thinking through what information EIA provides decision-makers now and whether it can be restructured to better support evolving marine management ambitions. The potential for CIA to support marine management ambitions in the 21st century will not be met by project-led CIA alone. The nature of environmental change is such that regional assessments are critical, as such assessments can incorporate broad enough spatio-temporal scales and include the multitude of activities effecting change in the environment. The OWF CIAs evaluated sit within Environmental Statements that do, however, provide a great deal of detail about the local environment, at a level of resolution that is substantially higher than regional assessments, e.g. [80,81]. Hence conceptual frameworks that seek to connect both approaches have been researched, e.g. [57], which seek to combine the benefits regional and project-level assessments can provide. Integrating CIAs completed at different scales may reap substantial benefits, as the opportunity exists to establish a feedback loop that improves practise at project and regional level (highlighted in Fig. 7), and which could lead to cost and efficiency savings in time.

4.3. *Evaluation challenges*

At this point, it is useful to reflect on the challenges encountered applying the framework. The principal challenge was due to the variability encountered in terms of content and presentation of the Environmental Statements evaluated, and due to variation of treatment of different activities/stressors within ESs. Many chapters cross-referenced different chapters and appendices, resulting in lengthy searches to identify and consider relevant chapters. Environmental Statements variably included separate CIAs, interrelationships and transboundary chapters, all of which had relevance to the evaluation. Evaluating the CIA inevitably also involved referencing specific receptor chapters, such as benthic ecology, which contained the bulk of the analyses used in the CIA and interrelationships chapters. The main EIA chapters contained the bulk of analysis and the assessment of stressor effects on valued receptors based on qualitative descriptions of receptor sensitivities to individual stressors contained in the EIA formed the foundation for CIAs and interrelationship chapters. Assessing how complete evidence within Environmental Statements was relative to some attributes was therefore challenging.

The analysis showed the variance was a significant component of ESs. Such variability is counter to the aspirations of the EIA process [77] and is problematic for decision-makers. The variability also posed a further challenge for the analysis. As the sample size was limited ($n = 9$), presenting the average scores risks masking significant variance between scores achieved by ESs evaluated, hence the specific consideration of variability presented in Fig. 5 and Table 4. Together with the variability encountered and the difficulty applying specific attributes, the challenges highlighted the more theoretical focus of the evaluation in comparison with, for example, an assessment of regulatory compliance, e.g. [82]. The objective of the evaluation was, however, to distinguish and provide a representation of the strengths and weaknesses of the CIAs. Despite the challenges and the small sample size, the results highlight where CIA practise requires attention if it is to provide decision-makers with meaningful analyses of the cumulative effect of a proposed development.

5. Conclusions

A novel evaluation framework was developed to assess offshore wind farm CIAs relative to the information needs of regulators and managers tasked with implementing the ecosystem approach, a key driver behind many maritime regulatory systems worldwide. While project-led CIA shortcomings have long been discussed, the method applied in this study enables a systematic approach to identifying specific strengths and weaknesses of current practise. The evaluation highlighted that CIAs do not provide confidence that potential cumulative effects have been identified or evaluated, indicating why delays during the consenting and regulatory processes may arise. Such shortcomings expose regulators and marine managers to the risk that significant environmental change may occur and legislated environmental protection targets are missed. The framework also enables between-CIA comparison including the identification of better practise that could be publicised to improve raise the standard of project-led CIA.

The focus of this study veered away from the legal obligations that dictate how project-led CIA is practised, towards the need to manage cumulative environmental change. This focus arguably led to some attributes being included in the evaluation framework that would be very difficult for a project-led CIA to address; adequate consideration of cumulative effects of multiple activities on a given receptor, for example. However, the weaknesses such attributes highlight serve to reinforce the need for regional assessments that can provide the broader context project-led EIAs lack. However, despite the constraints of EIA-led CIA, we feel EIAs should have a key role to play in marine regional assessments, as data gathered for such assessments is often of higher resolution than existing regional assessments and, if data gathering and presentation is consistent, the burden of future project assessments should reduce as the regional baseline improves, assuming developers make baseline and monitoring data available.

Perspectives of CIA cover a spectrum, from being an irritating legal requirement to a prerequisite for sustainable development [31]. While there are reasonable calls to reduce delays during the consenting and regulatory processes, it is crucial to recognise the uncertainties associated with CIA and the risk cumulative effects pose to ecosystem structure and functioning. Reducing CIA expectations would run contrary to sustainable development obligations. The onus to improve CIA practise is likely to grow, as emerging studies point to renewable energy developments having the potential to disrupt ecosystem processes [1]. Recognising that cumulative effects are enormously complex, meeting expectations of improved practise will require a concerted effort by developers, practitioners, regulators and scientists before the consenting process can reasonably be streamlined. In keeping with much of the research into cumulative effects (or impact) assessment, our study points to the need for integration with regional assessments. But recognising that such changes take time and that scaling-up of renewable energy infrastructure is needed now, together with other recent research seeking to improve CIA practise [18,25], our study points to straightforward improvements that would improve current practise and provide decision-makers with more robust assessments.

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Results (anonymised) and supplementary material are available. Enquiries regarding the data generated should be sent to researchdata@cranfield.ac.uk.

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