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Abstract

Increasing concerns over climate change have prompted rapid growth of renewable energy over the past few decades, particularly wind energy. However, as the installation of wind farms rises, so will the need for decommissioning and analysis of the environmental impacts associated with decommissioning. This paper investigates how Environmental Impacts Assessments (EIA) identify, estimate and manage potential impacts of decommissioning. EIAs from 12 onshore and offshore windfarms consented between 2009 and 2014 in England and Scotland were analysed and compared. Attributes of these windfarms' Environmental Statements (ES) were scored under six categories: decommissioning in EIA stages, definitions of decommissioning, amount of analysis, depth of analysis, impacts identified, and proactive planning. Onshore windfarms generally tended to investigate the impacts of decommissioning less than offshore windfarms, even those which gained consent in the same year. The investigation of the impact of decommissioning improved for windfarms consented in the latter years of the study period. Across the ESs there was a lack of analysis of potential impacts from decommissioning in their own right: not simply as a reversal of the construction process. The impacts of different end of life scenarios were not analysed in any of the ESs studied. There is evidence to suggest the presence of windfarms, especially offshore, could in some cases be environmentally beneficial for certain species. However, the ecological impact of removing offshore structures at the end of life is unknown and is currently not investigated nor predicted in EIAs. Understanding the potential implications of full or partial removal of marine structures, or alternatives to decommissioning, could ensure that appropriate mitigation is considered at an early stage by both developer and consenting authority. That being said, it is also important to update the assessment of potential impacts over the life of the project as more information on the environment is gathered and end of life plans develop.

1 Introduction

Renewable energy has steadily grown for the past few decades (IRENA, 2016) and even greater development rates are likely as the world tackles climate change (The Crown Estate, 2019). Significant capacity increase will be required from wind energy, and other low-carbon technologies, to reach the goal set up by the IPCC to prevent the global surface temperature change from reaching the 1.5° limit (UNFCC, 2015).

The more widespread installed renewable energy projects are windfarms (51% of total renewable generation in the UK came from onshore and offshore wind energy in 2018 (Department for Business, Energy and Industrial Strategy, 2019a) (Department for Business Energy and Industrial Strategy, 2019a). As the installation of windfarms increases, so will the need for decommissioning. Therefore, determining the environmental impacts of decommissioning of onshore and offshore windfarms will also increase in importance. Smart et al. (2014) found that addressing decommissioning was an important aspect of an EIA, partly because much of the argument for proving non-significant environmental effects due to windfarms has been that their presence, and therefore any effects caused by them, are temporary. Therefore, stating that a windfarm will eventually be removed would appear to be an integral part of this conclusion. There has been evidence that a disturbed environment might not fully recover to its pre-disturbed state (Elliott, et al., 2007), potentially bringing into question the temporary nature of windfarm impacts, especially where parts of the windfarm are left in situ after decommissioning however this is a matter for the EIA to determine (Smart, et al., 2014).

However, determining the environmental impacts of decommissioning is not straightforward. Many windfarms are coming to the end of their design life, yet whilst construction and operation are highly planned, decommissioning receives little consideration especially during the early stages of windfarm development (Topham & McMillan, 2017; Welstead, et al., 2013).

Very few onshore windfarms have been decommissioned and as such, there is little standardisation or protocol to follow (Topham & McMillan, 2017). Despite onshore windfarms having been established longer than those offshore, there is significant lack of guidance and best practice compared to offshore, especially from government. This, combined with the lack of certainty about what will happen at the end of a windfarm's life and the procedure that will be used, means that Environmental Statements (ES) generally tend to be vague, brief, lack detail, and use unclear methodology in their analysis of decommissioning (Welstead, et al., 2013).

Windfarms usually have an expected lifetime of 20-25 years (Topham & McMillan, 2017), and at the end of this time there are several potential scenarios for the fate of the windfarm, as outlined in Table 1.

Table 1. Potential scenarios at the end of the deign life of a windfarm, and the resulting actions.

Scenario		Action at end of design life	Power generation	Action at end of extended life	Waste Hierarchy/ Circular Economy (Parts no longer required)	Waste Hierarchy/ Circular Economy (Parts required/ retained)
Decommission	Full decommission	Full removal • Landfill • Recycle	Stops	N/A	4. Recycle 5. Disposal	N/A

	Partial decommission	Partial removal - Landfill unusable parts - Recycle unusable parts - Reuse remaining parts on-site - Reuse remaining parts elsewhere	Stops	N/A	4. Recycle 5. Disposal	2. Reuse
Life extension	Full repowering	Replace all parts	Continues	Decommission Life extension	4. Recycle 5. Disposal	1. Prolong life of windfarm
	Partial repowerin	Replace some parts	Continues	Decommission Life extension	4. Recycle 5. Disposal	1. Prolong life of windfarm 1. Prolong life of parts
	Refurbishment	Refurbish minor parts	Continues	Decommission Life extension	N/A	1. Prolong life of windfarm 1. Prolong life of parts 3. Refurbish parts

Waste Hierarchy/Circular Economy key:
1. Reduce/prolong life
2. Reuse
3. Refurbish
4. Recycle
5. Disposal

Full decommissioning typically entails removing above ground structures and restoring the site to its previous condition (Welstead, et al., 2013). Alternatively, partial decommissioning has been suggested under certain circumstances, for example where a structure will serve another purpose, or where entire removal would constitute an unacceptable risk to the marine environment (Department for Business, Energy and Industrial Strategy, 2019b) (Department for Business Energy and Industrial Strategy, 2019b). Alternatively, the windfarm may carry on operating, which may or may not require alterations to parts of the windfarm. Lifetime extension of a wind turbine results from turbine analysis whereby it is confirmed that it can continue operation beyond its expected life, with or without refurbishment or replacement of components (DNV GL, 2016). Repowering is a method of continuing operation through replacing turbines with newer units, or updating minor parts of turbines in the case of refurbishment (Topham & McMillan, 2017). Of course, if a windfarm has its life extended, through repowering or refurbishment, there will still come a time when decommissioning is required. Therefore, these other 'end of design life scenarios' do not negate the need for decommissioning, rather postpone it. Currently, consents for operation of an offshore windfarm are only granted for a limited time scale. At the end of this time, an operator may wish to extend the life of the windfarm, however this must be agreed with the regulator and further consent granted. Therefore, knowing in advance whether the windfarm will end its life at the end of the initial design life, or be extended, can be tricky. It is, however, feasible to explore the different options for actions when a windfarm will cease operating, and assess the impact of those actions, whether that be at the end of its original design life or after life extension or repowering.

The type of end of design life scenario carried out may be dependent on a number of factors, such as the cost of immediate decommissioning and any maintenance or monitoring that may be required, environmental impacts, and the legislation which determines what is or is not allowed (Kerkvliet & Polatidis, 2016). The evaluation of different options can be done through several methods, such as Best Practicable Option (BPO), comparative assessment and Net Environmental Benefit Analysis (NEBA) (Sommer, et al., 2019). There have been various methods of comparative assessment designed to assess the potential end of design life options. Most of these methodologies and assessments are in the context of offshore oil and gas structures (Ekins, et al., 2006; Fowler, et al., 2014; Henrion, et al., 2015), but lately also offshore windfarms (Kerkvliet & Polatidis, 2016).

The potential environmental impacts from end of design life activities is dependent on the location of the windfarm, and varies according to the type of end of design life scenario carried out. Potential impacts of onshore windfarms can include effect on receptors such as hydrology, ecology, the landscape, and visual amenity, to name but a few (Welstead, et al., 2013). Impacts identified during the construction phase are likely to resurface during decommissioning, along with elements that have been modified in light of construction impacts, which may need further modification upon removal, such as ground and surface water (Welstead, et al., 2013). Much like during construction, disturbance to the seabed is unlikely to be avoided. An increase in suspended solids, and therefore turbidity, follows such disturbance. This further has the potential to mobilise contaminants contained within sediments and be transported with currents (Gill, 2005). Noise associated with decommissioning activities further have the potential to impact sensitive species, again much like during construction (Fowler, et al., 2018).

Offshore windfarms present a further problem due to the prospect of reef effects. Any structure placed in the marine environment has the potential to be colonised by organisms therefore consideration should also be given to the impact of its removal (Fowler, et al., 2014; Macreadie, et al., 2011; Smyth, et al., 2015). Despite this recommendation from the literature, there is no precedent for it to be done through legislation or guidance. The removal of some structures may pose a threat to endangered species that have become associated the structure (Fowler, et al., 2018). Furthermore, as well as generating habitats and organism on the structure, artificial reefs can also enhance the abundance and diversity in the surrounding area, therefore the removal of structures may have indirect impacts to these wider interactions at various trophic levels (Gill, 2005). Methods of enhancing biodiversity have been suggested through scour protection (Wilson & Elliott, 2009), which may be left in-situ (Topham & McMillan, 2017) if abiding by OSPAR regulations (OSPAR, 2013). Therefore, understanding the implication of different end of life scenarios is vital to prevent loss of this recently generated biodiversity (Smyth, et al., 2015). Fowler et al. (2018) provide a case for leaving structures in the sea, providing policy reform is initiated to allow this; they argue that the likely best environmental outcome is not currently allowed through requiring all structures to be completely removed. When different decommissioning scenarios are discussed, retaining or removing structures are usually the two possibilities included. Partial removal is often not fully considered, yet experts agree that a flexible approach such as this would be the preferable approach to take (Fowler, et al., 2018).

Ecological aspects are not the only features of windfarms that require attention at the end of the design life; the handling of waste should also be considered. Typically, the waste hierarchy is implemented to deal with any waste from decommissioning activities; reduce, re-use, recycle, incinerate for energy recovery, and disposal as a last resort (Department for Business, Energy and Industrial Strategy, 2019b) (Department for Business Energy and Industrial Strategy, 2019b). Preliminary analysis has suggested that 80% to 90% of the weight of typical monopile structures could be recycled, however the blades still present a large recycling challenge due to their composite nature; as wind turbines increase and blades become larger efforts to combat this will become ever more important (Topham, et al., 2019).

The aim of this paper is to evaluate windfarm Environmental Statements to assess how adequate the Environmental Impact Assessment (EIA) was in identifying, estimating and managing potential impacts of end of design life scenarios for both onshore and offshore windfarms. The aim of the study was to explore whether there was a difference in the approaches taken by onshore and offshore windfarms in assessing end of design life scenarios, and the effects that were identified. The paper used onshore and offshore windfarms from England and Scotland as case studies. The paper starts by presenting the regulatory framework in the UK, then presents the methods used in the analysis, and finally presents the results and discusses the conclusions of the research.

2 Regulatory Framework in the UK

EIA is an integral part of the consenting process. The regulatory and legal frameworks and relevant consenting authority is dependent on the location and size of development. For example, in the UK, the Electricity Works Regulations (Section 6) states that for an application made for a Section 36 consent (of the Electricity Act 1989 to construct a generating station), "the relevant authority must not grant the application unless an environmental impact assessment has been undertaken in respect of the development". As part of the EIA process, a developer may request a scoping opinion from the regulatory authority in order for the authority to provide an opinion on the scope of the EIA and level of detail to be included. Table shows the regulatory framework in England and Scotland for both onshore and offshore windfarms.

Table 2. Regulatory framework in England and Scotland for onshore and offshore windfarms in 2019

Windfarm location		Windfarm output	Consenting authority	Legislation
Onshore	England	<50MW	Local authority	The Town and Country Planning (Environmental Impact Assessment) Regulations 2017
		>50MW	Planning Inspectorate	The Infrastructure Planning Regulations (Environmental Impact Assessment) 2017

	Scotland	<50MW	Local authority	The Town and Country Planning (Environmental Impact Assessment) (Scotland) Regulations 2017
		>50MW	Scottish Ministers	The Electricity Works (Environmental Impact Assessment) (Scotland) Regulations 2017
Offshore	England	<100MW	Marine Management Organisation	The Marine Works (Environmental Impact Assessment) (Amendment) Regulations 2017 The Electricity Works (Environmental Impact Assessment) (England and Wales) Regulations 2017
		>100MW	Planning Inspectorate	The Infrastructure Planning Regulations (Environmental Impact Assessment) 2017
	Scotland	All	Marine Scotland	The Marine Works (Environmental Impact Assessment) (Scotland) Regulations 2017 The Marine Works (Environmental Impact Assessment) (Amendment) Regulations 2017 The Electricity Works (Environmental Impact Assessment) (Scotland) Regulations 2017

There is no requirement within any of the regulatory frameworks highlighted in Table to specifically consider the potential impact of end of design life scenarios within the EIA. These UK regulations relating to Environmental Impact Assessment are based upon the EU Directive 2014/52. Annex IV (Section 5) of the Directive states that information for the EIA should include "A description of the likely significant effects of the project on the environment resulting from, inter alia: ... the construction and existence of the project, including, where relevant, demolition works". This statement is reflected in the UK legislation, however a definition of 'demolition' is not given. It is therefore unclear whether the 'decommissioning' of a windfarm, the term generally used, is included within this. In fact, the only time when decommissioning is mentioned is in the context of nuclear power stations, where "dismantling or decommissioning" are the terms used. EU guidance clarifies that "demolition" can be classified as a "project", therefore requiring an EIA under certain scenarios (European Union, 2017). The indication from this, therefore, is that an EIA may be required before the windfarm is decommissioned, assuming this is included under the title of "demolition". However, it does not clarify the requirement for decommissioning or any end of design life scenario to be analysed at the point of pre-construction consent EIA. That being said, the interpretation of legislation is a matter for the relevant planning authority and the fact that end of design life scenarios are not specifically identified in the legislation does not necessarily mean that they fall outside the scope of EIA (Welstead, et al., 2013). For instance, The Electricity Works (Environmental Impact Assessment) Regulations 2017 (Section 3) states that, under this regulation, a "development" is "...the carrying out of building, engineering or other operations in, on, over or under land or sea", allowing regulatory authorities to group decommissioning or other end of design life scenarios under "other operations". Furthermore, The Marine Works (Environmental Impact

Assessment) Regulations 2017 (Schedule 3, Section 6) state that Environmental Statements should include a description of "permanent and temporary" effects. This is especially relevant for end of design life scenarios, as the impacts from removal of turbines through decommissioning are likely to be very different to those from retaining structures through repowering (Smyth, et al., 2015). Applications for offshore wind must also conform with the Energy Act 2004 (as amended), which does specify the submission of a decommissioning plan, at the request of the Secretary of State: this means that the submission of a decommissioning plan, including the associated environmental impacts, is often included as a condition attached to the development consent.

There is currently no specific formal guidance as to what type of decommissioning or other end of design life scenario should be carried out. Welstead et al. (2013) describe the potential environmental impact of various types of onshore windfarm decommissioning, though the approach taken is often a matter for the local authority to determine how the site is restored, potentially constraining decommissioning. Department for Business, Energy and Industrial Strategy guidance assumes that any structure placed in the sea will eventually be removed at the end of its operational life, and suggests that developers should design and construct offshore windfarms which would facilitate their full removal (Department for Business, Energy and Industrial Strategy, 2019b) (Department for Business Energy and Industrial Strategy, 2019b). There is little guidance on analysing end of design life scenarios at the planning and consenting stage, however it is stated that a decommissioning programme should fully consider the environmental effects of full removal and "any other feasible options" and suggest mitigation measures (Department for Business, Energy and Industrial Strategy, 2019b, p. 27) (Department for Business Energy and Industrial Strategy, 2019b, p. 27).

In addition to legislation, guidance and best practice advice is gradually being developed by government, statutory consultees and stakeholders. Much of the previous guidance has been focussed on simply analysing the environmental impacts from onshore wind developments (Welstead, et al., 2013), and later for offshore wind (BSI, 2015). The International Maritime Organisation (IMO, 1989) has published general guidance on the removal of offshore installations, which includes analysing the potential effects of such removal on the environment. European guidance suggests that decommissioning should be taken into consideration with any EIA, but does not give further detail as to how this should be carried out (European Commission, 2017). Only recently has guidance been published specifically targeting decommissioning, however this tends to be based on developing a decommissioning programme. This advice mainly references the use of Best Practicable Environmental Option (BPEO), whereby the process of decommissioning should strike a balance between the environmental risk and the practical feasibility and cost of the chosen process. These options should therefore all be considered and their advantages and disadvantages compared, including different decommissioning options (Department for Business, Energy and Industrial Strategy, 2019b) (Department for Business Energy and Industrial Strategy, 2019b).

3 Method used to evaluate how the EIA of end of design life scenarios are being carried out

This section explains first how the Environmental Statements of onshore and offshore windfarms from England and Scotland were selected. It then explains the method to assess how adequate the EIA was in identifying, estimating and managing potential impacts of decommissioning and other end of design life scenarios.

3.1 Selection of Environmental Statements of onshore and offshore windfarms

Onshore and offshore windfarms (operational, under construction and consented) were found through RenewableUK's Wind Energy Projects search function via their website (RenewableUK, 2019). Details of the windfarms were collated and categorised by year of consent and proposed number of turbines, rated turbine power, and total power output of the windfarm. These windfarms' Environmental Statements were sought through various sources. Searches for consent applications of onshore windfarms in England and Scotland were carried out on the relevant local planning authority planning application website. Searches for consent applications of offshore windfarms in England were carried out on the Marine Management Organisation planning application search. Searches for consent applications of offshore windfarms in Scotland were carried out on the Marine Scotland "Current Marine Renewable Energy Projects" page. Where either of the two offshore windfarm searches yielded no results, The Crown Estate's Marine Data Exchange database was searched; this database collates data and reports from offshore windfarms situated on the seabed around the UK.

The twelve windfarms used in this study are shown in Table 3. These windfarms were selected from the onshore and offshore windfarms found that had publically available Environmental Statements based on the year of consent. Where a windfarm application had an Environmental Statement publicly available, the documents were downloaded, including all chapters of the ES. The Non-Technical Summary and decommissioning plan were also downloaded, where available. An upper and lower limit on the year of consent was set at 2009 and 2014, respectively, to enable comparisons between onshore and offshore windfarms to be made whilst limiting the potential changes in the consenting process over time. Table 3 shows the attributes of the windfarms as described in the Environmental Statement, as it is important to understand the context of each EIA. Many ESs described a potential range of the number of turbines to be constructed, the rated power of the turbines, and total power output of the windfarm. From this, the worst case scenario was used in the analysis, described by many of the windfarm EIAs as the largest potential number of turbines.

Table 3. Features of the onshore and offshore windfarms used in the analysis, as described in the Environmental Statements

Label	Location	Country	Name	Number of turbines	Rated power (MW)	Power output (MW)	Year consented
1	Onshore	England	Biggleswade	16	2	32	2011
2	Onshore	England	Sixpenny Wood	10	3	30	2009
3	Onshore	England	Twin Rivers	14	2	28	2009
4	Onshore	Scotland	Moy Estate	20	2.05	41	2013
5	Onshore	Scotland	West Browncastle	12	3	36	2012

6	Onshore	Scotland	Bhlaraidh	36	3	108	2014
7	Offshore	England	Humber Gateway	83	3.6	298.8	2011
8	Offshore	England	Kentish Flats Extension	17	3	51	2013
9	Offshore	England	Westermost Rough	80	3	240	2011
10	Offshore	Scotland	Beatrice	277	3.6	997.2	2014
11	Offshore	Scotland	Inch Cape	213	4.9	1050	2014
12	Offshore	Scotland	Moray East	339	3.6	1220.4	2014

Six onshore windfarm EIAs were analysed: of these, half were located in Scotland and half were in England. These were compared to six offshore windfarm EIAs, where again three were in Scotland and three in England. The proposed windfarms ranged from 10 to 339 turbines with windfarm outputs of anything from 28MW up to 1220MW (Table 3). When comparing onshore and offshore windfarms, there was a significant difference in the number of turbines (ρ=0.010), rated power of turbines (ρ=0.012) and total power output of the windfarm (ρ=0.006) (Table 4). Offshore windfarms had more turbines in the windfarm compared to onshore and the rated turbine power (generation capacity of an individual turbine) of offshore wind turbines was higher than those onshore. Similarly, the total power output of offshore windfarms was larger than onshore windfarms, given that this was the multiplication of the number of turbines and their rated power. However, these onshore and offshore windfarms are still comparable because the same or similar technology, basic structure and components are used. Offshore windfarm EIAs may consider different types of foundation, however the general form is equivalent. Additionally, they were all consented over the same five-year period (2009-2014).

Table 4. Difference (as determined by Mann-Whitney two-population test and T-test) in windfarm attributes between onshore and offshore windfarms. Means are presented with 95% confidence intervals denoted in parenthesis.

Variable	Onshore (n=6)	Offshore (n=6)	MW Statistic (*p*-value)	T_{10} (*p*-value)
Number of turbines	18.0 (± 9.9)	168 (± 133)	2.0 (p = 0.010)	2.88 (p = 0.016)
Rated power of turbines	2.5 (± 0.6)	3.6 (± 0.7)	3.0 (p = 0.012)	3.07 (p = 0.012)
Total windfarm output	45.8 (± 32.3)	643 (± 526)	1.0 (p = 0.006)	2.91 (p = 0.015)

3.2 Method to assess how adequate the EIA was in identifying, estimating and managing potential impacts of decommissioning and other end of design life scenarios

In order to assess the adequacy of the process in identifying, estimating and managing potential impacts of decommissioning and other end of design life scenarios, various attributes of Environmental Statements relating to the impacts of decommissioning were identified. These were based on the relevant legislation, guidance documents from statutory consultees, and similar ES reviews in the literature. The attributes were described in terms of how thoroughly the ES analysed the potential impacts of end of design life scenarios, then scored based on a four-point scale between 1 (a very weak answer) and 4 (a very strong answer). The twenty attributes that the ESs were assessed against are shown in Appendix A.

The attributes were grouped into six categories:

- End of design life scenarios in EIA stages
- Definitions of end of design life scenarios
- Amount of analysis
- Depth of analysis
- Impacts identified
- Proactive planning

Attributes in the category " End of design life scenarios in EIA sections" sought to address if and where end of design life scenarios had been analysed throughout stages of the EIA process, such as during scoping. "Definitions of end of design life scenarios" attributes looked at whether detailed definitions of end of design life activities had been determined and investigated. Attributes in the "Amount of analysis" category sought to quantify how much analysis had been carried out predicting the impacts of end of design life scenarios. Similarly, the "Depth of analysis" category investigated to what extent impacts of end of design life scenarios had been analysed. The "Impacts identified" category quantified the potential impacts that had been identified through the ES and the context in which impacts were predicted. Finally, "Proactive planning" analysed whether further analysis of end of design life scenarios was due to be carried out, if a decommissioning plan had been generated, and if it was due to be updated or reviewed in the future.

For example, an ES assessed against an attribute question such as "Are the effects of different scenarios of end of design life procedures or methods considered?" would score 1 if it was classified in the very weak category of "The effect of decommissioning options or different end of design life scenarios are not mentioned". Conversely, an ES would score 4 by being placed in the very strong category if "The effect of all alternative end of design life options are considered". The scoring system was tested on one onshore and one offshore windfarm ES, then reviewed and minor parts revised to take into account the realistic end of design life scenario analysis carried out in those ESs.

The potential impacts of end of design life scenarios that were identified were also scored based on the level of impact of end of design life scenarios stated in the ES:

1: a significant adverse impact

2: a moderate significant adverse impact

3: a minor significant adverse impact

4: no significant impact

5: a minor positive impact

6: a major positive impact

The significance of an impact, being between significant adverse impact and major positive impact, was often calculated in the ESs using a matrix approach, using the sensitivity of the receptor and the magnitude of the impact. The degree of magnitude was often described as the level of potential impact, such as the area of impact. The sensitivity of the receptor was defined in a number of ways, for instance being able to tolerate certain levels of disturbance, being an important species and/or habitat at various levels (international, regional, local etc.). Despite some ESs reporting a range of potential scenarios for activities at the end of life, those that did consider the environmental impacts of end of design life scenarios did not split the final significance of impact by scenario, instead giving a general impact significance.

Statistical analysis was carried out on the results in the form of Manny-Whitney and T-tests, and General Linear Models (GLM). Analysis was performed to determine if there was a statistically significant difference in the scores for each windfarm and attribute between onshore and offshore windfarm ESs. Analysis was then carried out to determine whether there was a relationship between the scores a windfarm obtained and the year that the windfarm was granted consent, the number of turbines, and the total power output of the windfarm.

Statistical analysis was also carried out on the impacts themselves to investigate if there was a statistically significant difference in the impact score between onshore and offshore windfarms. Analysis was then done to ascertain whether there was a relationship between the impact score and the year that the windfarm was consented, the number of turbines, and the total power output of the windfarm.

4 Quality of assessment of end of design life scenarios according to the 12 Environmental Statements studied

The scores obtained by the different onshore and offshore windfarms are graphically represented in Figure 1. Numbers 1-6 and 7-12 represent the onshore and offshore wind farms assessed, respectively, as written in Table 3, and were assessed against the attribute questions A-R as written in Appendix A.

	Question (summary description – full description in Appendix A)	Onshore wind farms						Offshore wind farms					
		England			Scotland			England			Scotland		
		1	2	3	4	5	6	7	8	9	10	11	12
		2011	2009	2009	2013	2012	2014	2011	2013	2011	2014	2014	2014
A	Are end of design life scenarios mentioned at every EIA stage?	**0**	**2**	**0**	**0**	**0**	**0**	**4**	**4**	**0**	**4**	**4**	**4**
B	Does a decommissioning programme exist?	**1**	**1**	**1**	**2**	**1**	**1**	**0**	**2**	**2**	**4**	**4**	**4**
C	Is the word "decommissioning" mentioned in the NTS?	**2**	**0**	**2**	**2**	**3**	**2**	**2**	**2**	**2**	**2**	**2**	**3**
D	Is decommissioning specifically defined?	**2**	**1**	**2**	**3**	**3**	**3**	**3**	**3**	**3**	**2**	**2**	**3**
E	What end of design life scenarios are described?	**2**	**2**	**2**	**3**	**3**	**3**	**2**	**2**	**2**	**3**	**2**	**3**
F	Is the word "decommissioning" mentioned in the ES?	**2**	**2**	**2**	**3**	**3**	**3**	**3**	**3**	**3**	**2**	**3**	**3**
G	Is there a part of the ES dedicated to end of design life scenarios?	**2**	**2**	**2**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
H	What percentage of the ES is dedicated to end of design life scenarios?	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
I	How much detail is given to decommissioning activities?	**2**	**2**	**2**	**3**	**2**	**3**	**2**	**2**	**3**	**3**	**2**	**2**
J	How much detail is given to the effect of decommissioning?	**1**	**1**	**2**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
K	How much detail is given regarding other end of design life scenarios?	**1**	**1**	**1**	**2**	**2**	**2**	**1**	**1**	**1**	**2**	**1**	**1**
L	Is the effect of other end of design life scenarios mentioned?	**1**	**1**	**2**	**2**	**2**	**2**	**3**	**2**	**1**	**2**	**2**	**3**
M	Is the effect of other end of design life scenarios analysed?	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
N	Regarding what impacts? E.g. ecology, sediment, hydrology.	**2**	**1**	**2**	**3**	**3**	**3**	**3**	**4**	**3**	**3**	**3**	**3**
O	In what context are the impacts described?	**3**	**1**	**2**	**3**	**3**	**3**	**3**	**3**	**3**	**2**	**3**	**3**
P	Mentions plan of what will be done about	**1**	**1**	**1**	**2**	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**4**

		1	2	3	4	5	6	7	8	9	10	11	12
	decommissioning or other end of design life scenarios?												
Q	Is there mention of a review or update in the future?	**1**	**1**	**1**	**2**	**1**	**1**	**3**	**1**	**2**	**2**	**1**	**2**
R	Is mitigation of end of design life scenarios impacts considered?	**1**	**1**	**4**	**3**	**3**	**3**	**2**	**2**	**4**	**1**	**3**	**4**

Figure 1. Quality of decommissioning of the Environmental Statements of the onshore and offshore windfarms studied.

Key: 1=Very weak, 2=Weak, 3=Strong, 4=Very strong

1-12 windfarms studied (see Table 3); A-R attributes to assess windfarms (see Appendix A).

As can be seen in Figure 1, ESs scored strongly in relation to describing proposed mitigation to combat the predicted impacts of decommissioning, and mentioning the impacts of decommissioning in many stages of EIA, such as during scoping and in the Non-Technical Summary (NTS). Conversely, ESs rarely described the alternative end of life scenarios, and so in turn did not analyse the potential impacts from activities such as repowering or life extension. Scores of "Weak" and "Strong" were most often obtained, closely followed by "Very weak". In comparison, few "Very strong" scores were obtained. More "Very weak" or "Weak" scores were obtained by onshore than offshore windfarms, as can be seen in Figure 2. Onshore windfarms generally tended to score lower than offshore windfarms: it was evident that Environmental Statements from onshore windfarms generally investigated the impacts of decommissioning to a lesser degree than offshore windfarms.

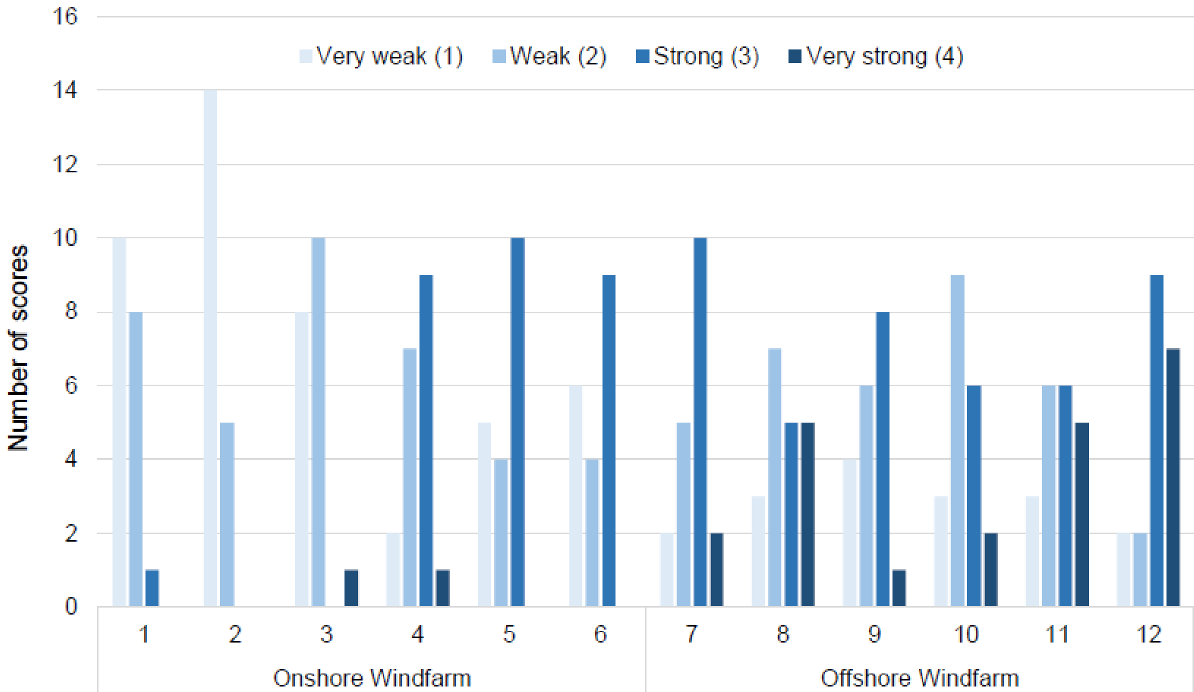

Figure 2. Number of scores with regards to quality of decommissioning obtained by each windfarm

For some individual attributes there was little or no difference in the scores obtained by the windfarms. For others there were marked differences in the scores. There was a significant difference in the score for questions A (p = 0.01), N (p = 0.045), and P (p = 0.006) between onshore and offshore windfarms (Table 5). On average, offshore windfarms scored higher than onshore in questions addressing the mentioning decommissioning in many EIA stages, the number of impacts identified from decommissioning, and the proactive planning of a decommissioning plan.

Table 5. Differences (as determined by Mann-Whitney two-population test and T-test) in scores between onshore and offshore windfarms. Means are presented with 95% confidence intervals denoted in parenthesis.

Question	Onshore (n=6)	Offshore (n=6)	MW Statistic (p-value)	T_{10} (p-value)
A	0.3 (± 0.9)	3.3 (± 1.7)	3.5 (p = 0.010)	4.02 (p = 0.002)
B	1.2 (± 0.4)	2.7 (± 1.6)	7.5 (p = 0.058)	2.36 (p = 0.04)
C	2.2 (± 0.4)	2.2 (± 0.4)	18 (p = 1.000)	0.00 (p = 1.00)
D	2.3 (± 0.9)	2.7 (± 0.5)	14 (p = 0.465)	0.85 (p = 0.418)
E	2.5 (± 0.6)	2.3 (± 0.5)	15 (p = 0.575)	-0.54 (p = 0.599)
F	2.5 (± 0.6)	2.8 (± 0.4)	12 (p = 0.241)	1.20 (p = 0.26)
G	2.5 (± 0.6)	3.0 (± 0.0)	9 (p = 0.056)	No result
H	1.0 (± 0.0)	1.0 (± 0.0)	18 (p = 1.000)	No result
I	2.3 (± 0.5)	2.3 (± 0.5)	18 (p = 1.000)	0.00 (p = 1.00)
J	1.5 (± 0.6)	1.2 (± 0.4)	12 (p = 0.241)	-1.20 (p = 0.26)
K	1.7 (± 0.5)	2.2 (± 0.8)	11 (p = 0.206)	1.34 (p = 0.209)
L	2.2 (± 1.0)	3.0 (± 0.0)	9 (p = 0.058)	No result
M	1.0 (± 0.0)	1.0 (± 0.0)	18 (p = 1.000)	No result
N	2.3 (± 0.8)	3.2 (± 0.4)	7.5 (p = 0.045)	2.24 (p = 0.049)
O	2.5 (± 0.9)	2.8 (± 0.4)	14.5 (p = 0.461)	0.88 (p = 0.401)
P	1.2 (± 0.4)	2.3 (± 0.8)	2.5 (p = 0.006)	3.13 (p = 0.011)
Q	1.2 (± 0.4)	1.8 (± 0.8)	8.5 (p = 0.083)	1.91 (p = 0.086)
R	2.5 (± 1.3)	2.7 (± 1.3)	16.5 (p = 0.804)	0.24 (p = 0.817)

In order to determine if these differences in score were due to windfarm attributes, the factors entered the GLM included “year of consent”, “power output” and “number of turbines” as the independent factors to predict “scores”, the dependant variables. The scores for questions B, G, and P could be statistically predicted by the independent variables (*p* = 0.001, *p* = 0.048 and *p* = 0.028, respectively, Table 6). Power output was the strongest contributor to the score for question B (*p* = 0.164, Figure 4, in Appendix B), whilst the year of consent was the strongest contributor to the score for question G (*p* = 0.017, Figure 5, in Appendix B). The number of turbines was the strongest contributor to the score for question P (*p* = 0.154, Figure 6, in Appendix B). Respectively, these questions related to the presence of a decommissioning programme, how much the EIA considered and analysed decommissioning, and future plans for analysing end of life scenarios. Graphs of prediction against observation for each of the questions can be found in Appendix C (Figure 7, Figure 8, Figure 9, Figure 10).

Table 6. GLM results with “year of consent”, “power output” and “number of turbines” entered to predict scores for each question.

Question	Constant	coefficient-year	coefficient-power	coefficient-number	Model
A	90.2 (± 678) (*p* = 0.897)	-0.044 (± 0.337) (*p* = 0.898)	0.005 (± 0.006) (*p* = 0.414)	-0.010 (± 0.025) (*p* = 0.711)	R = 0.697 R^2 = 0.486 (*p* = 0.132)
B	-123 (± 192) (*p* = 0.539)	0.062 (± 0.096) (*p* = 0.536)	0.003 (± 0.002) (*p* = 0.164)	-0.001 (± 0.007) (*p* = 0.908)	R = 0.951 R^2 = 0.904 (*p* = 0.001)
C	-37.2 (± 169) (*p* = 0.832)	0.020 (± 0.084) (*p* = 0.822)	-0.001 (± 0.002) (*p* = 0.509)	-0.005 (± 0.006) (*p* = 0.426)	R = 0.401 R^2 = 0.161 (*p* = 0.418)
D	-555 (± 234) (*p* = 0.045)	0.277 (± 0.117) (*p* = 0.045)	-0.003 (± 0.002) (*p* = 0.176)	0.010 (± 0.009) (*p* = 0.271)	R = 0.681 R^2 = 0.464 (*p* = 0.154)
E	-406 (± 155) (*p* = 0.031)	0.203 (± 0.077) (*p* = 0.030)	-0.003 (± 0.001) (*p* = 0.073)	0.011 (± 0.006) (*p* = 0.084)	R = 0.773 R^2 = 0.597 (*p* = 0.053)
F	-371 (± 188) (*p* = 0.084)	0.186 (± 0.093) (*p* = 0.082)	-0.000 (± 0.002) (*p* = 0.787)	-0.003 (± 0.007) (*p* = 0.642)	R = 0.596 R^2 = 0.356 (*p* = 0.463)
G	-399 (± 134) (*p* = 0.018)	0.200 (± 0.067) (*p* = 0.017)	-0.000 (± 0.001) (*p* = 0.737)	0.001 (± 0.005) (*p* = 0.783)	R = 0.781 R^2 = 0.609 (*p* = 0.048)
I	-301 (± 190) (*p* = 0.153)	0.151 (± 0.095) (*p* = 0.150)	-0.003 (± 0.002) (*p* = 0.192)	0.009 (± 0.007) (*p* = 0.246)	R = 0.577 R^2 = 0.333 (*p* = 0.472)
J	-422 (± 173) (*p* = 0.041)	0.210 (± 0.086) (*p* = 0.040)	-0.002 (± 0.002) (*p* = 0.280)	0.005 (± 0.006) (*p* = 0.442)	R = 0.673 R^2 = 0.453 (*p* = 0.427)
K	-183 (± 270) (*p* = 0.517)	0.092 (± 0.134) (*p* = 0.513	-0.001 (± 0.013 (*p* = 0.786)	0.005 (± 0.010) (*p* = 0.652)	R = 0.523 R^2 = 0.274 (*p* = 0.439)
L	-613 (± 268) (*p* = 0.052)	0.306 (± 0.134) (*p* = 0.051)	-0.001 (± 0.003) (*p* = 0.785)	0.003 (± 0.010) (*p* = 0.804)	R = 0.700 R^2 = 0.490 (*p* = 0.128)

N	-721 (± 232) (p = 0.015)	0.360 (± 0.116) (p = 0.014)	-0.001 (± 0.002) (p = 0.657)	0.002 (± 0.009) (p = 0.809)	R = 0.759 R^2 = 0.577 (p = 0.064)
O	-534 (± 241) (p = 0.058)	0.267 (± 0.120) (p = 0.057)	-0.00005 (± 0.002) (p = 0.982)	-0.002 (± 0.009) (p = 0.832)	R = 0.625 R^2 = 0.391 (p = 0.242)
P	-111 (± 240) (p = 0.655)	0.056 (± 0.119) (p = 0.651)	-0.002 (± 0.002) (p = 0.359)	0.014 (± 0.009) (p = 0.154)	R = 0.812 R^2 = 0.659 (p = 0.028)
Q	-74.6 (± 268) (p = 0.788)	-0.036 (± 0.134) (p = 0.792)	-0.003 (± 0.003) (p = 0.253)	0.015 (± 0.010) (p = 0.176)	R = 0.543 R^2 = 0.294 (p = 0.399)
R	-46.5 (± 547) (p = 0.934)	0.024 (± 0.272) (p = 0.931)	0.000 (± 0.005) (p = 0.974)	0.002 (± 0.020) (p = 0.933)	R = 0.133 R^2 = 0.018 (p = 0.985)

A recurring trend throughout this research was that the analysis of decommissioning impacts improved with the size of the windfarm. There was not a significant relationship between the year of consent and the power output of the windfarm, however there was a trend that windfarms consented later had larger power outputs. Therefore, it may have been that later EIAs and consent applications were subject to more rigorous protocol regarding analysis of decommissioning as knowledge and experience increased over time. Another factor may have been updates to the EU Directive on Environmental Impact Assessment in 2009, 2011, and 2014, with changes to UK legislation being implemented in 2011 and 2017. For instance, this was seen in the results from questions J and P (Figure 1), where analysing the effect of decommissioning and the intention of updating a decommissioning plan improved over time. A further reason for this could be due to the regulatory authority associated with onshore and offshore windfarms, respectively. Onshore windfarms are mostly consented by the local authority which deals with a whole range of developments. Only under the Energy Act 2004 can the Secretary of State can require a decommissioning programme to be generated which assesses the environmental impacts of decommissioning scenarios at offshore windfarms. Although onshore windfarms do not have the same requirement, neither have an explicit requirement to include decommissioning with the Environmental Impact Assessment.

5 Evaluation of impacts identified from decommissioning activities

In total, 26 potential impacts were identified from decommissioning activities: five impacts were found in onshore windfarms only, 16 impacts in offshore windfarms only, with the remaining five impacts relevant to both onshore and offshore windfarms. Across the onshore windfarms, between zero and nine impacts were identified from decommissioning, with an average of four impacts. Conversely, for offshore windfarms there were between nine and 15 impacts. The impacts that were identified and their scores are shown in Table 7.

Table 7. The average impact scores obtained by the windfarms and the corresponding receptors.

	Receptor	Average Impact Score	
		Onshore	**Offshore**

Biological Environment	Designated Sites		4
	Ecology	3.67	
	Fish		3.57
	Intertidal Ecology		4
	Marine Mammals		3.79
	Ornithology	4	3.86
	Subtidal Benthos		3.5
Physical Environment	Air and Climate	4	
	Contamination		4
	Hydrology, Geology and Hydrogeology	4	3.61
	Noise	3.83	4
	Water Quality		4
Human Environment	Aviation		4
	Commercial Fisheries		3.42
	Cultural Heritage	4	
	Landscape and Visual	4	3.3
	Marine Archaeology and Wrecks		4
	MOD		4
	Other Human Activities		3.75
	Radar		4
	Shipping and Navigation		3.25
	Socioeconomics	4	4.75
	Telecommunications	4	
	Traffic and Transport	4	
	UXO		4
Cumulative	Cumulative effect		4

Key:

1: a significant adverse impact

2: a moderate significant adverse impact

3: a minor significant adverse impact

4: no significant adverse impact

5: a minor positive impact

6: a major positive impact

There was no significant difference in the average impact score between onshore and offshore windfarms. However, there was a significant difference in the number of impacts between onshore and offshore windfarms (ρ=0.006, Table 8), with offshore windfarms citing more potential impacts from decommissioning. There was no significant relationship between the windfarm attributes and the number of impacts

(ρ=0.094, Table 99), however the year of consent was a much larger contributing factor to the trend compared to the power output of the windfarms and the number of turbines (ρ=0.079, Table 99); the later a windfarm was granted consent, the more potential impacts were identified (Figure 3). Again, this may have been as a result of increased knowledge as windfarms were developed, both on the side of the developer and the consenting authority, and the updates to the EU Directive which were brought into UK legislation.

Table 8. Difference (as determined by Mann-Whitney two-population test and T-test) in windfarm the number of impacts between onshore and offshore windfarms. Means are presented with 95% confidence intervals denoted in parenthesis.

Variable	Onshore (n=6)	Offshore (n=6)	MW Statistic (*p*-value)	T_{10} (*p*-value)
Number of impacts	4 (± 3.5)	12 (± 2.1)	21.50 (p = 0.006)	4.66 (p = 0.002)

Table 9. GLM results with "year of consent", "power output" and "number of turbines" entered to predict the number of impacts.

Factor	Constant	coefficient-year	coefficient-power	coefficient-number	Model
Number of impacts	-3222 (± 1606) (p = 0.08)	1.605 (± 0.799) (p = 0.079)	-0.0007 (± 0.015) (p = 0.965)	0.0103 (± 0.0587) (p = 0.866)	R = 0.7290 R^2 = 0.5315 (p = 0.094)

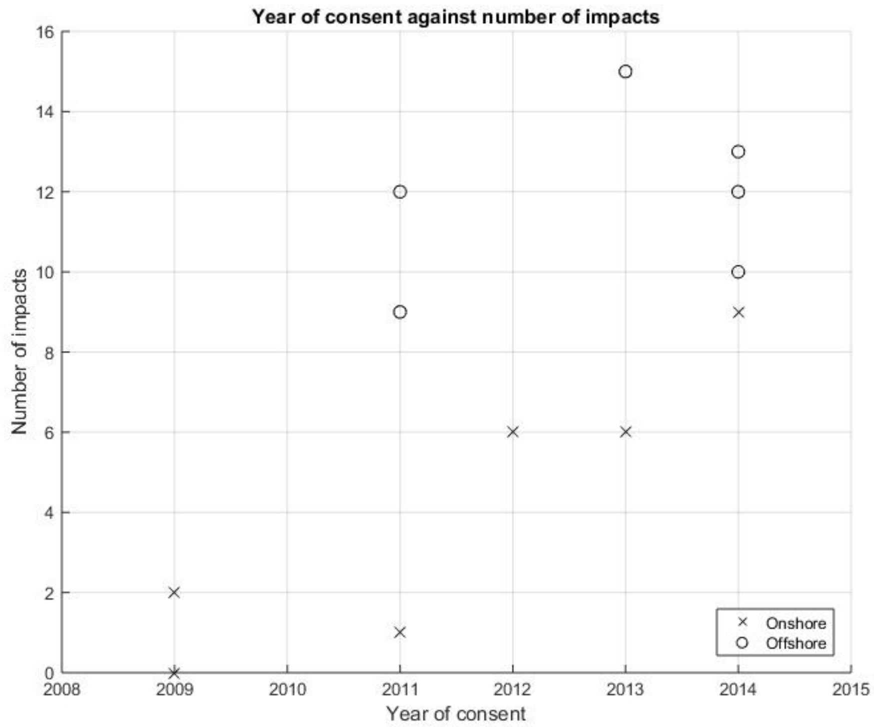

Figure 3. Number of potential impacts identified from decommissioning by year of consent of each windfarm

6 Comparison of the impacts of decommissioning versus construction

Despite many offshore windfarms analysing the impacts of decommissioning, often the analysis was done by comparing the impacts of decommissioning to impacts resulting from construction. A common conclusion from the ESs was that the impact of decommissioning was likely to be equal to or less than that of construction. It was suggested that decommissioning was simply the reverse of construction and that subsequently the impacts would be same. However, it was never considered that over the 20-25 year lifetime of the windfarm that ecology, habitats, or ecosystems may have been generated on the various structures, despite a wealth of evidence suggesting the fact (Causon & Gill, 2018; Langhamer, 2012; Smyth, et al., 2015; Wilson & Elliott, 2009).

Most ESs scored well on stating the mitigation of potential impacts from decommissioning. However, this was again based on the fact that the impact of decommissioning was likely to be the same or less than that of construction, therefore the same mitigation was applied. As previously stated, there was no analysis of removal of structures which might have directly or indirectly contributed to ecosystem change. Therefore, mitigation of such potential impacts have also not been analysed, or even suggested. The legislation relevant to the consent of onshore and offshore windfarm state that EIAs should include descriptions of reasonable alternatives, the reasons for selecting the chosen options, and a comparison of the environmental impacts. Guidance also recommends that, through the "Rochdale Envelope" approach, the likely worst case variation of the project should be assessed (The Planning Inspectorate, 2018). Clearly, where specific definitions of potential decommissioning procedures and alternatives have not been investigated, it is debateable whether an EIA has fully complied with the regulations, but this is for the consenting authority to determine.

Guidance on generating a Decommissioning Programme includes suggestions for the contents of such a Programme. One suggestion is for a specific EIA to be carried out for decommissioning activities (Department for Business, Energy and Industrial Strategy, 2019b) (Department for Business Energy and Industrial Strategy, 2019b). Given that the submission and approval of Decommissioning Programmes are often a condition attached to the consent, and such a Decommissioning Programme should include an assessment of the potential impacts of decommissioning, it would be recommended to include decommissioning within the original EIA. Governmental guidance expects that decommissioning programmes should be submitted for approval at least six months prior to the start of construction of the project. It further states that environmental impacts should be discussed within the Decommissioning Programme. Despite the acknowledgement that detailed predictions cannot be made on future decommissioning, the Decommissioning Programme should aim to do so, including "full removal and any other feasible options" (Department for Business, Energy and Industrial Strategy, 2019b, p. 27) (Department for Business Energy and Industrial Strategy, 2019b, p. 27). Given that these assessments should be carried out before construction, but in all likelihood after consent has been granted, it should not be unreasonable to include such assessments within the development consent application. If so, environmental impacts of decommissioning and other scenarios can be considered as part of a lifecycle assessment of the application.

In the future, once more onshore and offshore windfarms have been decommissioned, there may be more protocol and learning or studies from decommissioning activities which may shed more light on what impacts may occur. In turn, the analysis of decommissioning may be more accurately analysed, and appropriate mitigation put in place. There would also be an argument for considering decommissioning during the design stage in order to efficiently perform the most appropriate decommissioning (Topham & McMillan, 2017).

7 Conclusions and recommendations for future work

This research studied 12 Environmental Statements of both onshore and offshore windfarms within England and Scotland to determine how the potential impacts of decommissioning have been analysed and whether there was a difference in the approach between onshore and offshore windfarms.

There were limitations to the study in that only four categories, and therefore scores, were generated for assessing attributes of the Environmental Statements against: very strong, strong, weak, and very weak. Relatively coarse categories such as these, and the differences in scores between onshore and offshore windfarms yet lack of statistical difference, suggest that a finer scoring system may have generated more distinct results. Additionally, a limited number of windfarm EIAs were studied, limiting the statistical analysis and representation of reality.

This study has shown both a trend in the analysis of decommissioning within EIAs and differences in such analysis between those carried out for onshore and offshore windfarms. Trends have been seen over time and with increasing total power output of the windfarm in question. Differences have also been seen in the analysis of decommissioning between onshore and offshore windfarm's Environmental Statements. Generally, analysis of decommissioning has improved, both for onshore and offshore windfarms, despite onshore windfarms lagging behind offshore. Given that legislation was amended over the time period studied and guidance introduced, there is the suggestion that these have the potential to prompt better EIAs.

However, this analysis has also brought to light the lack of analysis of potential impacts from decommissioning in their own right: not simply as a reversal of the construction process. The very nature of introducing something into the marine environment is quite different to removing something, therefore it is reasonable to assume that the environmental impacts shall also be different. Therefore, the impacts of decommissioning of offshore windfarms have the potential to differ substantially from those during construction. As a result of this, it is possible that the mitigation suggested to reduce the impacts of construction may not be appropriate to alleviate those from decommissioning. It is very important that the potential alternative end of life procedures should be included within the EIA in order to encapsulate the worst case scenario, analyse the relevant impacts, and suggest mitigation. As more windfarms are decommissioned, more examples will be available for review which may help developers determine their approach to end of life procedures. This could also lend itself to better planning for decommissioning during windfarm conception and allow analysis of methods other than full decommissioning. There are several methods for considering various potential options, such as Best Practicable Option and comparative assessment. Strategically placed structures in the sea, for example, could provide environmental enhancement after the windfarm has been removed. The analysis and early consideration of other scenarios at the end of design life, such as life extension and repowering, might then allow these scenarios to come to fruition. For instance, partial turbine repowering using the existing foundation and tower may be seen as less favourable than full repowering because of the limitations associated with the original structure (Lantz, et al., 2013). However, forward planning might aid the re-use of foundations by designing them with partial repowering and the support of larger turbines in mind.

It was observed during this study that the consideration of different end of design life scenarios were rarely considered; scenarios were either not mentioned, decommissioning alone assumed, or to be decided in the future. The fate of materials once removed from windfarms was infrequently discussed, yet there is scope for more sustainable disposal than simply sending to landfill (Topham, et al., 2019). Likewise, analysis of the environmental impacts of the source material, and in combination with the fate of materials was rarely mentioned. Life Cycle Assessment (LCA) and Environmental Impact Assessment have a tendency to sit independently of one another, yet they both assess the potential impacts of a development. However, there is precedent to incorporate LCA within EIA in order to fully assess the impact of waste, recycling, and source material, among other things (Tukker, 2000; Židoniene & Kruopiene, 2015). This would also allow for different decommissioning options to be comparatively assessed, and Best Practicable Environmental Option sought.

Taking a longer-term view of leasing and consenting windfarm area would allow for developers to consider their actions at the end of the initial design life more fully. This could provide an opportunity to design windfarm with a certain end goal in mind. For instance, foundation attributes that allow the structure to be retained or repowered after a number of years, such as diameter, wall thickness, and corrosion protection, perhaps with similar or upgraded components (Bouty, et al., 2017).

Much work is still required both on the environmental impacts of end of life activities and in the field of decommissioning as a whole. Further monitoring of windfarms, especially offshore, is required to better understand not only the impacts of renewable energy structures but also the change they bring about, both at species and ecosystem level. The impact of removing such structures at the end of their life can then be analysed taking this change into account. It could also help to inform other types of decommissioning such as partial removal, based on the type of environmental change that has occurred (Smyth, et al., 2015).

Rigs-to-reef programmes have been successfully implemented in the US, whereby offshore oil and gas structures are strategically placed in areas of the sea once they come to the end of their usable life in order to provide a structure to act as an artificial reef (Macreadie, et al., 2011). However, a North Sea equivalent has not been established, potentially due to reactions to the Brent Spar incident which prevented rigs-to-reef programmes from being included in OSPAR legislation (Jørgensen, 2012). Despite the IMO advising that structures may be left in the sea in certain circumstances, for instance for "enhancement of a living resource" (IMO, 1989, p. 3), and the OSPSAR Commission developing guidelines on artificial reefs (OSPAR, 2013), the current governmental standpoint is that any structure placed in the sea should eventually be removed, and designed considering that fact. Only under exceptional reasons will a structure be allowed to remain in the sea (Department for Business, Energy and Industrial Strategy, 2019b) (Department for Business Energy and Industrial Strategy, 2019b).

The success of a renewable energy installation acting as an artificial reef is likely to be highly site specific, and therefore retaining such structures at the end of life will also be dependent on the location and the habitat created in the context of the surrounding environment (Langhamer, 2012). Reef effects can also provide ecosystem services, such as nutrient cycling (Causon & Gill, 2018), therefore the reason for retaining the structures and maintaining them in such a way as to achieve this should be considered. Likewise, preventing negative impacts, for example destructive impacts from non-native species, should also be examined (De Mesel, et al., 2015).

Conversely, the removal of onshore windfarms is seen as being a positive step, providing best practice and appropriate restoration measures are put into place (Welstead, et al., 2013). According to RenewableUK (2019) there have been 22 onshore windfarms consented in England and Scotland with a total windfarm output over 50MW, meaning that they were consented by the respective governments. The remaining 367 onshore windfarms were therefore consented by a local authority. It is these consenting authorities which determine, crucially along with the landowner, how the land is restored. The environmental impact of removing onshore windfarms has not been assessed in the same way as offshore windfarms, potentially due to the differences in environmental impact and the receptors involved. This may be seen through, for instance, the impact of noise on human populations onshore and marine mammals offshore (Kaldellis, et al., 2016).

Regardless of the end of life scenario, its environmental impact should be analysed during the windfarm's planning in order for the consenting authority to make an informed decision based on the impact of the life of the project. This research has shown that the analysis of impacts from decommissioning have improved, however further examination is still required, especially on the potential environmental impact of different end of life scenarios.

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Appendix A

Matrix of attributes onshore and offshore windfarm Environmental Statements were assessed against

Label	Category	Question	Description	Very weak (1)	Weak (2)	Strong (3)	Very strong (4)
A	End of design life scenarios in EIA stages	Are end of design life scenarios mentioned at every EIA stage (screening, scoping, and ES)?	The EIA stages explicitly mention end of design life scenarios at each stage of the planning process	End of design life scenarios are not mentioned at any EIA stage	End of design life scenarios are mentioned within one EIA stage	End of design life scenarios are mentioned within two EIA stages	End of design life scenarios are mentioned within all three EIA stages
B	End of design life scenarios in EIA sections	Does a decommissioning programme exist?	A decommissioning programme is available	No	A draft is available	A draft has been submitted to the consenting authority	Yes and has been approved by the consenting authority
C	End of design life scenarios in EIA sections	Is the word "decommissioning" mentioned in the Non-Technical Summary?	The Non-Technical Summary explicitly mentions decommissioning in the context of the EIA	Decommissioning is not mentioned	Decommissioning is mentioned less than five times with no definition	Decommissioning is mentioned more than 5 times with no definition	Decommissioning is mentioned with full definition
D	Definitions of end of design life scenarios	Is decommissioning specifically defined?	The ES explicitly defines decommissioning in the context of the EIA	Decommissioning is not defined	Decommissioning is mentioned but not defined	At least one decommissioning activity is mentioned but not defined	Decommissioning is fully defined
E	Definitions of end of design life scenarios	What end of design life scenarios are described (full decommissioning, partial decommissioning, repowering, life extension)?	The ES describes a range of different potential end of design life scenarios	End of design life scenarios are not mentioned	Decommissioning and one other end of design life scenario is mentioned	Decommissioning and more than one, but not all, end of design life scenario is mentioned	All alternative end of design life options are mentioned
F	Amount of analysis	Is the word "decommissioning" mentioned in the ES?	The ES explicitly mentions decommissioning in the context of the EIA	Decommissioning is not mentioned	Decommissioning is mentioned in one part of the ES	Decommissioning is mentioned in more than one, but not all parts of the ES	Decommissioning is mentioned in each part of the ES

Label	Category	Question	Description	Very weak (1)	Weak (2)	Strong (3)	Very strong (4)
G	Amount of analysis	Is there a part of the ES dedicated to end of design life scenarios?	A part of the ES is dedicated to end of design life scenarios	No section on end of design life scenarios	Sentence on end of design life scenarios	Paragraph or section on end of design life scenarios	Chapter on end of design life scenarios
H	Amount of analysis	What percentage of the ES is dedicated to end of design life scenarios?	Adequate attention is paid to the impact of end of design life scenarios	0% to 4%	5% to 9%	10% to 14%	>15%
I	Depth of analysis	How much detail is given regarding decommissioning activities?	The ES describes what would be involved during decommissioning	Decommissioning is not mentioned	A brief overview is given on what the decommissioning might entail (<200 words)	Some indication is given on what decommissioning might entail (>200 words)	A full plan is given on what all decommissioning might entail
J	Depth of analysis	How much detail is given regarding the effect of decommissioning?	The ES describes the effect of decommissioning	The effect of decommissioning is not mentioned	The effect of decommissioning is mentioned but not analysed	The effect of decommissioning is analysed but not in every part of the ES	The effect of decommissioning is analysed throughout the ES
K	Depth of analysis	How much detail is given regarding different end of design life scenarios?	The ES describes what would be involved in the different end of design life scenarios	End of design life scenarios are not mentioned	The process of one end of design life scenario is described	The process of more than one but not all end of design life scenarios are described	The process of all end of design life scenarios are described
L	Depth of analysis	Is the effect of different end of design life scenarios mentioned?	The ES mentions the effect of different end of design life scenarios	The effect of different end of design life scenarios are not mentioned	The effect of decommissioning alone is mentioned	The effect of more than one but not all end of design life scenarios are mentioned	The effect of all end of design life scenarios are mentioned
M	Depth of analysis	Is the effect of different end of design life scenarios analysed?	The ES analyses the effect of different end of design life scenarios	The effect of different end of design life scenarios are not mentioned	The effect of different end of design life scenarios are mentioned but not analysed	The effect of more than one but not all end of design life scenarios are analysed	The effect of all end of design life scenarios are analysed

Label	Category	Question	Description	Very weak (1)	Weak (2)	Strong (3)	Very strong (4)
N	Impacts identified	What impacts are analysed? E.g. ecology, sediment, hydrology	All environmental impacts are analysed with regard to end of design life scenarios	End of design life scenarios are not considered	End of design life scenarios are analysed with regard to one impact identified in the ES	End of design life scenarios are analysed with regard to more than one but not all impacts identified in the ES	End of design life scenarios are analysed with regard to all impacts identified in the ES
O	Impacts identified	In what context are the impacts described?	Impact of end of design life scenarios are regarded as an individual activity	End of design life scenarios are not considered	The impact of end of design life scenarios are said to be the same as or less than the impact of construction	The impact of end of design life scenarios are said to be the same or less than the impact of construction and analysed without comparison to construction	End of design life scenarios are analysed without solely a comparison to construction
P	Proactive planning	Is there mention of a plan for what will be done regarding decommissioning or other end of design life scenarios?	A decommissioning plan is available	A decommissioning plan is not available or considered	A decommissioning plan will be considered at a later date, which is not specified	A decommissioning plan is being written or will be written at a set date	A full, complete plan is available
Q	Proactive planning	Is there mention of a review or update in the future?	A decommissioning plan will be reviewed at a planned date in the future	Decommissioning update is not considered	Decommissioning may be reviewed at a later date	Decommissioning will be reviewed at a later date	A plan for when decommissioning will be reviewed is stated
R	Proactive planning	Is mitigation of end of design life scenarios impacts considered?	Mitigation of predicted impacts arising from end of design life scenarios are outlined	End of design life scenarios and respective mitigation are not considered	Impacts will be determined at a later date, along with respective mitigation measures	Mitigation of some but not all impacts is suggested	Mitigation of all identified impacts are suggested, or no mitigation is required

Appendix B

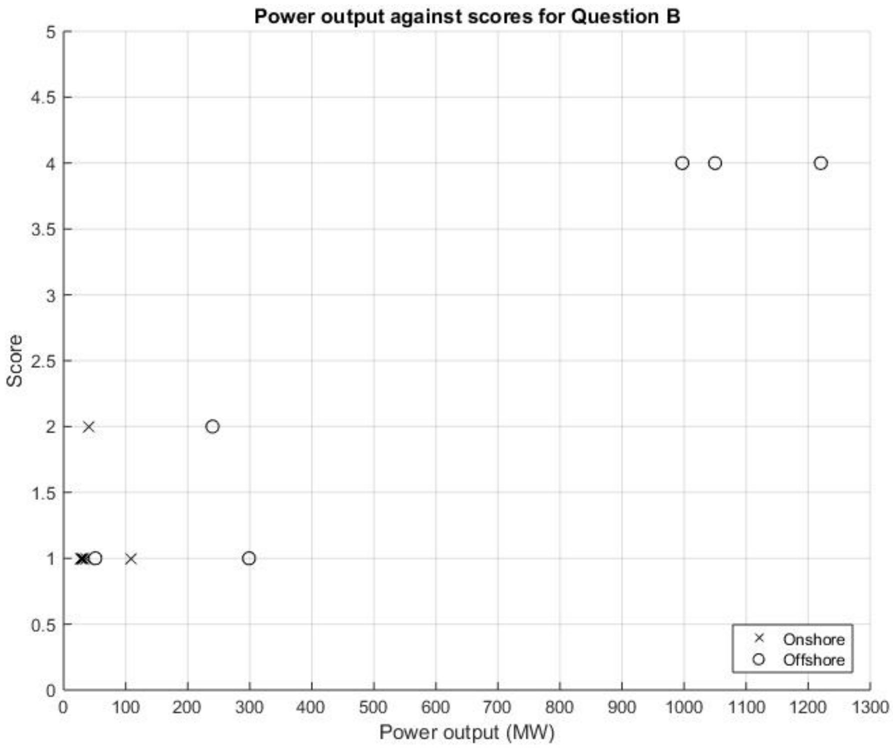

Figure 4. Power output against score for Question B.

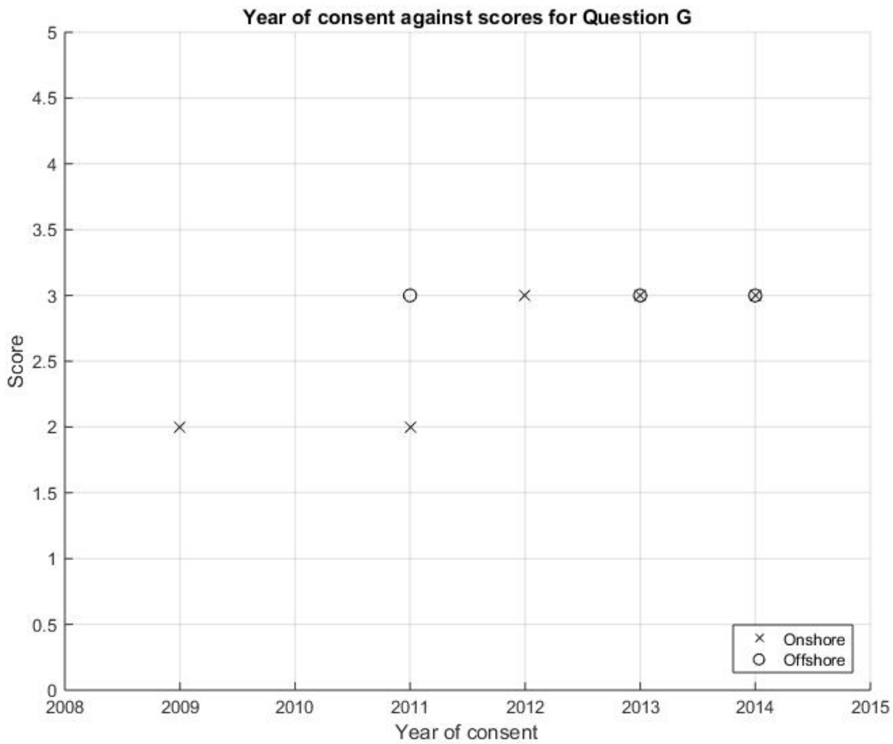

Figure 5. Year of consent against score for Question G.

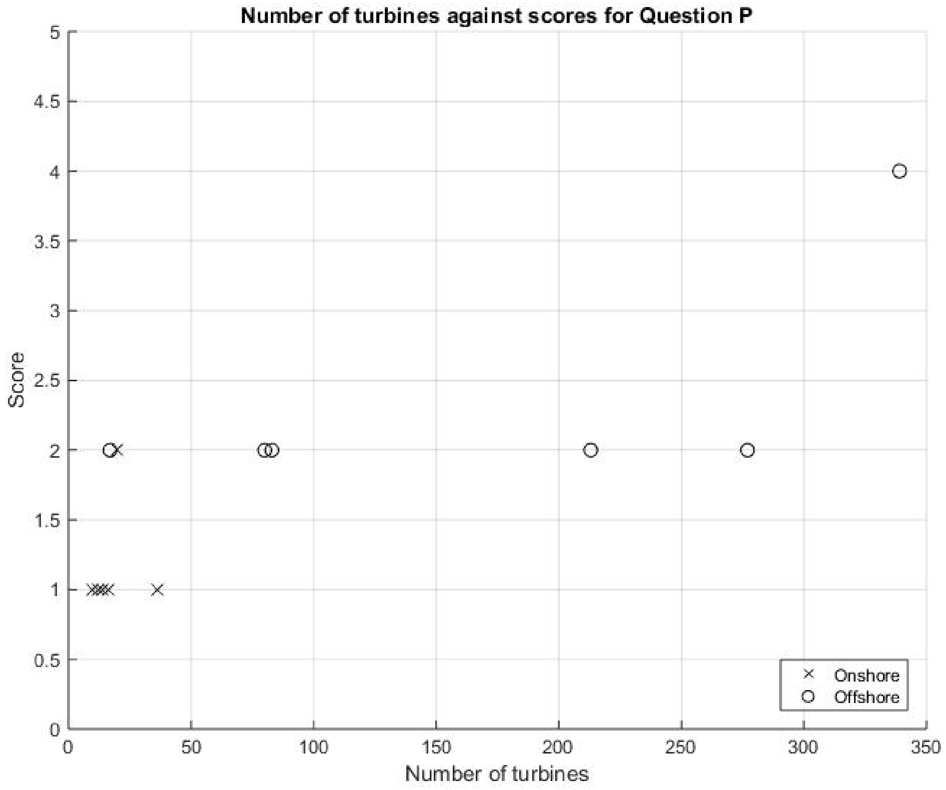

Figure 6. Number of turbines against score for Question P.

Appendix C

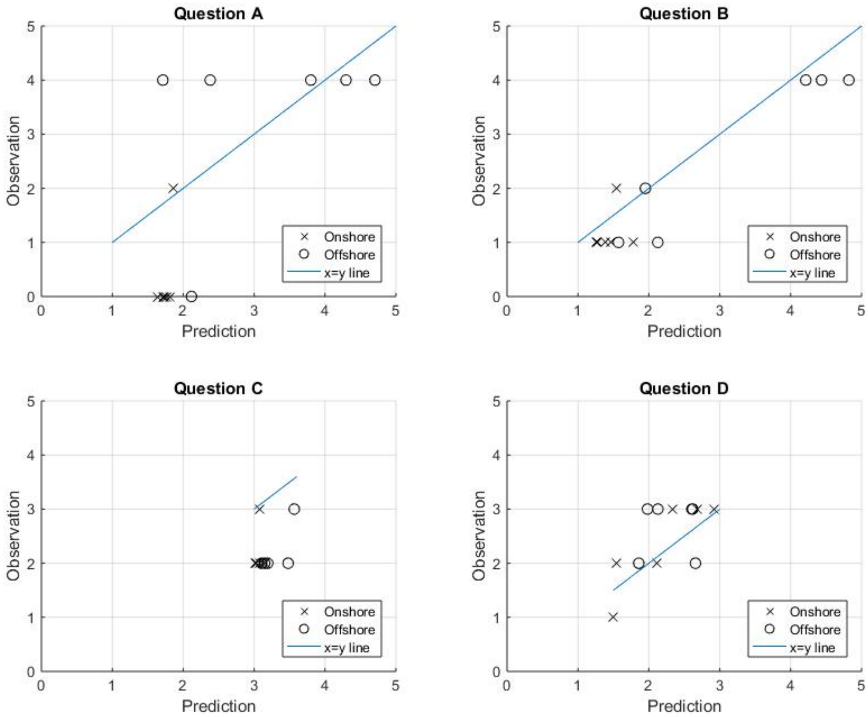

Figure 7. GLM results: Prediction against observation for questions A, B, C and D

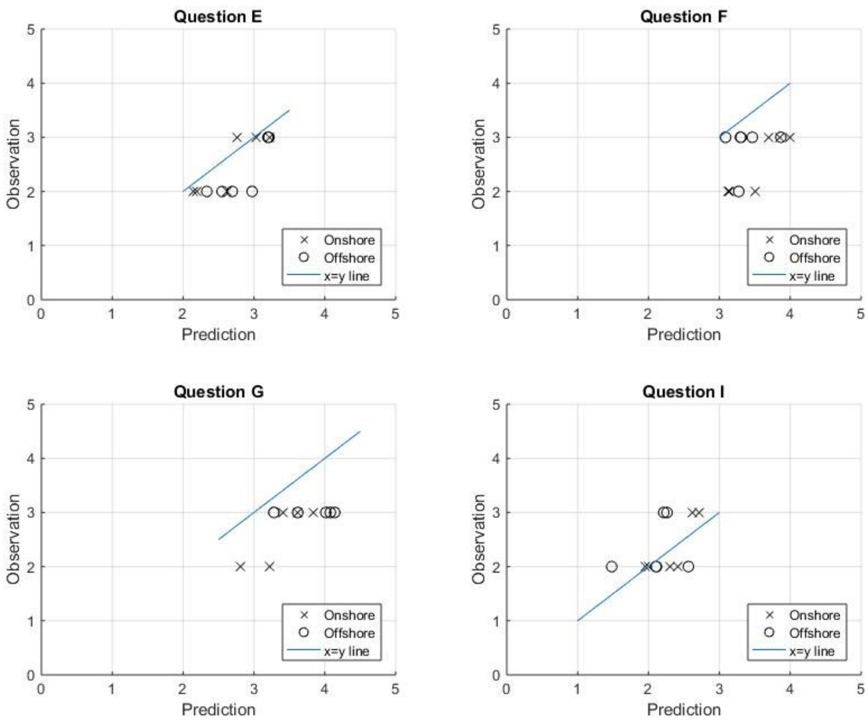

Figure 8. GLM results: Prediction against observation for questions E, F, G and I

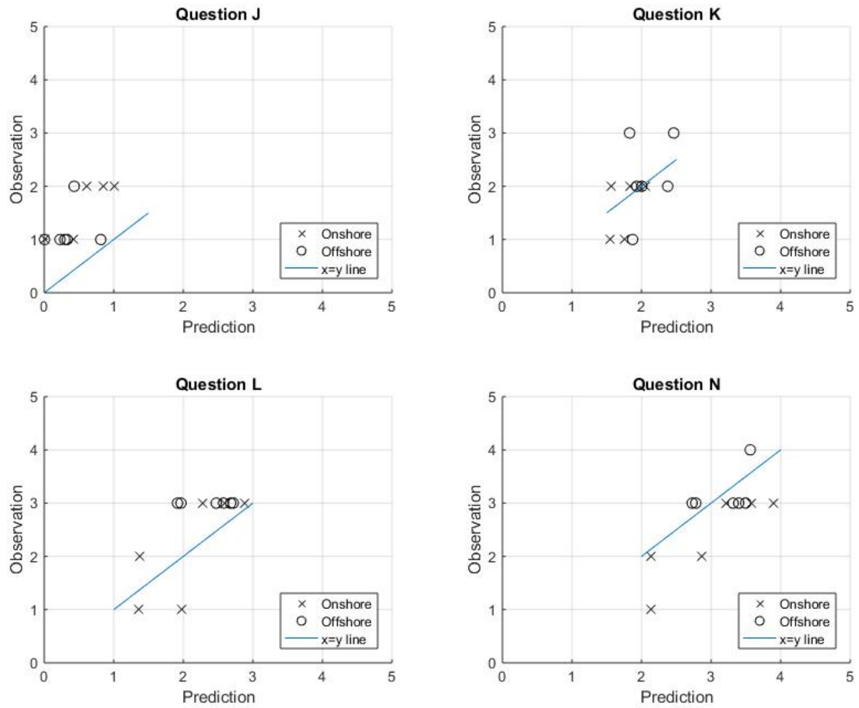

Figure 9. GLM results: Prediction against observation for questions J, K, L and N

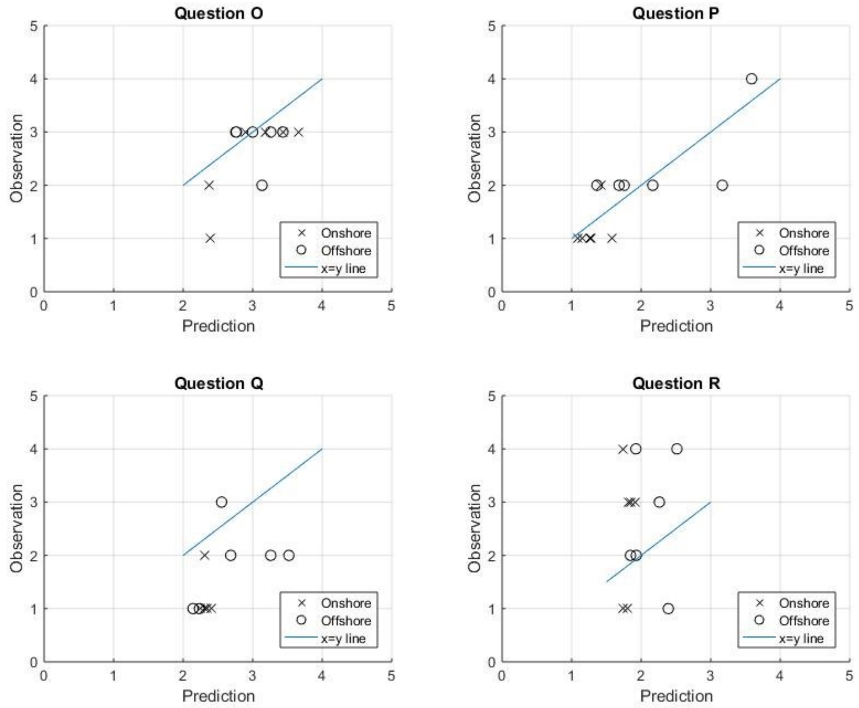

Figure 10. GLM results: Prediction against observation for questions O, P, Q and R