**Indirect impacts of oil and gas development: Cumulative impacts, widespread impact and precautionary approach**

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# Executive summary

The development of oil and gas fields has both direct and indirect impacts on the marine environment. Indirect impacts can be just as significant as those occurring directly. However, indirect impacts are often much more difficult to quantity.  
  
Cumulative impacts can also occur from the interaction between different types of impacts of oil and gas development. Oil and gas exploration, operation activities and decommissioning can involve the same individual impact occurring at the same site multiple times together or at multiple sites. Cumulative impacts can also involve the interaction between different types of impacts of oil and gas development (e.g., noise disturbance may interact with oil pollution). The additive (cumulative) impacts can often cause a more significant impact overall. In some cases, this increased impact is an increased intensity (additive at a single site), whilst in others, it may be an increased spatial footprint (additive across multiple sites). In some cases, it may be both.

An expansion of UK oil and gas licencing is expected to increase the number of installations within a relatively small offshore area (mostly the North Sea). Understanding how the different impacts of oil and gas development interact and stack up to cause cumulative impacts is essential to prepare for and mitigate any damage to the marine environment. However, a lack of research directly investigates the cumulative impacts of oil and gas activity. This report, therefore, provides a theoretical introduction to the potential cumulative environmental impacts that may arise from increased oil and gas activity on the UK marine environment. Potential cumulative impacts of oil and gas development include:

**Cumulative impacts of noise**

***Seismic survey noise pollution***

* Cetaceans may have to travel much greater distances to avoid the cumulative noise pollution of increased seismic survey activity in UK waters.
* Cetaceans on migratory journeys may deviate away from key feeding grounds in UK waters to avoid the cumulative noise pollution of increased UK seismic survey activity.
* The recovery of Atlantic cod (*Gadus morhua*) in the North Sea may be threatened by the cumulative noise pollution of increased airgun pulse exposure in the area.
* Zooplankton biomass may be significantly reduced with major ecological consequences following the cumulative noise pollution of seismic survey activity over an increased spatial scale.

***Construction and operation noise pollution***

* Cetaceans may alter communication to overcome the cumulative noise pollution of increased oil and gas operational activities, with energetic costs.

**Cumulative impacts of seabed disturbance**

* Cumulative impact of the increasing number of installations could facilitate a stepping-stone corridor for opportunistic fish species, with implications for native species' survival and biodiversity.

**Cumulative impacts of marine pollution**

* There is an increased statistical chance of an oil spill with an increased number of oil and gas platforms.
* Irrespective of whether an oil and gas operation discharge a small amount or catastrophic amount of effluent, concentrations will likely increase over the long term if the UK increase investments in oil and gas and more operations come online.
* Multiple sites within one area would make it highly likely that the marine environment would be constantly exposed to some level of oil pollution.
* The environment would be in a constant state of repair and recovery from oil pollution incidents (large or small).
* With increased oil and gas production, the concentration of pollutants associated with effluent discharges would be expected to build up in the marine environment.
* Whether accumulations-over-time reach “catastrophic” levels are yet to be seen.

**Other Impacts**

Cumulative impacts on the marine environment can also occur when oil and gas-related impacts interact with the impacts associated with other marine users (e.g., offshore wind installations and commercial fishing activity) or environmental issues such as climate change. Key points include:

***Climate change***

* Warming ocean temperatures and oil and gas-related seismic sound pollution could cause major shifts in cetacean migrations (routes and timings).

***Commercial fishing sector***

* Cumulative noise pollution from oil and gas activities and commercial fishing vessels could lead to a loss of daily foraging time for cetacean species – with energetic cost implications.
* Combined damage to the UK offshore seabed could be expected from the installation of oil and gas infrastructure and destructive fishing gear (e.g., trawlers being dragged along the sea floor).
* Substantial cumulative implications for the UK’s blue carbon stores could be expected from these impacts.

***Offshore wind energy sector***

* The rapid increase in the number and size of offshore wind farms in UK offshore areas alongside oil and gas development could result in much greater cumulative noise levels and seabed disturbance.
* The cumulative noise and seabed disturbance impacts of offshore oil and gas and wind energy activities have not been considered together, yet their effects on the marine environment are likely similar.
* When combined, their impacts would be expected to be at least additive with unknown longer-term impacts on the marine environment.

In general, a paucity of research was uncovered that directly investigates the cumulative impacts of oil and gas activity – impacts of the same and different impacts. Interactions between oil and gas development and other sectors in the offshore environments have not been compressively studied, making the cumulative impacts unknown. While some research has touched on the interaction of oil and gas activity and climate change impacts on the marine environment, much more comprehensive research is needed to fully understand potential cumulative impacts.

# Cumulative Impacts

# Introduction

The development of oil and gas fields has both direct and indirect impacts on the marine environment. Direct impacts relate to an impact's immediate effect, such as seismic survey noise causing instant mortality in nearby fish larvae. Indirect impacts, however, relate to secondary effects that occur because of the direct impacts, often sometime after the original direct impact has occurred. The instant mortality of fish larvae causing reduced commercial fish catches the following year leading to knock-on economic and social impacts for fisheries, is just one example of this direct-to-indirect impact scenario. Indirect impacts can be just as significant as those occurring directly. However, indirect impacts are often much more difficult to quantity.

In addition to the direct/indirect division of classifying oil and gas impacts on the marine environment, cumulative impacts are also worthy of mention. Cumulative impacts are defined in different ways in literature (Kirkfeldt et al., 2017). However, a straightforward definition is that cumulative impacts are ‘changes to the environment that are caused by an action in combination with other past, present and future actions’ (Hegmann et al., 1999). Oil and gas development, operation and decommissioning can involve the same individual impact occurring at the same site multiple times together or at multiple sites. The additive (cumulative) impacts can often cause a more significant impact overall. For example, many fish larvae dying (direct) at the same or multiple sites, increasing the risk of population-level impacts later (indirect). In some cases, this increased impact is an increased intensity (additive at a single site), whilst in others, it may be an increased spatial footprint (additive across multiple sites). In some cases, it may be both.

Cumulative impacts can also involve the interaction between different types of impacts of oil and gas development. For instance, noise disturbance may interact with oil pollution. This may cause additive impacts – fish larvae dying from the sound impacts added to surviving fish larvae having physiological problems from the pollution. There is also the possibility of multiplicative impacts occurring both in scenarios with one impact and those with multiple different impacts. For example, sound impacts may cause mortality in larval fish, but exposure to oil may weaken larval fish making them more likely to die from sound impacts. Overall, this would increase the mortality (a larger direct impact) more than just adding the two impacts together, in turn causing larger indirect consequences later.

This report discusses some of the potential cumulative environmental impacts that may arise from the oil and gas industry in marine systems. There was, however, a paucity of literature uncovered that directly investigates the cumulative impacts (reviews of cumulative assessment tools, however, were uncovered, including (Kirkfeldt et al., 2017; Turschwell et al., 2022)). We have therefore drawn from real-world case study examples of oil and gas environmental impacts and used hypothetical scenarios to elaborate on what the cumulative impacts of such may mean for the marine environment. We begin by discussing the impacts of noise and follow by addressing the impacts of pollution from the oil and gas industry. We then discuss the interaction of the oil and gas industry with the offshore wind energy sector and the commercial fishing sector. The interactions of marine oil and gas production with other industries and the different catalogues of impacts that each produces theoretically can result in a list of cumulative impacts that are well beyond the scope of this work. We, therefore, provide a standalone conclusion on what needs to be undertaken to try and help us understand the gaps in this space and how knowledge of cumulative impacts can be incorporated robustly into future environmental decision-making processes accounting for the precautionary approach clearly and robustly.

# Main Content

## Cumulative impacts of noise disturbance

### Introduction

Noise disturbance associated with oil and gas development occurs from exploration activities (e.g., seismic surveys) and operational activities (e.g., the installation and construction of physical infrastructure (oil rigs, pipelines etc.), drilling activity, support vessels and oil tankers). At an individual site level, noise disturbance can impact marine species within several kilometres (see work packages 1 and 2 for more detail on the impacts of noise pollution associated with oil and gas development on UK priority species). However, when combined with multiple sites over an offshore area, the cumulative impact of noise pollution can increase the intensity and spatial footprint of the impact.

#### Seismic survey noise pollution

##### Introduction

Seismic air gun sound, used to locate oil and gas deposits, is a major source of anthropogenic sound in the ocean. Sound impulses are typically over the 230 decibels (dB) range (Nowacek et al., 2015) and cover hundreds and thousands of square kilometres (km2). Seismic surveys can take weeks to months to complete (McCauley et al., 2017) and have far-reaching impacts (with one study recording seismic air gun sounds almost 4,000 km away from the survey vessel) (Nieukirk et al., 2012). Impacts of seismic activity from an individual site have been identified. However, the cumulative impacts of multiple projects undertaking seismic activity within a relatively small area of water (e.g., the UK EEZ) remain unknown (Carroll et al., 2017). Any UK oil and gas licencing expansion is expected to lead to intensified seismic survey activity in UK waters as projects work to locate oil fields. This section, therefore, aims to identify some of the possible cumulative impacts of seismic activity on UK priority species if the proposed expansion of oil and gas licencing were to go ahead.

**Cetaceans may have to travel much greater distances to avoid the cumulative noise pollution of increased seismic survey activity in UK waters.**

Multiple species of whales, dolphins and porpoises have shown sound avoidance behaviour to seismic noise pollution associated with oil and gas exploration up to several kilometres (km) from the source (Madsen et al., 2006; McCauley et al., 2000, p.; Sarnocińska et al., 2020). Increased seismic activity in the UK, particularly in the North Sea, where many of the proposed developments are planned, could lead to fewer safe, seismic noise-free spaces for cetaceans. To avoid the increased spatial footprint of seismic noise disturbance, cetaceans will likely have to swim much greater distances, with potentially significant energy expenditure costs. For example, a whale may attempt to avoid noise pollution from seismic surveys occurring at one oil field development, only to swim several kilometres into the seismic pulse noise from another site. Consequently, it is expected that the whale will continue to travel away from the noise, using vital energy reserves needed to find food and return to its original location. Cetaceans, however, have a limited ability to cope with any prolonged starvation period due to their high metabolic rates (Pirotta et al., 2014). Therefore, the cumulative impact of an increased spatial footprint of seismic noise disturbance and sound avoidance response in cetaceans could lead to long-term effects on individuals and populations.

The cumulative impacts of an increased spatial footprint of seismic noise disturbance in UK waters could be amplified further for the harbour porpoise *(Phocoena phocoena)* that is known to decrease buzzing behaviour (high repetition click trains used in prey capture) and echolocation within several km (25km) of seismic sound activity (Pirotta et al., 2014). These behavioural changes are thought to disrupt harbour porpoise foraging. Therefore, the longer the length of time harbour porpoises spend avoiding multiple seismic sound-impacted sites, the longer their foraging behaviours may be reduced or hindered. The long-term effects of such disturbances are, however, still unknown.

**Cetaceans on migratory journeys may deviate away from key feeding grounds in UK waters to avoid the cumulative noise pollution of increased UK seismic survey activity.**

Some cetaceans (such as the humpback whale *(Megaptera novaeangliae)*) have been found to respond to a full seismic array by deviating from their normal migratory course (Dunlop et al., 2017). The cumulative impact of increased seismic survey activity in UK waters will result in the increased intensity and spatial footprint of seismic noise pollution. This increased spatial footprint of noise pollution could lead to a cetacean avoidance zone around parts of the UK with heavy offshore oil and gas exploration, with migratory cetacean species such as the humpback whale, diverting from key feeding grounds in the north and west of the UK to avoid such noise disturbance. Observations in previous studies have found that if displacement from normal migratory feeding grounds is continuous occurring one after the other, then it could lead to severe and profound effects on individuals and populations (McCauley et al., 2000). The cumulative impact of seismic noise pollution will likely have similar effects on other cetacean species migrating within UK waters (Johnson, et al., 2022).

**The recovery of Atlantic cod (*Gadus morhua*) in the North Sea may be threatened by the cumulative noise pollution of increased airgun pulse exposure in the area.**

The chronic exposure of Atlantic cod embryos to noise pollution can negatively impact the quality and quantity of Atlantic cod embryos (Sierra-Flores et al., 2015). Increased seismic activity in the North Sea could, therefore, threaten the recovery and conservation of North Sea Atlantic cod which is currently outside safe biological limits and suffering reduced reproductive capacity (Marine Conservation Society, 2022). Furthermore, as the known impacts of noise disturbances on fish species are relatively similar between species, it is likely, that the cumulative impacts of increased airgun pulse noise exposure on cod could also stretch across multiple fish families in the North Sea.

**Zooplankton biomass may be significantly reduced with major ecological consequences following the cumulative noise pollution of seismic survey activity over an increased spatial scale.**

Zooplankton abundance has been found to be significantly reduced following seismic airgun noise exposure up to 1 km away (McCauley et al., 2017). Zooplankton performs key biogeochemical roles (Cavan et al., 2019) and form the main diet of many marine predators. Therefore, any reduction in zooplankton biomass is expected to have significant ecological consequences. An expansion of offshore oil and gas development sites in UK waters would increase the spatial scale of seismic noise pollution and its subsequent impact on zooplankton communities over a greater spatial extent. The cumulative impact of increased seismic airgun noise pollution over an expanded spatial scale could therefore significantly reduce the abundance of zooplankton communities within UK waters, with potentially serious knock-on effects for ocean ecosystem functioning such as food chain dynamics (McCauley et al., 2017).

#### Construction and operation noise pollution

##### Introduction

Once oil and gas has been located (via seismic surveys), the extraction process begins. Underwater noise is generated at every stage of the extraction process – during the construction of physical infrastructure (e.g., production rigs, underwater pipelines, and cables etc.) and operational activities, including drilling of production wells, vessel traffic and pipeline laying. With the proposed expansion of oil and gas licensing in UK waters, the impacts associated with construction and operational noise pollution would potentially have a larger cumulative footprint on marine species and habitats.

To date, there has been limited research into the direct impacts of noise pollution associated with the construction of oil and gas related infrastructure on marine priority species. Therefore, this section, aims to identify some of the potential cumulative impacts of noise pollution associated with only the operational activities on UK priority species if the proposed expansion of UK oil and gas licencing were to go ahead.

**Cetaceans may alter their communication to overcome the cumulative noise pollution of increased oil and gas operational activities, with energetic costs.**

Some cetaceans (such as the northern minke whale *(Balaenoptera acutorostrata)* and killer whale (*Orcinus orca*) have been found to adjust their vocal behaviour to compensate for anthropogenic noise once it reaches a threshold level (Foote et al., 2004). The cumulative impact of expanded oil and gas developments will increase the number of support and operation vessels in UK waters, with the volume of subsequent underwater noise potentially breaching safe thresholds. This increased intensity of underwater noise pollution could lead to cetaceans altering their vocalisation to overcome the masking effect of vessel related background noise. Observations in a previous study found that killer whales increase the duration of their calls as vessel traffic intensified (Oberweger and Goller, 2001). However, this form of vocal compensation could have negative implications that effect their activity budget of UK cetaceans, such as altered energetic costs and elevated stress levels. Therefore, as oil and gas related noise levels increase in UK waters, the health of cetacean populations is expected to be negatively impacted (Helble et al., 2020)

## Cumulative impacts of seabed disturbance

### Introduction

The construction and installation of oil and gas related subsea infrastructure (e.g., rigs, control cables, export lines etc) is known to cause seabed disturbance to the immediate area, with direct impacts to the marine environment including sediment resuspension, burial by seafloor anchors and pipelines (Cordes et al., 2016). The construction and installation of multiple oil and gas installations within an area is expected to expand the spatial footprint of impact. However, extensive research has not been carried out on the various cumulative impacts that could occur. This section, therefore, highlights the cumulative impact of the increasing number of oil and gas installations that has been identified in previous research.

**Cumulative impact of the increasing number of installations could facilitate a stepping-stone corridor for opportunistic fish species, with implications for native species' survival and biodiversity.**

The physical infrastructure related to oil and gas development provides a hard substrate suitable for artificial reefs to form (Hjorth et al., 2021). Oil and gas production often occurs in areas with a homogeneous substrate; therefore, a physical structure can promote marine life by providing a complex and durable place for fish and invertebrates to shelter and form habitats (Hjorth et al., 2021). However, artificial reefs can provide a steppingstone corridor for opportunistic fish and invertebrate species, if spaced too frequently and close together (Schramm et al., 2021). The cumulative impact of an increasing number of installations within UK waters could facilitate the movement and colonisation of invasive species in the UK offshore area, assisting the successful expansion of their geographic range. The expansion rate of invasive species across a connected habitat mosaic of UK oil and gas sites could be expected to increase quickly, threatening native biodiversity and causing changes to fish biomass (Hjorth et al., 2021). However, little information is available on potential non-native fish species that could be a risk to the North Sea or wider British waters. Instead, current knowledge on invasive non-native species in UK waters focuses heavily on invertebrates, marine plants (Horton, 2022; Nature Scot, 2021; The Welsh Government, 2017; Water Framework Directive UK TAG, 2021) or fresh water fish species (APEM, 2021). In 2021, however, a lionfish *(Pterois)* native to the Pacific Ocean,was caught off the south coast of Britain (The Independent, 2021). Lionfish have become an invasive species across large parts of the world, especially in the Caribbean and Mediterranean due to their tolerance for a range of temperatures, their high fertility and their potent venom (Natural History Museum, 2021). Their arrival in British waters, therefore, poses a threat to native wildlife and provides an insight into the range of tropical fish that may expand into warming northern oceans as a result of climate change.

## Cumulative impacts of marine pollution

### Introduction

Marine pollution associated with oil and gas developments occurs from operational activities (e.g., waste materials produced during the installation and construction of physical infrastructure (oil rigs, pipelines etc.) and drilling activity), oil spill incidents and the decommissioning process (e.g., waste materials produced during the extraction of oil and gas-related infrastructure). At an individual site level, released oil pollution can have acute and sublethal impacts on the marine environment and life within it. Nevertheless, the likelihood of a major impact occurring from oil pollution levels associated with a single site is often downplayed in Environmental Impact Assessments (EIA) and considered low risk to the environment. However, an increased number of oil and gas installations in the UK offshore area would be expected to cumulatively cause harmful levels of oil pollution, over a larger spatial scale, as a result of the activities of each site interacting.

This section, therefore, aims to briefly identify how the interaction of multiple offshore installations could lead to cumulative increases in oil pollution concentrations in the marine environment and a larger spatial impact.

#### Oil and gas effluent discharge

**Increased statistical chances of an oil spill with an increased number of oil and gas platforms.**

The current EIA literature surrounding UK oil and gas appears to downplay the potential impacts of an oil spill in UK waters. This low risk “status” can be considered to result from a combination of two trains of thought: 1) that an oil spill is so unlikely that the risk to the UK EEZ is low and 2) that any oil spill will not have a major impact because technology today is sufficient to halt a spill developing into a major catastrophe. If the UK does invest in the development of more oil and gas platforms within the UK EEZ, the first point above becomes ever more relevant. Even if the risk of an oil spill is low from a single oil platform, the risk from multiple platforms is increased. One may also argue that more oil and gas platforms may also lead to increased logistical complexities for oil and gas companies which in turn may increase the risk per platform as well. Although somewhat speculative, such points need careful consideration considering the legacy that previous oil spills have left – long term environmental damage (some argue irreversible damage).

**Cumulative discharges increase overall extant pollutant concentrations.**

Waste material discharge (including drill cuttings, drill muds and produced water) leak into the marine environment during construction and operational activities (e.g., pile diving of physical infrastructure into the seabed and drilling). Irrespective of whether an oil and gas operation discharge a small amount or catastrophic amount of effluent, concentrations will likely increase over the long term if the UK increase investments in oil and gas and more operations come online. Effluents associated with oil and gas industry take a varied amount of time to be broken down naturally in the water column and in the seabed (Bociu et al., 2019). The only way in which increased oil and gas infrastructure will not cause an increase in overall pollutant concentrations is if effluent discharge is sporadic enough to allow effluents to fully breakdown in the environment before the next discharge event. We know this is highly unlikely considering some effluent discharges from oil and gas platforms occur regularly (produced water for example) (Beyer et al., 2020), longer than the time it likely takes for the effluent to breakdown naturally in the environment.

Furthermore, constant oil and gas activity would mean that the environment is in a constant state of repair and recovery from oil pollution incidents (large or small). If an oil spill (not produced water discharge) were to occur at an isolated site, some may argue that it is unlikely that another similar spill would occur at that site within the space of time needed for the surrounding environmental to recover (unlikely but not impossible). However, when multiple sites occur within one area, it is highly likely that the marine environment would be constantly exposed to some level of oil pollution. Consequently, a situation would be expected where pollution occurs on top of previous pollution, as not enough time has occurred between the pollution events for it to disperse. A situation of chronic oil exposure resulting from cumulative increases in oil and gas activity in a given area.

It is highly likely, that over time, with increased oil and gas production, the concentration of pollutants associated with effluent discharges will in fact build up in the marine environment. Depending on currents and the location of installations, these discharges may reach coastlines at which point their accumulation and natural breakdown may differ compared to open-water accumulation. Whether these accumulations-over-time reach “catastrophic” levels are yet to be seen. Such moving baseline syndromes are common in many different ecological fields and should be of considerable concern if the UK does up the number of oil and gas installations in the coming years. This is particularly so if we also consider potential cumulative impacts between pollutants and other impacts such as warming waters, noise pollution, ocean acidification and alike.

## Other impacts

Further cumulative impacts on the marine environment can occur when oil and gas related impacts interact with the impacts associated with other marine users (e.g., offshore wind installations and commercial fishing activity) or environmental issues such as climate change.

### Climate change

The challenges associated with climate change are causing profound impacts on the oceans and life within it (Bijma et al., 2013). Oceans absorb the heat and energy generated by rising greenhouse gas emissions, causing increasing ocean temperatures that lead to cascading effects including the melting of ice caps, sea-level rise, marine heatwaves, and acidification.

The cumulative impacts of climate change effects on marine ecosystems and oil and gas impacts have not been comprehensively studied, and therefore remain largely unknown. However, some studies have mentioned (largely in passing) how oil and gas impacts could interact with changing environmental conditions because of climate change.

For example, warming ocean temperatures and oil and gas related seismic sound pollution could cause major shifts in cetacean migrations (routes and timings). For example, some cetaceans are known deviate away from normal migratory courses in response to seismic survey noise pollution (Dunlop et al., 2017), potentially diverting them away from key feeding grounds. Warming ocean temperatures, are also expected to result in changes to the timing of cetacean migrations (Braithwaite, et al., 2015). In the UK, for example, scientists expect cetaceans to arrive earlier than usual under warmer ocean conditions (Evans and Waggitt, 2020). However, food availability for some migratory cetaceans such as humpback whales is highly season (e.g., krill biomass increases in warmer months). Therefore, any shift in migratory timing could, mean that cetaceans arrive to feeding grounds before enough food is available to replenish vital energy supplies needed to reach breeding grounds in the south. Combine the avoidance of cetaceans that is linked to seismic noise pollution (or noise pollution from construction or decommissioning) with climate related changes to migration timing, and cetaceans could be at increased risk from depleted energy reserves, alterations in seasonal behaviours and in extreme cases possible starvation.

### Commercial fishing sector

In the UK, commercial fishing offers many benefits including providing a local source of food security and creating employment and income. However, if managed unsustainably, it can contribute to the degradation of UK marine ecosystems through overfishing, habitat damage (via destructive fishing gears) and bycatch of vulnerable/juvenile species (Jennings and Kaiser, 1998). Furthermore, commercial fishing vessels contribute to high levels of vessel traffic in UK waters, causing underwater noise pollution via vessel engines and propellers, and fishing gears that drag along the seafloor.

Commercial fishing grounds and oil and gas developments in UK waters often overlap. Fishers are also known to target areas close to oil and gas infrastructure to benefit from the artificial reef effect on fish stocks (Rouse et al., 2018). Nevertheless, the cumulative impact of both industries on marine ecosystems has not been extensively studied.

Cumulative impact of the noise pollution associated with oil and gas vessels (support vessels, operating vessels, and oil tankers) and commercial fishing boats, to the best of our knowledge has not been investigated. However, research into the cumulative impact of noise associated with whale watching boats and commercial fishing vessels on cetacean foraging provides a useful reference to understand potential impacts. Cumulative noise from whale-watching boats and commercial fishing vessels can result in roughly 20% loss of foraging time in killer whales each day. This loss has been equated to 5 to 5.5 hours per day (Port of Vancouver, 2017) a significant amount of time that could contribute to major energetic cost implications and thus weakened health of impacted individual. Long-term population implications could result if enough individuals are impacted within a given area or population.

Further cumulative impacts that could be expected but not yet highlighted in research include the combined damage to the UK offshore seabed as a result of the installation of oil and gas infrastructure and damage caused by destructive fishing gear (e.g., trawlers being dragged along the sea floor). Substantial cumulative implications for the UKs blue carbon stores could be expected from these impacts, with the potential disturbance of carbon previously stored in UK offshore sediment for millennia. The contribution of blue carbon to climate change mitigation was recently acknowledged in UK policy (see the [UK’s Net Zero Strategy (2021)](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf)). However, greater understanding and prevention of the cumulative damage to UK seabeds from the combined impacts of oil and gas and commercial fishing industries needs to be a research priority.

### Offshore wind energy sector

The rising cost of energy, increasing concern around depleting non-renewable energy sources and the awareness of their harmful environmental effects (e.g. related CO2 emissions) has propelled the growth of offshore wind development in the UK (Global Wind Energy Council, 2018).

While wind energy provides a clean, climate-safe alternative to traditional oil and gas, the construction and operational phases of offshore wind can be damaging also.

Pile driving and dredging associated with the construction of wind farms generate underwater noise pollution and vibrations (Siddagangaiah et al., 2022). The shipping and towing of the turbines and their foundations brought out to sea also contribute further to noise pollution (Bailey et al., 2014), while the operation of a turbine generates sustained low frequency (below 1kHz) and low-intensity harmonic vibrations underwater. The rapid increase in the number and size of offshore wind farms in UK offshore areas could result in much greater cumulative noise levels (Tougaard et al., 2020).

Similar to oil and gas construction and operation, negative environmental impacts associated with the noise pollution generated during offshore wind farm construction and operation stages have been reported. For example, noise disturbance associated with pile driving has been found to influence fish behaviour by causing auditory masking and alteration of foraging patterns, social behaviour, and metabolism (Bailey et al., 2014). Marine mammals are also known to be vulnerable to noise associated with wind farm operational noise. However, there is currently insufficient knowledge regarding the long-term effects of such operational noise (Bailey et al., 2014; Madsen et al., 2006).

Seabed disturbance also occurs as a result of the construction of offshore wind turbines. For example, fixed turbines (such as monopile and jacket/ tripod turbines) require pile driving for installation, similar to oil and gas physical infrastructure (e.g., rigs and pipelines etc.) (Rouse et al., 2018). Major environmental concerns have been linked to the seabed disturbance associated with wind farm construction, including changes to benthic habitats, alterations to food webs and the release of contaminants from seabed sediment (Bailey et al., 2014; Boehlert and Gill, 2010; Gill, 2005; Inger et al., 2009). Nevertheless, six fixed offshore wind projects were given the green light by the UK government in July 2022 (Offshore Wind Leasing Round 4 projects), three of which will be located in the North Sea (The Crown Estate, 2022).   
  
Damage to offshore carbon stores caused by wind farm installations is also likely; however, no research has yet been carried out on the blue carbon implications of wind farm installation. The cumulative impact of all three offshore industries discussed (oil and gas, commercial fishing, and wind energy) can potentially threaten a relatively large area of UK deep-sea blue carbon, potentially hindering UK climate change mitigation efforts. Until further research is undertaken into the soft sediment carbon stores around the UK and the impacts of the three industries on them, this remains highly speculative.

The cumulative noise and seabed disturbance impacts of offshore oil and gas and wind energy activities have not been considered together, yet their impacts on the marine environment are likely similar. Therefore, it is somewhat straightforward to assume that when combined, their impacts would be at least additive with unknown longer-term impacts on the marine environment.

# Poor implementation of the precautionary approach

The precautionary approach (or precautionary principle) is a legal approach to decision-making that takes preventative action in the face of uncertainty. For example, the precautionary principle enables decision-makers to adopt precautionary measures when scientific evidence about an environmental or human health hazard is uncertain, and the stakes are high (European Parliament, 2015). Precautionary measures could include emphasising caution, pausing, and reviewing the situation before going ahead with an innovation/project that may prove problematic (Read and O'Riordan, 2017). In the case of extremely high risks, regulators may choose to restrict or prohibit an innovation/project, particularly if the suggested risks are uncertain.

The precautionary approach is well-established in international law and has been implemented widely by the UK government in policy (European Commission, 2022). The European approach to the principle is the *"better safe than sorry"* approach. Before Brexit, the UK implemented the precautionary approach in the same way; regulating an environmental risk even if the likelihood of it happening is slim and / or putting the burden on the operator to show that a potential innovation / project / operation is safe (European Parliament, n.d.). However, following Brexit, the UK appears to have taken a similar stance to the precautionary principle as the United States, focusing more on the financial impact of restricting or banning an innovation/ project before regulating it ( Ashford, 2006). The UK replaced EU law with its own environmental legislation in 2021 (UK Parliament, 2021). It later released a [Draft Environmental Principles Policy Statement](https://consult.defra.gov.uk/environmental-principles/draft-policy-statement/supporting_documents/draftenvironmentalprinciplespolicystatement.pdf) in which it proposed that while applying the precautionary principle, UK regulators *"should only prevent or defer an innovative development where that risk outweighs the benefits".* Some have argued that this interpretation/ implementation of the approach may allow lucrative technologies/projects to permanently damage the environment and public health before the inherent risks are clear (Hemphill, 2020).

Poor UK implementation of the precautionary approach has led to the UK government backing expansions to oil and gas licencing in UK waters, despite the known evidence of environmental harm caused by oil and gas development (harm to the marine environment and the wider climate) (Bussey, 2022). According to the UK government, proposals that involve oil and gas drilling are subject to a rigorous, evidence-based approach across the Environment Agency, Health and Safety Executive, local councils, the Oil and Gas Authority and the Department of Energy and Climate Change (Offshore Petroleum Regulator for Environment and Decommissioning and Department for Business, Energy & Industrial Strategy, 2022). However, multiple knowledge gaps and uncertainties remain around the threat and impact of drilling operations on the marine environment and around other aspects of oil and gas development (exploration, operational, accidental events, and decommissioning impacts) (see previous work packages separately for detail on the impacts of each stage of oil and gas development).

# Conclusion

An expansion of UK oil and gas licencing is expected to increase the number of installations within a relatively small offshore area (mostly the North Sea). Understanding how the different impacts of oil and gas development interact and stack up to cause cumulative impacts, is essential to prepare for and mitigate any damage to the marine environment. However, there is a paucity of research that directly investigates the cumulative impacts of oil and gas activity – impacts of the same and different impacts.

Furthermore, research on the interaction between the multiple offshore industries operating in the North Sea e.g. oil and gas, wind energy and commercial fishing is in the early stages. Cumulative impacts of the sectors on the offshore environments have not been compressively studied yet and therefore the combined damage is unknown. With offshore industries expected to grow in the coming years, research is needed to understanding where major area of damage could occur and put mitigation measure in place to protect the marine environment and the industries that rely on healthy seas.

Some research to date has touched on the interaction of oil and gas activity and climate change impacts on the marine environment such as increasing ocean temperatures. However, this has generally been made in passing. The cumulative impact of oil and gas activity and climate change impacts on the marine environment should be a priority research area if we are to fully understand the impact of oil and gas under future climate change conditions.

Real-world case studies have been used to highlight the potential cumulative impacts of oil and gas activity on the marine environment. It is clear that the cumulative impacts of increased sites within a relatively small offshore area will multiply the intensity and spatial footprint of most oil and gas impacts e.g., underwater noise, seabed disturbance and oil contamination of the marine environment. Where possible, species-specific impacts have been given to highlight the potential cumulative impacts on an expansion of UK oil and gas licencing on UK priority species.

Finally, analysis of the UK’s use of the precautionary approach highlights potential poor implementation – with offshore oil and gas projects given the green light regardless of major knowledge gaps around potential impacts.

Overall, this report provides a hypothesised introduction to a much needed, large piece of work on the cumulative impacts of offshore UK oil and gas activity on the marine environment.

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# Key challenges

* A paucity of information was uncovered on the cumulative impacts of the oil and gas industry, resulting in hypothetical examples being drawn.
* Lack of research on the cumulative impacts of different marine users interacting with the oil and gas sector.
* However, it is noteworthy that OSPAR plan to develop methods for the analysis of cumulative effects in the marine ecosystems of the North-East Atlantic by 2028 (Michael Carder, 2022). This would include taking into account relevant spatial and temporal information on human activities, pressures, sensitive receptors and habitats, and use the results to inform the establishment of measures and actions to prevent, reduce or otherwise manage impacts.

# Infographic ideas

* Single site – infographic showing all the different impacts that can occur at one site at the same time to cause cumulative impacts, e.g., noise pollution associated with a seismic survey and noise disturbance, seabed disturbance and waste discharge associated with the construction and installation of physical infrastructure that’s going on alongside it. Also, noise pollution associated with survey vessels and support vessels- e.g., those bringing the infatuation out to sea etc.
* Multiple sites – infographic showing all the different impacts interacting across multiple locations, e.g., one site is shown performing a seismic survey with noise disturbance depicted (e.g., sound wave icons), and another site is drilling, with noise pollution shown alongside seabed disturbances and waste materials.

# Follow-up research ideas

* Plenty of hypothetical cumulative scenarios can be drawn up based on the known direct impacts of oil and gas. It could be worth undertaking a more comprehensive study that brainstorms and links peer-review research between the hypotheticals in a formalised and standardized way.
* Blue carbon – An in-depth study on the cumulative impact of offshore industries on blue carbon stores (e.g. via seabed disturbance). Important to understand, considering the UK is pushing for wind farm expansion to meet net-zero commitments.