North Sea Futures

Environmental Impacts of the Decommissioning of Offshore Installations in the North Sea

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Or

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Contents

Executive Summary

This report seeks to provide an answer to the question: ***What are potential environmental impacts (positive and negative) of a more flexible approach to decommissioning of offshore installations in the North Sea?***[1] In doing so, we focus on decommissioning of oil and gas installations and offshore wind farms. The work is based on the current state of knowledge available in the public domain and within the scientific community: articles in scientific journals; technical and factual information from internet sources; the very recently published results of the INSITE programme and a survey among international experts on marine ecosystems, offshore installations and decommissioning (see Annex 1 for further details).

In the North Sea alone, there are now some 1,350 oil and gas installations, more than 27,000 shipwrecks and more than 2,300 offshore wind turbines. The number of wind turbines is growing with hundreds each year, forecasts predicting an additional 4,000-8,000 turbines by 2030 and up to 25,000 by 2050. Eventually the result could be that almost 8% of the North Sea area (57,000km^2) might be occupied by offshore energy installations by 2050 and that some 300-600 wind turbines would have to be built and decommissioned each year until 2050, while almost all oil and gas installations would have to be decommissioned within the same period of time. Next to these offshore installations, there are some 45,000 ship wrecks in the North Sea and more than 70 artificial reefs within the OSPAR area (of which at least 7 in Denmark). All these man-made structures, mimic functions of natural reefs in an ecosystem, which is otherwise dominated by so called soft sediment habitats.

According to current regulations, based on OSPAR Decision 98/3, all disused offshore installations have to fully removed and transported to shore for reuse, recycling or final disposal. Derogations from this rule are allowed for specific types of installations, based on technical considerations. Derogation requests must be accompanied by a comparative assessment of various decommissioning options including assesment of safety, potential negative impacts on the environment, costs, feasibility and impacts on other users of the sea. The intention of this policy is that the seabed should be restored to its 'original' pre-installation state and material from installations reused or recycled. After removal, the area is opened up to other users again, incl. fisheries and trawling.

Offshore installations are primarily made from high-quality steel and concrete. Over time, they develop into artificial reefs, which provide various kinds of ecosystem services, incl. habitat functions for a variety of species. They differ from (most) artificial reefs, ship wrecks and natural reefs in the North Sea in that they pass all way through the water column, incl. the intertidal zone, while standing in the middle of the sea. Secondly, they are surrounded by a 500m safety zone, where a.o. fishing is not allowed for.

No assessments have been published on the cumulative effects of decommissioning in the North Sea (nor of the cumulative effects of the placement of thousands of new renewable energy installations). Hence, we can only provide a qualitative assessment of potential environmental effects of a more flexible approach to decommissioning in the North Sea.

[1] A '***more flexible approach to decommissioning***', in this document is defined as an approach that explicitly provides (limited) room and describes procedures for leaving clean, ecologically valuable parts of offshore installations in situ to continue providing ecosystem services as artificial reefs, in cases where this option can be proven to be the best option for the marine ecosystem and/or the environment in general. It does ***not*** entail a more flexible approach to plugging of wells or the handling of contaminated seabed areas.

Conclusions

- **Over time, offshore installations develop into artificial reefs, which can be of significant value to the ecosystem**, especially if they replace lost historical reefs, provide habitat for threatened or protected species, function as a stepping stone for larval exchange between natural reefs, provide food and shelter for mobile species/biomass or support important commercial species. Most of the experts consulted believe that valuable reef habitats should in principle be maintained and protected.
- **We seem to know more about what will happen to the ecosystem if we leave offshore installations in place** (established communities will develop further), **than we know about what will happen if we remove them** (established communities will disappear, which may possibly affect the wider ecosystem via related food webs and loss of connectivity).
- **There is a large degree of consensus among scientists that a more flexible approach to decommissioning could benefit the North Sea ecosystem**, especially if such an approach takes into account the role of individual installations within the wider network of reef habitats. Partial decommissioning options are seen to be at least as valid or even preferable to full removal options.
- **If partial decommissioning options are chosen, it is important to maintain or even enhance the safety zone around the installation.** Safety zones add ecological value by protecting the artificial reef from being damaged and protecting species around the reef from being caught by fishermen. Moreover, they reduce the risk of vessel collisions and snagging of fishing nets.
- **There is a strong need for practical experience and further research** on positive and negative effects of partial decommissioning options as compared to full removal, through **pilot projects** and through **modelling of cumulative effects**.
- In the table below, we **summarize the potential positive and negative effects** of introducing a more flexible approach to decommissioning in the North Sea. It is expected that **most of the negative effects can be mitigated** through improved EIAs, case-by-case measures and clear procedures for management of material left offshore.

Potential positive effects of flexile decommissioning	***Potential negative effects of flexible decommissioning***
General for all offshore installations	**General for all offshore installations**
Reduced loss of reef habitat, especially in Southern and Central North Sea	Lost opportunities for restoration of seabed to its 'original' (pre-placement) state
Protection of habitat for endangered species attached to offshore installations	Continued connectivity for invasive species (primarily intertidal zone)
Continued connectivity between natural and artificial reefs (offshore installations) for valuable species	Loss of non-renewable resources that could otherwise be reused or recycled (steel, copper, plastics, concrete)
Maintenance of valuable communities that have developed on man-made structures, including continued production of additional biomass	Loss of offshore space that can be freely used for any purpose (clean seabed)
Increased stability of ecosystem as artificial reef habitats are not continuously being removed and constructed	Increased long-term risk of damage due to vessel collisions with material left offshore
Continued (physical) protection from trawling (i.e. refuge, shelter and reduced seabed disturbance) around installations	Increased long-term risk of ghost fishing (by snagged gear)
Reduced impact of noise from decommissioning activities (vessels, cutting)	
Reduced negative impacts on coastal communities near decommissioning yards (pollution, space, odour)	
Reduced energy-use and emissions to air for removal, transport and onshore cutting of installations	
Reduced disturbance of seabed around offshore installations	
Specific for oil and gas installations	**Specific for oil and gas installations**
Reduced risk of resuspension of contaminants in seabed surrounding installations (during decommissioning and afterwards as a result of trawling)	
Specific for offshore wind farms	**Specific for offshore wind farms**
Incentive for eco-design of offshore wind farms (or at least removal of a possible incentive to minimize scouring protection and other elements that may improve ecosystem functions)	

Note: There is some disagreement as to whether 'loss of offshore space' is an environmental effect.

1. Introduction

This report seeks to answer the question: ***What are potential environmental impacts (positive and negative) of a more flexible approach to decommissioning of offshore installations in the North Sea?*** Since the response to this question very much depends on how we define a 'more flexible approach to decommissioning' (more flexible than what?), we spend the first couple of chapters on contextual background information:

- In **chapter 2**, we provide some **context on offshore installations in the North Sea**: what types of installation, how many, where, and how can we expect this to develop in the near future?
- In **chapter 3**, we explain **what decommissioning is and how it works**; what kind of activities it entails. Without some basic knowledge of the process of decommissioning it is very difficult to understand the potential environmental impacts of this process.
- In **chapter 4**, we explain **how current decommissioning regulations work**. When we talk about 'more flexible', we refer to current regulations, which has a fundamental preference for one decommissioning option: full removal to shore and return of the seabed to its 'original state'.
- In **chapter 5**, we first provide an **overview of the environmental impacts of offshore installations in different stages of their life cycle and then get into a discussion of the environmental impacts of a more flexible approach to decommissioning.**

For those who would like to jump straight to chapter 5, here are a few key points to keep in mind when reading:

- ***Offshore installations are not only oil and gas installations, but also wind turbines***, wave energy installation, bridges, etc. In this report, we deal only with oil and gas installations and offshore wind turbines, but many considerations might be extended to other types of installations, too.
- ***Current international decommissioning regulations do not distinguish between the economic purposes for which an installation has been placed*** (that would be discriminatory), but primarily makes distinctions on the basis of the material used for construction.
- ***Current regulations, based on OSPAR Decision 98/3, assumes that "reuse, recycling or final disposal on land will generally be the preferred [decommissioning] option"*** (OSPAR Decision 98/3, 1998). Exceptions to this rule are defined for specific types of installations, based on technical considerations.
- When we talk about a ***'more flexible approach to decommissioning', we talk about an approach that explicitly provides (limited) room and describes procedures for leaving clean, ecologically valuable parts of offshore installations in situ*** to continue providing ecosystem services as artificial reefs, in cases where this option can be proven to be the best option for the marine ecosystem and/or the environment in general.
- When we talk about a ***'more flexible approach to decommissioning' we do <u>not</u> talk about creating more flexibility in the approach to the plugging of wells*** or the management of contaminated seabed areas around an offshore installation or the decommissioning of pipelines and cables. ***Wells should always be properly plugged, and regulations and approaches to the management of contaminated seabed areas, pipelines and cables are rather flexible already.***

2. Blue Growth and the Energy Transition: Unprecedented Industrialisation of the North Sea

As space and resources on shore become increasingly scarce, governments and business are increasingly looking to our oceans and seas as a place of new opportunities for mining resources, producing energy and food to meet the future needs of a growing population and growing economies. In the OSPAR region, the European Commission's Blue Growth strategy and the "Political Declaration on energy cooperation between the North Sea Countries" are characteristic for this development. The result is an ***increasing industrialisation of the North Sea (and other seas), which presents us with new challenges in ensuring sustainable use of marine resources and in conserving important marine species and habitats***. This process does not only have an impact in terms of potential pollution, increasing pressure from fisheries and disturbance of valuable coastal and marine areas, but also through the placement of a huge number of offshore installations, made of various materials.

In the North Sea alone, there are now some 1,350 oil and gas installations, more than 27,000 shipwrecks and more than 2,300 offshore wind turbines. The number of wind turbines is growing with hundreds each year, forecasts predicting an additional 4,000-8,000 turbines by 2030 and up to 25,000 by 2050. [2] Eventually the result could be that almost 8% of the North Sea area (57,000km^2) might be occupied by offshore energy installations by 2050 and that some 300-600 wind turbines would have to be built and decommissioned each year until 2050, while almost all oil and gas installations would have to be decommissioned within the same period of time.

Within the OSPAR area, more than 70 artificial reefs have been constructed since the early 1970's, for various purposes: creating opportunities for artisanal fishing, diving and surfing, protection from (illegal) trawling and restoration of reef habitats. Most of these reefs have been established after 1998, of which at least 7 in Denmark (see Annex 2 for an overview of artificial reefs in the OSPAR region). In Denmark, especially active restoration of stone reefs has been successful adding biodiversity and biomass and in supporting species which are under pressure. Though most artificial reefs in the OSPAR region are built from natural stone or concrete, there are also several examples of reefs created from disused cleaned vessels or even military tanks. After 2000, the average deployment cost per m^3 of artificial reef has been approximately €500 (Tessier et al, 2015). Presumably, these costs could be substantially reduced by reusing clean material from disused offshore installations or by considering the use of such installations as artificial reefs in their present location.

When looking at the map below (fig. 1), indicating the location of offshore installations and shipwrecks, the North Sea seems full of offshore installations and other forms of man-made items. In reality, all these man-made structures – oil and gas installations, offshore wind turbines and shipwrecks including surrounding safety zones – 'only' cover an area of 1000 - 1500km^2 or 0.13 – 0.2% of the total surface of the North Sea[3].

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[2] *www.ospar.org/work-areas/oic/installations, https://www.ewea.org/fileadmin/files/library/publications/reports/EWEA-Wind-energy-scenarios-2030.pdf, https://en.wikipedia.org/wiki/List_of_offshore_wind_farms_in_the_North_Sea*

[3] *This calculation is based on the following assumptions: 650 - 1300 O&G installations with each a safety zone of 500m = 510 - 1020km^2; 30,000 shipwrecks with a mean surface of 1200m^2 = 36km^2; 2400 wind turbines with an average safety zone of 0,22km^2 = 550km^2. The safety zones of O&G installations are partially overlapping, but to exactly what extent is unknown. The wind turbine safety zones differ per country: in the Netherlands wind parks are closed for fishing and many other activities, but in the UK and Denmark, only limited areas (especially around cables) are closed.*

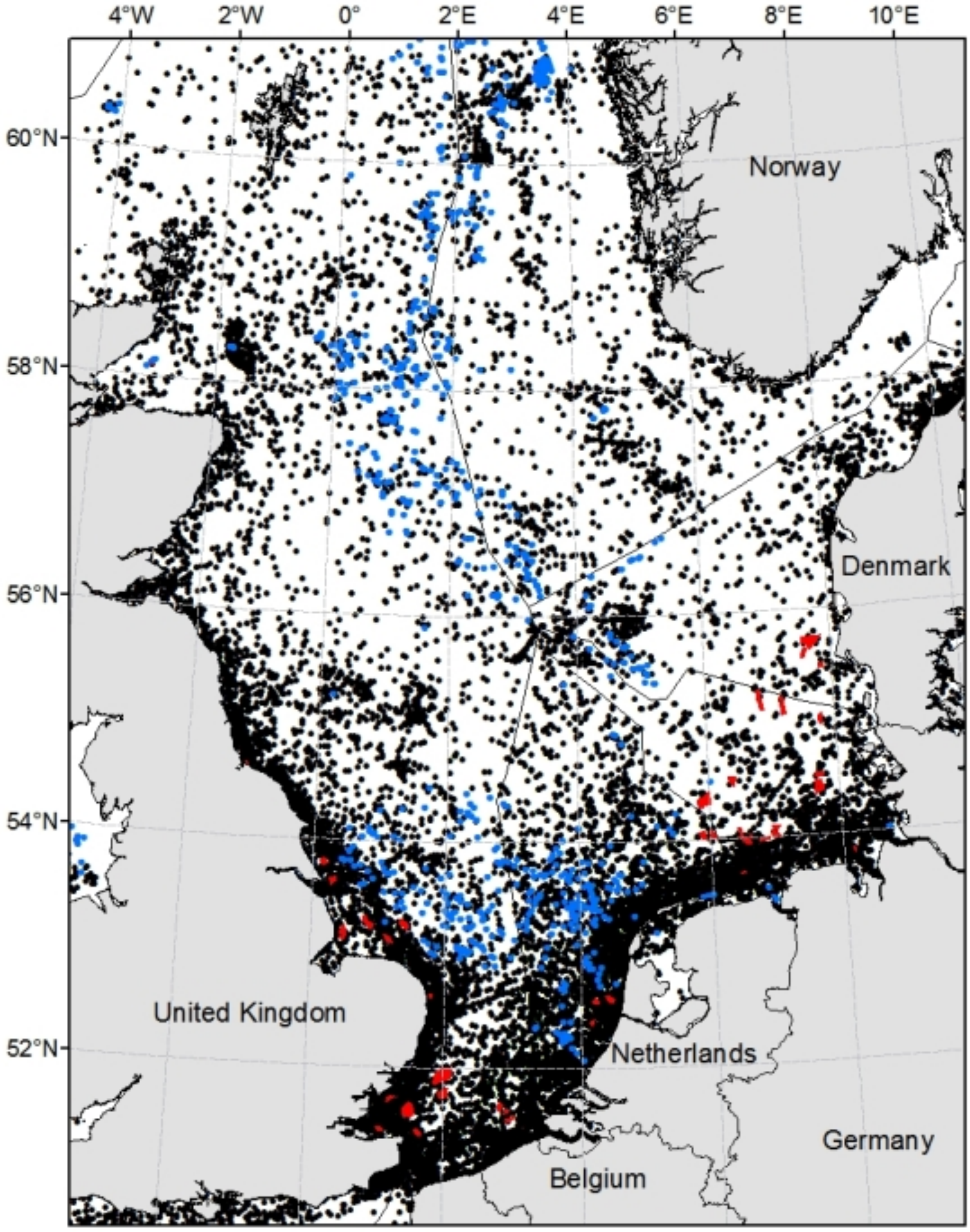

Figure 2.1. Map from Coolen J.W.P. (2017) North Sea Reefs: Benthic biodiversity of artificial and rocky reefs in the southern North Sea. PhD-thesis Wageningen University & Research, 203p
Black dots = ship wrecks; **Blue** dots = oil & gas installations; **Red** dots = wind parks

With the growth in offshore wind farms, projected in the Energetic Odyssey scenario presented at the IABR in 2016 (see fig. 2.2 and video presentation on https://vimeo.com/199825983), however, this percentage may increase to some 7.5% of the North Sea (±57,000km^2) [4].

[4] *https://www.natuurenmilieu.nl/wp-content/uploads/2016/04/20160713-IABR-Symposium-Outcomes.pdf*

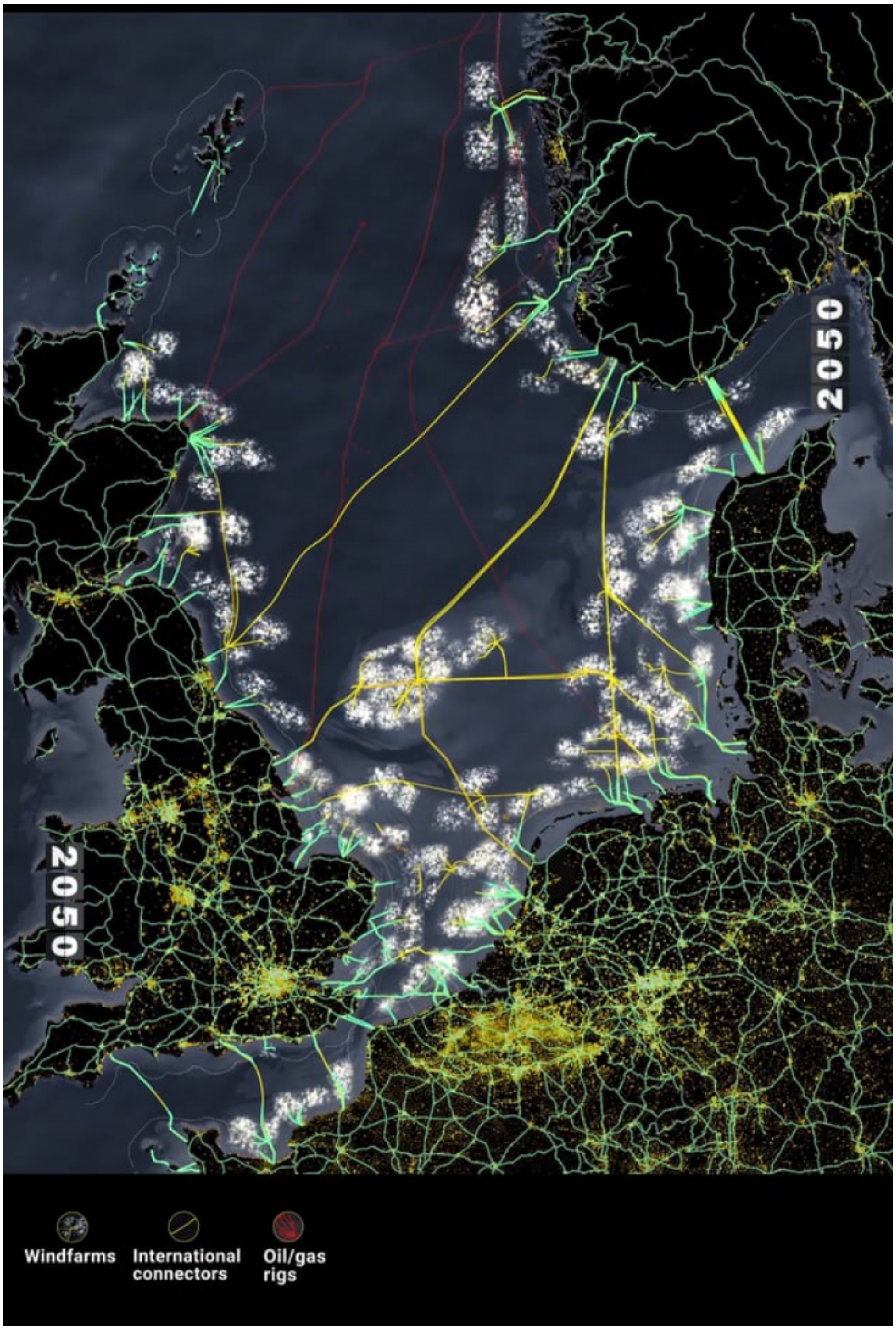

Figure 2.2. Map of offshore installations in 2050 Energetic Odyssey scenari*o*

2.1. Different types of installations in the North Sea

2.1.1. Oil and gas installations

The development of offshore oil and gas fields in the North Sea took off in the late 1960's and early '70s, with the discovery of the Ekofisk, Montrose, Forties and Brent fields. Only after the oil crisis in 1973, it became commercially interesting to develop offshore oil and gas fields in the North Sea and the number of producing fields rapidly increased. North Sea oil production peaked in 1999 with six million barrels a day, representing 9% of global oil production at that time. It is estimated that some 54% of oil reserves and 45% of gas reserves are located on the Norwegian Continental shelf (CS) and some 30% of oil reserves on the UKCS. More than half of them (possibly more than 60-75%) have already been exploited[5]. According to prognoses most North Sea reserves will have been exploited around 2050 and oil and gas installations will have lost their current function.

Today, there are some 1,300 operational oil and gas installations in the Greater North Sea region and some 5,000 wells. See table 2.1. for an overview of types of installations per country.

Country/Operational installations	Fixed Steel	Concrete GBS & Floating concrete	Floating steel	Subsea steel	Other	All
DK	56	1	1	5	1	64
NL	123	1	0	15	0	139
N	62	12	19	350	9	452
D	1				1	2
UK	277	8	30	359		674
All North Sea countries	**519**	**22**	**50**	**729**	**11**	**1331**

Table 2.1. Types of oil and gas installations in the North Sea. OSPAR Inventory of Offshore Installations https://www.arcgis.com/home/webmap/viewer.html?useExisting=1&layers=09d1eda5da6d4dbe93b4b8b3be578dd2&layerId=0

The overwhelming majority of oil and gas installations in the North Sea are steel structures; only 22 of them are so-called concrete gravity-based structures (concrete GBS), almost all of which are located in the deep, northern part of the region.
Fixed steel and concrete GBS installations consist of a **topside**, where all the activity takes place and people can walk around, a **jacket**, carrying the topside, and **footings or piles** that are driven deep into the seabed keeping everything in place. The jacket is connected to the footings/piles (see figure below). Floating structures do not have a jacket and footings/piles, but are held in place by anchor lines. Subsea structures are installations without topside; they are fully submerged by water.
Fixed steel installations are open structures, consisting of a jacket and footings (see figure below) made of high-quality steel. The footings have been driven many metres into the seabed and are protected against scouring by mattresses, of various material, and rocks (scouring protection). Concrete GBS are closed structures placed on top of the seabed and kept there by their own weight. The bottom parts of concrete GBS are often used for oil storage (see figure below).

[5] https://en.wikipedia.org/wiki/North_Sea_oil#Reserves_and_production

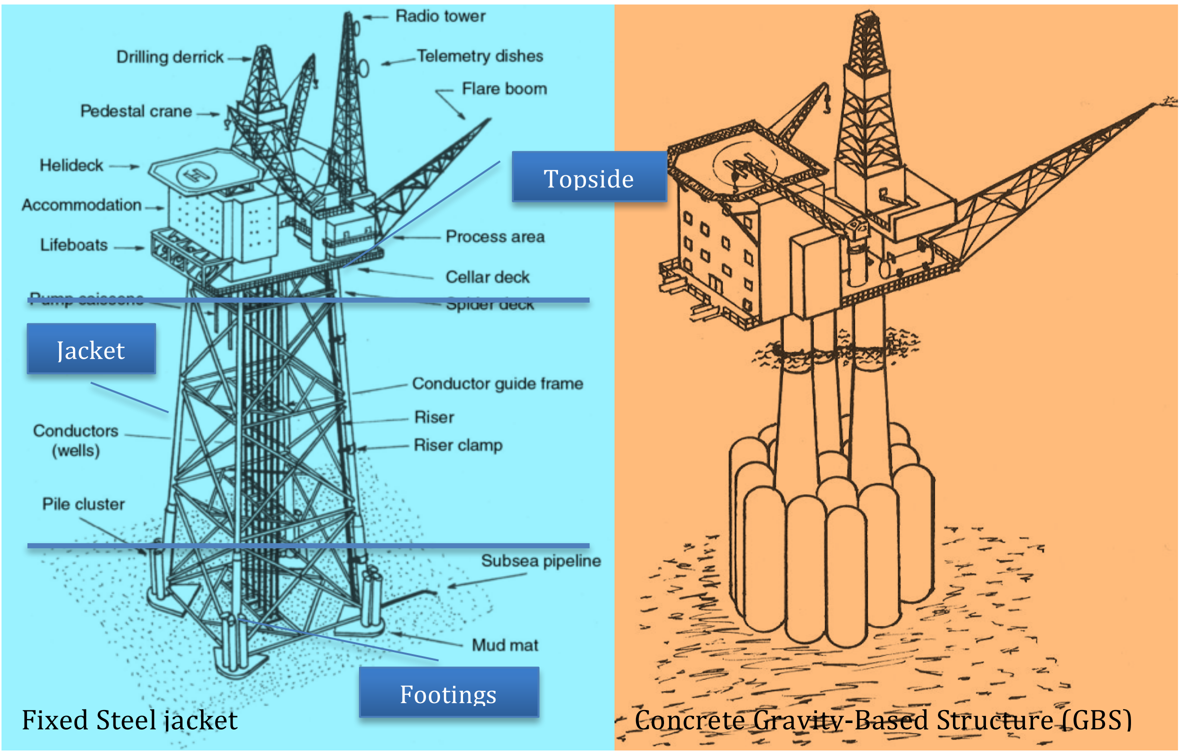

Figure 2.3. Illustration of fixed steel jacket and concrete gravity based structure (GBS).

Oil and gas installations are located at water depths ranging from 2m (Mittelplatte in Germany) to more than 800m (Ormen Lange in Norway). Ca. 190 installations are located in <30m water depth, ca. 510 between 30 and 100m and some 640 are located in waters deeper than 100m[6].

Beneath and around the installations, the seabed is often partly covered by drill cutting piles. These are piles of rock mixed with chemically polluting oil and drilling fluids/muds that have surfaced during the process of drilling the well. In the Northern, deep waters, drill cuttings have often stayed in place – sometimes in piles of several metres high - and slowly become covered by sediment, while in the Southern, shallower parts of the North Sea, they have often been spread over a large surface by currents and waves.

Each oil or gas installation is surrounded by a 500m safety zone, in which no activities (e.g. shipping, fishing or diving) are allowed for that are not related to the installation.

2.1.2. Offshore wind turbines

The first offshore wind farm in the world was built at Vindeby in Denmark in 1991, followed in 2000 by the first offshore wind farm in the North Sea, Blyth Offshore in the UK and in 2002 by Horns Rev I in Denmark. Since then, the number and size of turbines has been growing rapidly. Until now, wind turbines were built relatively near the coast, but in recent years, interest in moving further offshore has grown as a result of resistance from coastal communities concerned about the touristic value of their beaches, environmentalists concerned about

[6] OSPAR Inventory of Offshore Installations https://www.arcgis.com/home/webmap/viewer.html?useExisting=1&layers=09d1eda5da6d4dbe93b4b8b3be578dd2&layerId=0

potential impacts on birds, bats and sensitive coastal ecosystems, and innovations making it commercially feasible to build and maintain wind turbines further offshore.
By 2016 there were some 2400 wind turbines in the North Sea, but each year hundreds of new ones are being built.

Offshore wind turbines consist of each turbine consists of the turbine itself (which includes the blades and hub), supported by a tower connected to a transition piece, foundation pile or jacket and scour protection (see figure 2.4). Depending on site condition, including maximum wind speed, water depths, wave heights, currents and surf, wind turbines are installed on different types of foundations, including monopiles (steel), gravity-based structures (concrete), tripod, jacket and tri-piles (see figure for a general overview, excl. tripods, tripiles and gravity-based foundations[7]. Except for the gravity-based structures, which are placed on the seabed like the gravity-based oil and gas installations, all these types of foundations are driven into the seabed and protected against scouring by mats and rocks. For deep waters, also floating structures are being used, which are attached to the seabed with anchor lines (see figure). These are still in their experimental phase with the demonstration project Hywind Scotland producing its first electricity in October 2017.

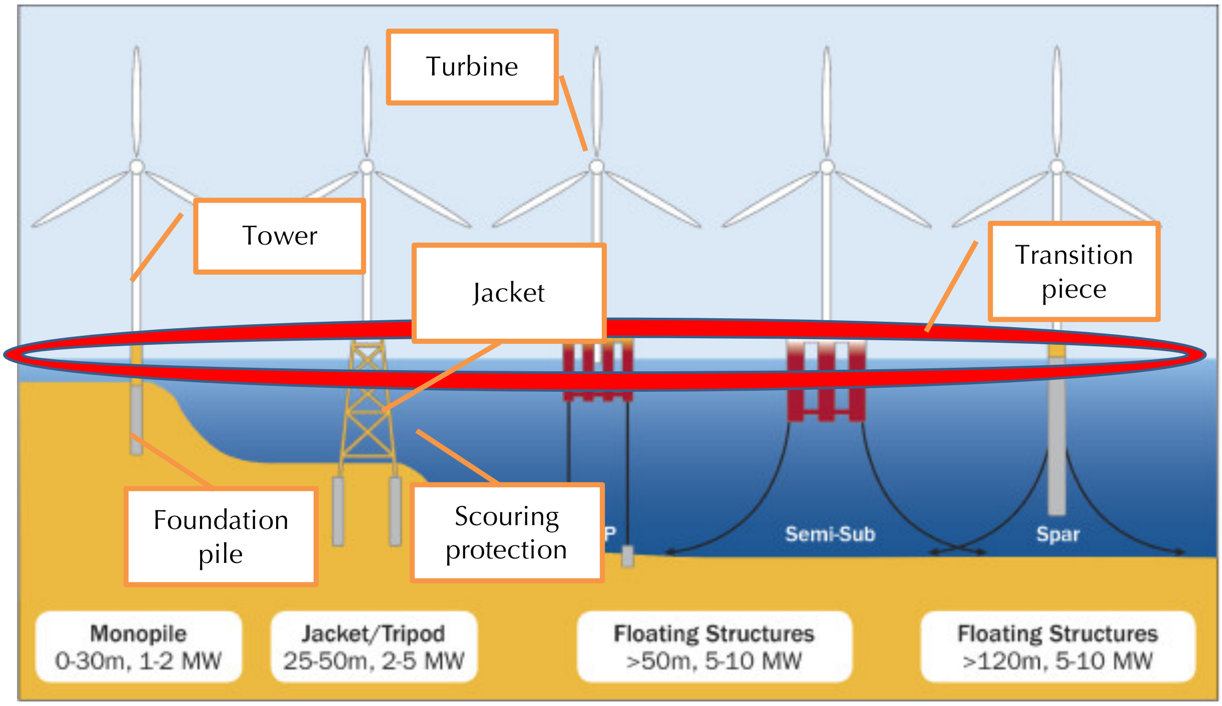

Figure 2.4. Different types of offshore wind turbines. From Bailey, Helen & Brookes, Kate & Thompson, Paul. (2014). Assessing Environmental Impacts of Offshore Wind Farms: Lessons Learned and Recommendations for the Future. Aquatic biosystems. 10. 8. 10.1186/2046-9063-10-8.

Since 2015, approximately 80% of foundations used in the EU have been monopiles, 9.1% are gravity-based foundations, jackets account for 5.4%, tripod for 3.6% and tri-piles account for only 1.7% (EWEA, 2015).
Next to the individual wind turbines, offshore wind depends on so called transformer platforms, which transform the electricity generated by the turbines into electricity suitable for the grid. These are structures comparable to offshore oil and gas installations, with a topside based on a jacket substructure.

[7] Kaiser, Snyder (2012). Offshore Wind Energy Cost Modeling Installation and Decommissioning. London: Springer-Verlag

Operators of offshore wind farms are usually given a permit for 20 years. After this period of time, the operators will have to decide what to do next: continue with the current installations if they are still in a good state and deliver electricity at competitive costs, repower the wind farm (i.e. remove parts or all of the old installations and replace them with new ones) or fully decommission the location. In the first two cases, the operator needs to get a new permit for continuing his activities.

2.1.3. Cables and pipelines

Oil and gas installations and wind turbines are connected to each other and to the shore by more than 45,000km of pipelines and cables[8]. The cable systems of oil and gas and wind have so far been developed independently from each other.

Until recently, the two types of offshore energy production were regarded as mutually exclusive: especially oil and gas operators have been keen to avoid having wind parks installed in their vicinity, as these might hinder new explorative activities and helicopter movements to and from the oil and gas installations. Recently, however, various researchers and the World Energy Council have set out to explore the possibilities for linking the two types of infrastructure, in order to facilitate e.g. electrification of offshore oil and gas production, reuse of oil and gas installations for storage of CO_2 and excess energy from wind turbines (the so-called power-to-gas-technique) and easier grid-connection for and maintenance of wind turbines far offshore[9].

2.1.4. Safety zones around offshore installations

Offshore oil and gas installations are surrounded by 500m safety-zones, in which no human activities are allowed that are not related to the installation itself. This rule accounts for installations all over the North Sea.

For ***offshore wind turbines***, regulations regarding safety-zones differ per country. In the Netherlands and Belgium, offshore wind farms also have a 500m safety zone around them, within which no vessels are allowed. In Denmark, only specific areas within a wind farm are closed for specific activities (especially trawling). In the UK, safety zones for renewable energy installations are defined for individual areas by the minister issuing a safety notice. In principle, UK wind farms are private property that cannot be trespassed without permission of the owner. ***From an environmental perspective, safety zones are relevant, because they function as mini-MPAs (marine protected areas) and make up some of the very few areas in the North Sea, where fishing is not allowed.*** In practise, operators and other stakeholders indicate that safety zones are regularly being trespassed by fishermen, but in this report, we work from the assumption that these areas are at least less intensively fished than other areas of the North Sea.

[8] http://oilandgasuk.co.uk/wp-content/uploads/2015/04/pipelines-pdf.pdf

[9] World Energy Council (May 2017). The North Sea Opportunity. http://www.wereldenergieraad.nl/wp-content/uploads/2017/06/20170619-WEC-rapport-.pdf

3. Decommissioning: what is it and how does it work?

Decommissioning is the final stage, before disposal and waste handling, of the life cycle of any offshore installation (see figure 1). Though it is called a life 'cycle', offshore installations are usually ***not*** managed in a circular way, though the steel used may in the end be recycled and potentially reused for new offshore installations. Typically, offshore installations are constructed for singular use within a certain span of time (20-30 years depending on the length of the permit provided by government).

Figure 3.1. Illustration of a typical offshore installation life cycle.

During its life time, an offshore installation and related infrastructure may be transferred several times to new owners, who want to use the installation for the same or a different purpose (e.g. CO_2 storage, offshore diving hotel, aquaculture facility or an artificial reef), or it may be 'mothballed' – made/kept ready for future use - for several years by its original owners before it is decommissioned. If an installation is transferred to a new owner and reused on the spot, the new owner takes over liabilities and the responsibility for decommissioning the installation at a later stage.

Mothballing is especially relevant for oil and gas installations, where a low oil price can make it attractive to cease production until an increase in oil price or technical developments make it profitable to start production again. Alternatively, an installation can be mothballed to await a new function or simply because the equipment necessary to dismantle it, is not yet available. Independent of the type of lifetime extension, however, at some point in time the installation must be decommissioned.

3.1. Different options for decommissioning

Decommissioning involves the removal and disposal of the equipment used for energy production and, for oil and gas installations, the safe plugging of the hole in the earth's surface.

Offshore decommissioning involves the following steps:

For oil & gas installations[10]	For wind farms[11]
1. Project management, engineering, and planning;	1. Project management, engineering, and planning;
2. Permitting and regulatory compliance;	2. Permitting and regulatory compliance;
3. Platform preparation;	3. Offshore preparations
4. Well plugging and abandonment;	
5. Conductor removal;	
6. Mobilization and demobilization of derrick barges;	4. Mobilization and demobilization of derrick barges
7. Platform removal	5. Structure removal:
a. Topside	a. Turbine
b. Jacket	b. Tower & transition piece
c. Footings	c. Foundation
	d. (Scouring protection – if removed)
	e. (Offshore substation – if present)
	f. (Meteorological mast – if present)
8. Pipeline and power cable decommissioning;	6. Power cable decommissioning
9. Materials disposal;	7. Materials disposal
10. Site clearance.	8. Site clearance.

Table 3.1. Steps in the offshore decommissioning process

Most steps in the decommissioning process are very much alike for oil and gas installations and wind farms. ***For oil and gas installations***, **wells** have to be 'plugged and abandoned'. This involves plugging the wellbore with concrete (or in the future possibly with other, more modern and non-shrinking materials) to avoid future leaking of oil or gas. For each installation, there are often several wells to be plugged and this process usually takes place before

10 Based on http://petrowiki.org/Offshore_decommissioning
11 Based on Topham, E. & D. McMillan. 2017. "Sustainable decommissioning of an offshore wind farm" in Renewable Energy 102 (2017) 470e480.

decommissioning of the installation itself starts. **Pipelines** either have to be removed or cleaned and made safe for future users. **Drill cutting piles**, which are sometimes present under and around oil and gas installations, are sometimes removed and sometimes left in place, depending on what is deemed technically and economically feasible and what is considered to be the safest option for the environment.

For offshore wind farms, there is relatively little practical experience with decommissioning (until now, only two offshore wind farms have been decommissioned; Yttre Stengrund in Sweden and Vindeby in Denmark), but Topham, E. & D. McMillan (2017) describe the *intended* practise of several UK wind farms, based on the decommissioning programmes they have had to deliver as part of the original permission process. In line with regulations and practise for oil and gas installations, they describe that the structures themselves (turbine, tower & transition piece, foundation, substations and meteorological masts) will be removed, sometimes leaving the foundation and scouring protection in place in order to avoid damaging the marine communities, which have developed there, whereas **cables** are sometimes removed and sometimes buried and left offshore.

In principle, decommissioning does not necessarily mean that an installation is being fully removed to shore and disposed of there. In theory, there is a variety of options for how to decommission an offshore installation, depending primarily on the type and size of the installation and its location. All these options essentially form combinations and variations of three primary decommissioning options and three disposal options described in table 1.

Option	Description	Disposal/end-point
Leave in place	*For oil and gas installations:* The entire installation, with or without the topside, is left in place, standing with decks sticking out, toppled over or with the top part placed on the seabed next to the lower part. *For wind turbines:* The entire installation is left in place, with the tower either sticking out of the water (the turbines will be removed whatsoever) or toppled in place.	In situ (see fig 2 & 3)
Partial removal	This option involves removal of the topside (for oil & gas installations) or turbine and tower (for wind installations) and cutting of the substructure (jacket, tower or foundations) at a certain height: either to the footing/foundation or to a height that leaves at least a 25m or 55m clear water column above the structure. 25m is common in Rigs2Reef programmes; 55m is in line with the IMO guidelines for unobstructed passing of ships.	Substructure (fully or partially): In situ Topside/tower: onshore disposal with possible reuse offshore (artificial reef) (see fig. 2)
Full removal	This option involves removal of the topside or turbine and tower, of the jacket and conductors, and of the footing or foundation and scouring protection from the seabed. Parts of an installation that are under the seabed, pipelines and concrete anchor foundations that do not present an obstacle to fisheries do not always have to be removed, but in principle, as much as possible is removed and taken to shore. Sometimes a 'trawl sweep' follows full removal in order to check if the seabed is safe for bottom-trawlers.	Onshore disposal (all structures) with possible reuse offshore (artificial reef, see fig. 1)

Table 1. Overview of major decommissioning options

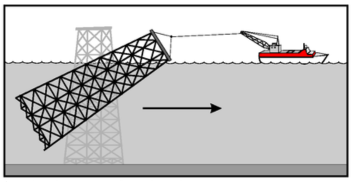

Fig. 1 Towing a jacket to a reef location elsewhere

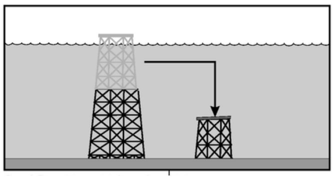

Fig 2. Top & placing top on seabed next to jacket

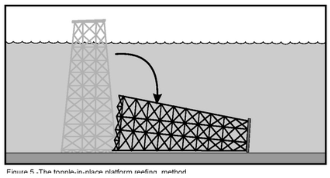

Fig 3. Toppling a jacket, leaving it in place

In the figure 3.2. we provide a schematic overview of all decommissioning options and how they combine with disposal options.

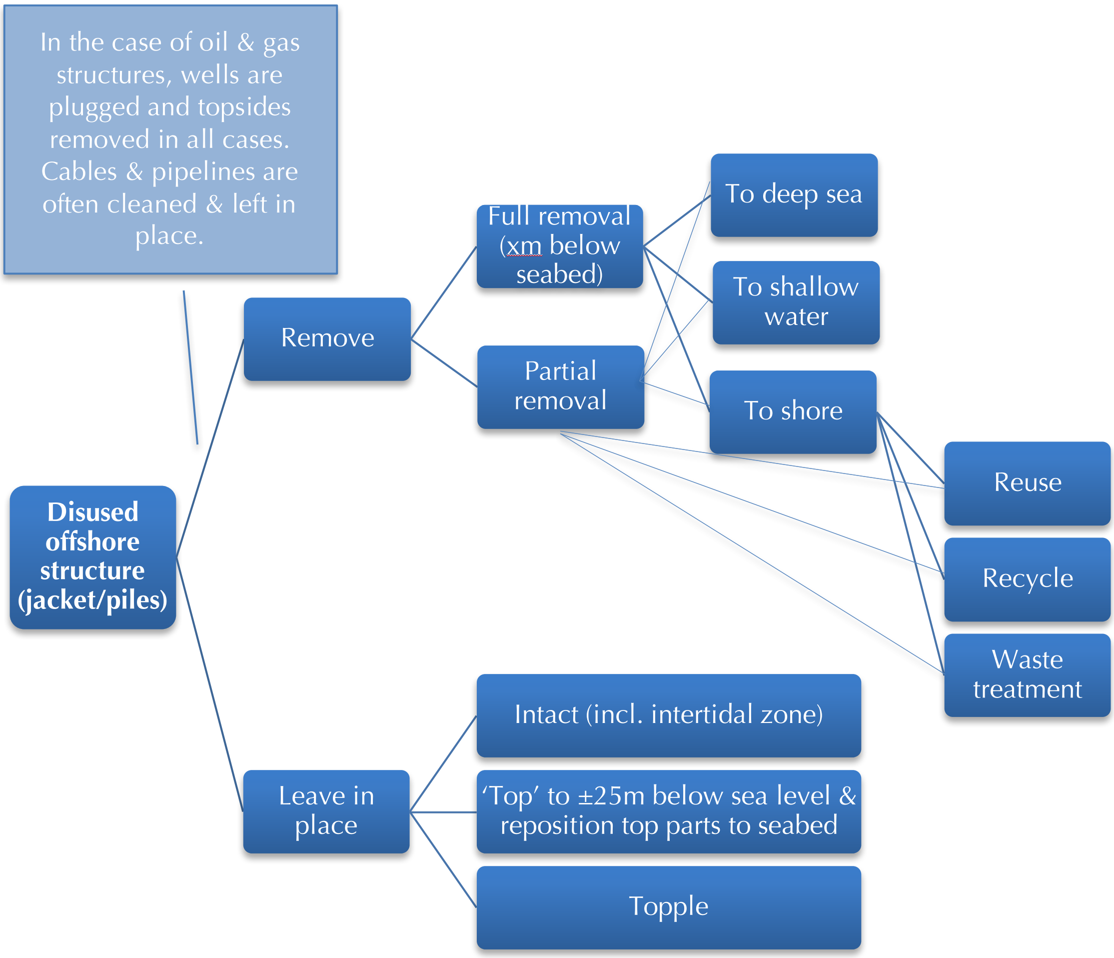

Figure 3.2. Schematic overview of different decommissioning options and how they combine with disposal options.

The activities that need to be performed to decommission an offshore installation depend on the type and size of the installation, the chosen decommissioning option and on the facilities and approach of the chosen contractors. Generally speaking, decommissioning activities include a lot of cutting and separating of various parts of the installation so that they can be loaded unto barges or special vessels – in the North Sea area there are only a few vessels that can lift up a small to medium-sized topside or jacket of an oil or gas installation in one piece. At a minimum, the topside needs to be separated from the jacket and the jacket from the footings (see figure 3). For offshore wind farms, the turbine needs to be removed separately and then the transition piece is separated from the foundation. The foundation itself is cut just above or below the mudline, leaving a several meters of the monopile in the seabed. Usually, the most time consuming, dangerous and environmentally damaging part of the work is the cutting and removal of sub-sea parts, especially the so-called footings of oil and gas installations. According to expectations, the removal of the rammed part of monopile wind turbines could also be very complex.

Once removed, all materials need to be transported to shore (or somewhere else), cleaned and cut into smaller pieces. Before that happens, marine growth usually is removed, as it often adds tonnes of weight to sub-sea parts of the structure and creates local odour problems if it is taken to shore. In cases where drill cutting piles are located around the footings of an oil or gas installation, these may have to be (temporarily) moved in order to be able to actually remove the footings.

At the end of the decommissioning process the surrounding seabed area is checked for any additional debris and sometimes a trawl sweep takes place to make sure that the area is safe for fishermen, who will afterwards be allowed back into the area.

The duration of the decommissioning process widely differs: whereas the decommissioning of the Brent field (with some of the largest offshore installations in the North Sea) are expected to take 8 years, whereas the Vindeby wind farm was removed in less than a month.

4. Regulatory Framework

Though a variety of decommissioning options are theoretically possible, the current regulatory framework in the North Sea area puts very clear limitations to which options are actually being implemented.

4.1. OSPAR Decision 98/3

In the North Sea and more widely in the OSPAR region, offshore installations may be placed on the seabed only with a specific, well-defined purpose such as energy production, aquaculture, recreation or nature creation (e.g. an artificial reef). When an installation is no longer needed for that particular purpose, OSPAR Decision 98/3, which has been implemented into national law, dictates that it may be rebuilt or repurposed into fulfilling another legitimate purpose and transferred to another owner. If that is not feasible, however, the "preferred option" is that disused installations are taken to shore for "reuse, recycling and final disposal on land"[12]. OSPAR refers to the precautionary principle and the polluter pays principle as being fundamental for any decommissioning policy or decision[13].

In practise, this policy implies that all disused offshore installations in the North Sea and wider OSPAR region have to be removed to shore. There are a few exemptions ('derogations') to this general rule, which are based on technical rather than environmental considerations:

- The footings of steel installations placed in the maritime area before February 9 1999 and weighing more than 10,000 tonnes in the air.
- Gravity-based and floating concrete installations and concrete anchor-bases that do not interfere with other legitimate uses of the sea. In principle, this exception might apply to some scouring protection and concrete foundations of offshore wind turbines, but this is unclear.
- Other disused installations for which exceptional and unforeseen circumstances resulting from structural damage or deterioration, or from some other cause presenting equivalent difficulties, can be demonstrated.
- Pipelines and cables are ***not covered by OSPAR Decision 98/3***, but are regulated at the national level. Most often, the smaller ones have to be removed, whereas the larger ones can be left in place on the condition that they are cleaned and burrowed or otherwise protected from moving around or being caught in trawling nets. Management of drill cutting piles is addressed under different measures within OSPAR (Decision 2000/3 and

[12] This general rule is often referred to as the 'clean seabed principle', which refers to the principle that the sea(bed) should be accessible for all potential users – especially fisheries – and that therefore a piece of seabed is only temporarily being 'given' to a specific user, who then has the obligation to return the seabed to its original state, when he is done using it.

[13] In Article 2 of the OSPAR Convention these principles are defined as follows:

(a) the precautionary principle, by virtue of which preventive measures are to be taken when there are reasonable grounds for concern that substances or energy introduced, directly or indirectly, into the marine environment may bring about hazards to human health, harm living resources and marine ecosystems, damage amenities or interfere with other legitimate uses of the sea, even when there is no conclusive evidence of a causal relationship between the inputs and the effects; (b) the polluter pays principle, by virtue of which the costs of pollution prevention, control and reduction measures are to be borne by the polluter.

Recommendation 2006/5), which leave open various options, incl. onshore treatment as well as in situ disposal options.

Every five years (next in 2018), the room for derogations is being reviewed by OSPAR's Offshore Industry Committee (OIC), on the basis of experiences with decommissioning up till then. The intention behind these reviews is that this room should be reduced as technical innovations make it feasible to safely remove ever-larger installations. Any request for derogations from the general rule has to be presented to the national government ('competent authority'), which is obliged to consult with the other OSPAR contracting parties before taking a final decision.

In Annex 2 to Decision 98/3, OSPAR has outlined a clear framework for the assessment of proposals for the disposal at sea of disused offshore installations, which includes technical, safety, environmental, economic, 'future use' and long-term management aspects.

In practise, OSPAR Decision 98/3's clear ban on disposal at sea sends a strong signal to owners of offshore installations and to competent authorities, making them automatically consider full removal to shore as the default option. Only in cases where installations clearly meet the derogation criteria, alternative options are being actively being explored. Therefore, limited information is available about how different decommissioning options actually compare in terms of environmental (and other) impacts for installations in the North Sea region. On a more general basis and for installations outside the OSPAR region, some comparative assessments have been made. Overall, these studies seem to agree that the outcome in terms of ecosystem impact is likely to be more certain (and neutral to positive) in cases where installations are partially left in place than in cases where they are fully removed and the seabed returned into its 'original state'. There is a large degree of uncertainty as to whether a cleaned seabed will actually restore to its original ecosystem value over time, whereas there is a large degree of certainty that ecosystems that have developed on and around an installation over 20-30 years will remain more or less unchanged for many years, if they are left undisturbed. Exactly which decommissioning option is the best environmental option differs per location and type of installation[14].

4.2. Liability

OSPAR Decision 98/3 dictates the different options that are available to national governments to allow for certain decommissioning options, but they do not deal with issues pertaining to liability for any material left offshore, nor do they deal with the question of who is to pay for the costs of decommissioning if an owner of an installation are unable to do so. Liability and who pays what is regulated at the national level.

In practice, the so-called 'residual liability' (liability for plugged and abandoned wells and for any material left offshore) has turned out to be a highly relevant factor when companies decide which decommissioning strategy to pursue. North Sea countries have taken different approaches in regulating liability for disused offshore installations.

[14] *See e.g. Fowler, A.M., et al (2014) "A Multi-criteria decision approach to decommissioning of offshore oil and gas infrastructure". Ocean & Coastal Management: 87:20-29. Smyth, K., et al (2015) "Renewables-to-reefs? Decommissioning options for the offshore wind power industry". Marine Pollution Bulletin: 90: 247-258. Cantle, P., et al. "Evaluating Alternatives for Decommissioning California's Offshore Oil and Gas Platforms: A Technical Analysis to Inform State Policy."*

In the UK and Denmark, the final owner(s) of an installation before its abandonment remains liable in perpetuity. In cases of default, previous owners are alternatively liable. Only if all previous owners are unable to fulfil their responsibilities, liabilities may fall back on the state.

In the Netherlands, liability follows ownership of the installation, with no residual liability for previous owners. Since the Dutch State is always one of the owners, however, this means the costs will eventually have to be covered by the State if other owners fail to pay their part of the bill. In Norway, operators can transfer liability over abandoned assets to the State, if they provide sufficient compensation.

With the possible exception of Norway, current liability regimes provide a strong disincentive for considering decommissioning options where structures are (partially) left offshore.

5. Environmental Effects of Decommissioning and their relative importance

5.1. Environmental effects of offshore installations in different phases

The environmental effects of decommissioning in many aspects forms an 'undoing' of effects that have been caused in previous phase of an offshore installations life cycle. Hence it is important ***to first understand the environmental effects of the installation itself, before it is decommissioned*, *but excluding the disturbance caused by the installation of the structure and by the activities associated with the productive phase of the installation's life.***

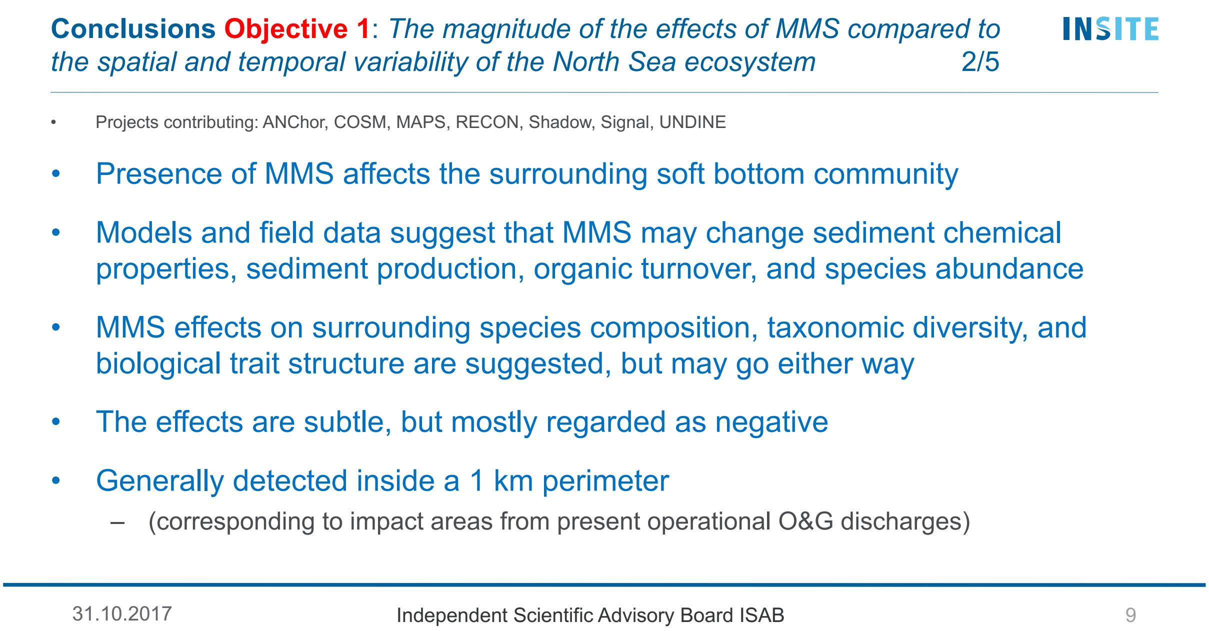

Figure 5.1. Conclusions of the ISAB of the INSITE Programme on phase 1 with regard to the effects of presence of man-made structures (MMS) in the North Sea.

Bailey, Helen et al. (2014) describe the **major environmental effects of *offshore wind developments*** as *"increased noise levels, risk of collisions, changes to benthic and pelagic habitats, alterations to food webs, and pollution from increased vessel traffic or release of contaminants from seabed sediments. As well as potential adverse impacts, there are possible environmental benefits. For example, wind turbine foundations may act as artificial reefs, providing a surface to which animals attach. Consequently, there can be increases in the number of shellfish, and the animals that feed on them, including fish and marine mammals. A second possible benefit is the sheltering effect. A safety buffer zone surrounding the wind turbines may become a de-facto marine reserve, as the exclusion of boats within this zone would reduce disturbance from shipping. Exclusion of some or all types of fishing could also result in local increases in prey abundance for top predators, whilst reducing the risk of bycatch in fishing gear. Further research is required to understand the ability of wind turbines to attract marine species and the effect of excluding fisheries."*[15] To this list of effects, we should add seabed disturbance and the risk of birds and bats being hit by the turbine blades.

[15] Bailey, H., Brookes, K. & Thompson, P. (2014). Assessing Environmental Impacts of Offshore Wind Farms: Lessons Learned and Recommendations for the Future. *Aquatic biosystems. 10. 8. 10.1186/2046-*

The **environmental effects of *oil and gas installations*** overlap with those of offshore wind developments, when it comes to seabed disturbance, increased noise levels, risk of collisions, changes to benthic and pelagic habitats, alterations to food webs, and pollution from increased vessel traffic or release of contaminants from seabed sediments. Also, the potential positive effects of functioning as artificial reefs and de-facto marine protected areas equal those of offshore wind farms. However, in addition, oil and gas installations cause large emissions to air (in particular greenhouse gases, VOCs and NOx), energy use, (by both the drilling and production process itself and by transportation to and from shore), discharges of hazardous chemicals to sea (through drilling and emissions of produced water) and noise from seismic surveys.[16]

In table 5.1. we characterize some major potential environmental effects relating to the different phases of an offshore installation's life cycle. In phases where there is a significant difference between oil and gas (O&G) and offshore wind installations, this is mentioned. In this table, we do not differ between the effects of different decommissioning and disposal options. These differences will be discussed in the following paragraph.

Key points we can conclude from the table above are the following:

- ***The location and design of offshore installations are fundamental to determining their impact on the surrounding ecosystem.*** If the original placement of installations leads to long-term disturbance or loss of existing ecosystems, it is highly uncertain whether these ecosystems will be able to recover once the installations are removed. Any effects on hydrodynamic regimes (flows of currents), however, may be expected to be undone when the installation is removed.
- ***Many 'disturbance' effects, such as underwater noise, light, vibrations and risks to birds and bats, which play a major role in environmental impact assessments for construction, placement and management of new installations, disappear as soon as an installation is taking out of operation.*** Hence, these effects are not relevant in assessing decommissioning options. ***Chemical contamination,*** which is primarily relevant for oil and gas installations, in some cases disappears (emissions of polluted water from oil and gas production) and in some cases remains (contaminated drill cutting piles left on the seabed, norm scale in pipelines and storage cells/tanks forming part of an installation).
- ***Land use of an installation may remain intact offshore or change from offshore to onshore depending on the decommissioning option chosen.***
- ***Energy and resources used in the design and construction phase may be partially 'undone' in the onshore waste handling phase***, if recovered material (resources) are efficiently reused or recycled. However, some energy and resources will always be lost, as it takes additional energy to dismantle and transport the materials to shore and to the recycling location and because a 100% recycling rate is never achieved.

9063-10-8. Available from: https://www.researchgate.net/publication/266086383_Assessing_Environmental_Impacts_of_Offshore_Wind_Farms_Lessons_Learned_and_Recommendations_for_the_Future

[16] *See e.g. http://www.environment.no/topics/marine-and-coastal-waters/oil-and-gas-activities/environmental-impacts-of-oil-and-gas-activities/*

Type of Effect	Construction deployment	Operations & production phase	Decommissioning (offshore)	Disposal & waste handling (onshore)
Energy use	+ (for structure, production & vessels)	+ (O&G for production & vessels) + (wind for vessels only)	+	+/- (avoided energy use from recycling of materials may cause net negative use)
Emissions to air	+ (from structure production & vessels)	+ (O&G; from vessels & production) + (wind; from vessels only)	+ (from decom vessels & activities)	+/- (avoided energy use from recycling may cause negative use)
Resource use	+	0	0	- (Resource recovery)
Underwater noise	+	+	+	0
Light		+	-	n.a.
Risk to birds & bats	0	+ (wind) 0 O&G	-	n.a.
Vibrations		+	-	
Chemical emissions to seabed/soil & water		+ (O&G) 0 (wind)	0/+/- (O&G; existing contaminants may remain (0), spread to wider areas (+) or be removed (-)) 0 (wind)	0/+ (chemical contamination may remain offshore (0) or be moved to onshore locations (+))
Alteration of hydrodynamic regimes	+	0	0/-- (alteration remains or is removed)	n.a.
Seabed disturbance	+	0 (or – if compared to areas outside no-fishing	0/+ (depending on decom option)	n.a.
Disturbance/loss of original ecological community	0/+ (depends on location & type of community)	0	0 (/-)* (no new disturbance; recovery of original community after removal is highly uncertain)	n.a.
Protection from trawling		+	- (after decommissioning, the safety zone is cancelled)	n.a.
Provision of reef habitat		+	+/0/- * (If material is left without regular cleaning the encrus-ting community can develop further. If material is remo-ved, habitat is removed.)	
Enhancement of biodiversity (local)		+	+/0/- * (same as above)	
Production of additional biomass		+	+/0/- * (same as above)	
Smothering of soft-bottom communities		+	0/- *	
Alteration of trophic webs		0/+	0/- *	
Spread of invasive species		0/+ (depends on connectivity with disease-containing communities – via maintenance vessels & currents)	0/-* (via currents only)	
Facilitation of disease		0/+ (same as above)	0/- * (same as above)	
Habitat damage from scattering debris		+	+/0 * (if all material is removed without incidents, no damage)	
Impacts resulting from safety risks		+	+/- *	
Land use	+ (offshore)	0	0/- *	+ (onshore)

Table 5.1. Overview of potential environmental effects relating to different phases of an offshore installations life-cycle. ***Explanatory notes:*** + = significant effect (may be positive or negative); 0 = the already created effect remains unchanged; - = the created effect is reduced or undone.
* Depends on decommissioning option. See table y for a comparison.

- ***Most of the effect that an offshore installation has on surrounding ecosystems, develops and will be visible already during the operations & production phase***, e.g. the provision of reef habitat, protection from trawling, enhancement of biodiversity, smothering of soft-bottom communities and the provision of foothold for invasive species. ***The extent to which these effects can be expected to change as a result of decommissioning, depends on the decommissioning option chosen***: if a structure is removed, all these effects will more or less disappear (including protection from trawling), though it is highly uncertain whether the original seabed community will redevelop. If material from an installation is left in place, most of the effects are likely to remain or even be reinforced, as the encrusting community on the material is no longer being disturbed by regular cleaning.

5.2. Environmental effects of different decommissioning options

Assessing the relative environmental effects of the different decommissioning options described in § 2 is a complex task. Though it does occur that one specific decommissioning option scores better than other options on all effects (lower negative impact and more positive effects), the ***most common situation is that some options score better on some effects and others on other effects. That means that making a choice between options often also implies a relative weighting of different environmental effects.*** For example, what do we consider more important: reduced emissions to air and a very small loss of resources or the provision of reef habitat for e.g. cold water corals and continued production of additional biomass?
Weighting of environmental effects is inherently value-based and therefore, we have tried to gain some input on how to rank various environmental effects in decommissioning decisions, through an expert survey (see Annex 1 for a description of methodology of the survey).
The experts participating in our survey provided us with the following rankings for oil and gas installations and offshore wind farms respectively.

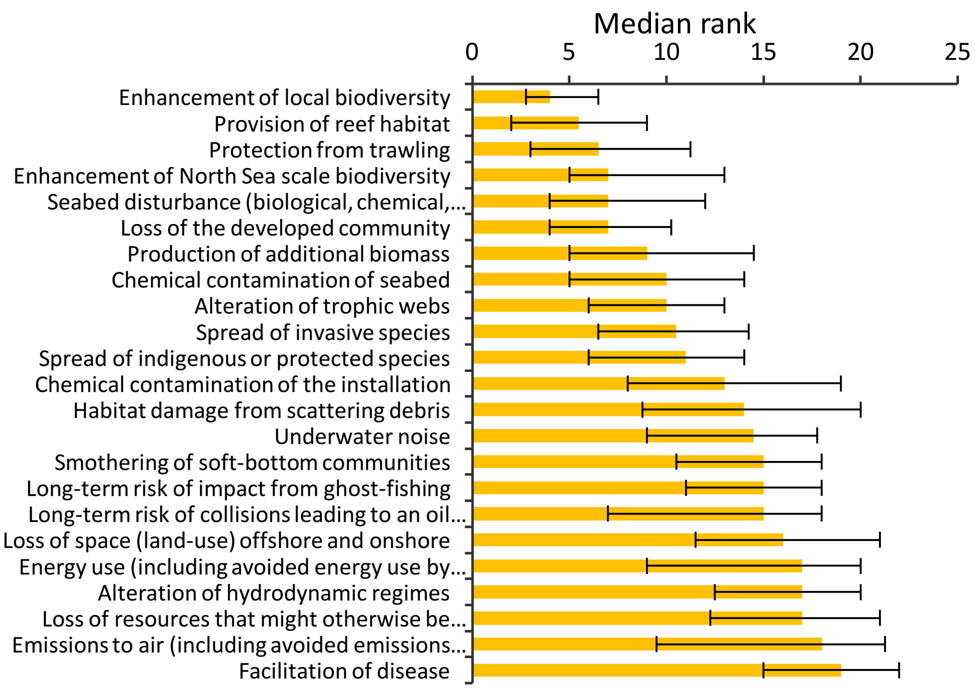

Figure 5.2. Experts' ranking of Environmental Criteria for Decommissioning of Oil & Gas Installations. The lower the score, the more important the criterion.

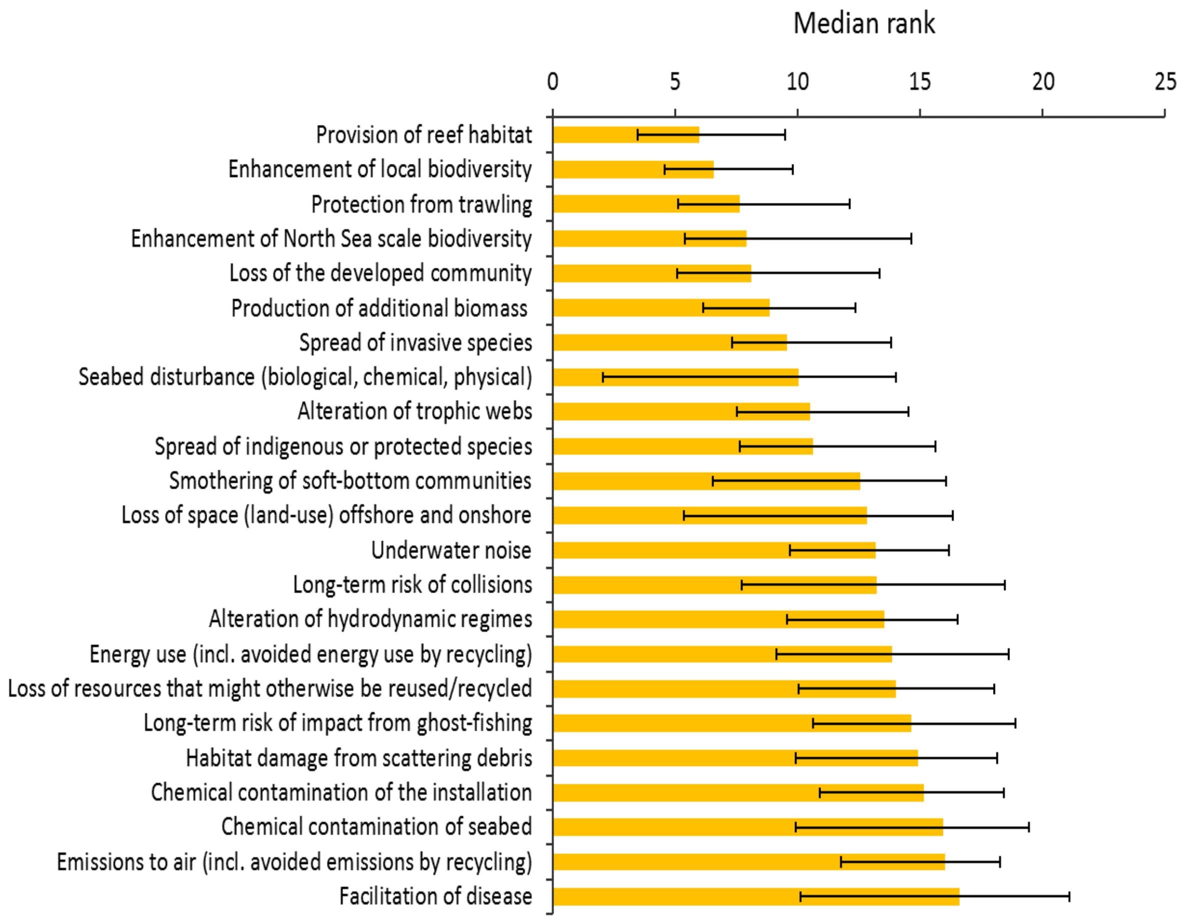

Figure 5.3. Experts' ranking of Environmental Criteria for Decommissioning of offshore wind installations. The lower the score, the more important the criterion.

The top-10 ranking is very similar for both types of installations and focuses primarily on ecosystem-related criteria rather than criteria related to energy use and loss of resources. The only major difference between oil and gas installations and offshore wind is in the ranking of chemical contamination of the seabed and installation, which are not surprisingly ranked much higher for oil and gas installations. The focus on ecosystem services in the top-10 is remarkable, since current Environmental Impact Assessments (EIAs) of offshore oil and gas decommissioning programmes, emphasize very different criteria: energy use and atmospheric emissions, underwater sound/noise, seabed/physical disturbance, hydrocarbon and chemical emissions, waste and onshore impacts, and socio-economic impacts[17]. Sometimes, potential (negative) impacts on nearby Natura 2000 areas are also considered, but only in cases where it is considered to leave parts of an installation in place, EIAs may include a discussion of some of the criteria ranked in the top-10 here, such as loss of provision of reef habitat for protected species. For decommissioning of offshore wind farms, hardly any EIAs have been published until now. The EIA made for Vindeby, however, does consider various criteria in our top-10,

[17] This list is based on the contents of various decommissioning programmes listed on https://www.gov.uk/guidance/oil-and-gas-decommissioning-of-offshore-installations-and-pipelines. Socio-economic impacts were also mentioned by several of the experts we consulted, but have been excluded here as we have chosen to focus on environmental effects only.

such as loss of reef habitat and species (biodiversity and biomass) related to this habitat.[18] In cases where 'loss of habitat' is considered, the importance of this criterion is usually discounted by referring to the 'original state' of the seabed, i.e. the state of the seabed before the installation was placed: the underlying reasoning is that if there was no hard substrate in the (near) past, it doesn't belong there and hence, it is OK to take it away.

On the basis of the criteria ranking above, an environmental assessment of different decommissioning options can be made on a case-by-case basis – not for all offshore installations in general. The scoring on various criteria for different options will depend on factors such as type and material of an installation (complexity of the subsea structure, steel versus concrete, etc.), distance to shore, water depth, age, surrounding seabed community, accessibility for pelagic species and marine mammals, etc.

With this precaution in mind, we provide an overview of what is currently known and assumed about the environmental effects (criteria) ranked above and how these relate to different decommissioning options.

5.2.1. Provision of reef habitat, loss of developed community and enhancement of biodiversity

Wind turbines and oil and gas installations provide so-called 'hard substrate habitats' – reefs – reaching from the sea floor up to the surface. 95% of the experts participating in our expert survey agreed with the statement that **valuable artificial reef habitats should be maintained and protected.** In doing so, they defined an artificial reef habitat as being environmentally valuable when it:

- **Replaces lost natural reefs** (92% agreed)
- Provides **habitat for species that are endangered** or under pressure (89% agreed) – removing them may form additional threat (76% agree)
- Forms a crucial **stepping stone for larval exchange between natural reefs** (87% agreed)
- Provides **shelter and foraging opportunities for mobile species/biomass** (84% agreed)
- **Supports commercial species** (78% agreed)

When the decommissioning option 'full removal to shore' is chosen, this habitat-function and hence the ecological communities that have developed on (and around) an installation will be lost. If (parts) of an installation are left in place, it is to be expected that the communities that have developed on and around the installation will also persist – depending largely on the extent to which fisheries will be allowed for after decommissioning (see § 5.2.2). Experience has shown that it is highly uncertain whether the community that used to thrive on the location before the installation was placed will be restored and also phase one of the INSITE programme concludes that "*as structures are removed from the sea, they will disturb any communities that have become associated with them, which may ripple through the food web to cause ecosystem level effects*" [19]. Consistent with this finding, almost 65% of the experts we

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[18] https://ens.dk/sites/ens.dk/files/Vindenergi/miljoevurdering_for_nedtagning_af_vindeby_havmoellpark_inkl_bilag.pdf

[19] Bailey, H., Brookes, K. & Thompson, P. (2014). Assessing Environmental Impacts of Offshore Wind Farms: Lessons Learned and Recommendations for the Future. *Aquatic biosystems. 10. 8. 10.1186/2046-9063-10-8.* Available from: https://www.researchgate.net/publication/266086383_Assessing_Environmental_Impacts_of_Offshore_Wind_Farms_Lessons_Learned_and_Recommendations_for_the_Future

engaged through our survey believe ***we know more about what happens if we leave offshore installations in place that have been there for >20 years than we do about what happens if we remove them.*** Only some 20% of the experts consulted, expressed serious concerns that such installations may have unexpected negative effects on the surrounding community on the long term.

The extent to which offshore installations develop into valuable artificial reef habitats depends on a number of factors that we discuss below.

Location, seabed characteristics and water depth

- In some cases, the hard substrate provided by offshore installations mirrors the underlying habitat (also containing some form of hard substrate). In other cases, it does not: then the installation is located in 'sandy' or other soft bottom habitats. In the North Sea, sandy or soft bottom habitats are absolutely dominant and especially many offshore wind farms have been and are being placed in such areas. Though offshore installations may contribute to **increased biodiversity** when located in areas with a soft bottom, there is **also concern that these new habitats may negatively affect surrounding soft-bottom communities**, through smothering and increased competition for food. As illustrated in figure 5.1, the INSITE ISAB concludes that man-made structures generally do have a small, local, negative effect on surrounding, soft-bottom communities. However, wind farm monitoring has also shown that effects vary widely and in a 7-year-long study of the Horns Rev 1 wind park C. Steenberg et al., 2015 conclude that *"Species diversity was significantly higher close to the turbines. Overall, these results indicate that the artificial reef structures were large enough to attract fish species with a preference for rocky habitats, but not large enough to have adverse negative effects on species inhabiting the original sand bottom between the turbines."*[20] Moreover, it is highly uncertain whether the original community will actually restore once an installation has been removed, as the larger ecosystem has in the meantime (20-40 years) adapted to the presence of the offshore installations[21]***. Of the experts in our survey, 71% disagreed with the notion that hard substrate should always be removed from soft sediment habitat, because it does not 'belong' there.*** This is not very surprising, considering the fact that reef habitats are some of the most threatened habitats in the world[22] and that the North Sea used to contain much larger areas of (semi-)hard substrate than it does now, but has lost many of these habitats due to various human activities. Hence, the special emphasis placed on the value of artificial hard substrate that replaces lost natural reefs.
- Coolen, J.W.P. concludes that in the Southern North Sea **species richness is the largest in the zone between 5 and 15 metres, then declines and then increases slightly again in deeper waters (>25m)**[23]. In the Northern North Sea, this situation may be different with cold corals Lophelia Pertusa having been found on oil and gas jackets at a depth of 59-

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Lynam,C., Steenbeek, J. et al. (2017). COSM: Investigating food web effects due to man-made structures using COupled Spatial Modelling. Available on http://www.insitenorthsea.org/

[20] The considerations made here do not account for the placement of a new offshore installation, but exclusively for structures that are already there. The placement of an offshore installation in an already well-functioning, bio-diverse and productive ecosystem is likely to do more damage than good to that ecosystem. In that case, the precautionary principle should always prevail.

[21] See note 14

[22] Halpern, B.S., Selkoe, K.A. et al. (2007). Evaluating and Ranking the Vulnerability of Global Marine Ecosystems to Anthropogenic Threats. In Conservation Biology Volume 21, No. 5, 1301–1315 And http://www.ices.dk/explore-us/Action%20Areas/ESD/Pages/Greater-North-Sea-State-Habitat.aspx

[23] Coolen J.W.P. (2017). North Sea Reefs: Benthic biodiversity of artificial and rocky reefs in the southern North Sea. PhD-thesis Wageningen University & Research, 203p

132m[24].

Connectivity: Distance to other reef habitats and the flow of currents carrying algae and larvae of various species to and from the installation.

- Marine growth on a new installation or reef arises from algae in the upper light zone and encrusting and colonial invertebrate assemblages further down. For these species to settle, seed and larvae need to be transported (or actively swim) to the installation from somewhere else. Naturally, species that do not actively swim are transported by currents from one hard substrate to the next (this is called interconnectivity), but also various kinds of vessels play an increasing role in transporting species, including exotic species, across the sea.
- **Any direct ecological effect of offshore installations (be it negative or positive) is likely to be multiplied by connectivity between offshore installations and between installations and natural reefs.** Modelling suggests that 60% of oil and gas installations in the southern UK Sector are directly connected via tidal flows and 23% in the northern UK Sector[25]. ***The findings of INSITE phase 1 suggest that there are two well-connected networks of larval exchange for selected hard bottom species across the greater North Sea:***
    - One in the south region
    - One in the north, central region
    - The northern is subdivided into clusters of MMS.
    - Certain installations may act as bridges between separated networks.

  Within these networks, some installations act as "Suppliers/sources", others as "Conductors", and yet others as "Receivers" of organisms.[26] ***Connectivity implies that the impact of decommissioning – especially of full removal to shore - of offshore installations is larger and less predictable than otherwise expected.*** Whereas current decommissioning decisions are taken for each individual installation, 90% of the experts participating in our survey believed that decommissioning options should be evaluated for groups of ecologically interconnected installations instead of individual installations only.

- **Offshore installations are being used by a large variety of species, including threatened, protected and commercially valuable species, but also by exotic, invasive species.** In that regard, of particular note is the presence of Lophelia pertusa coral on a large number of oil and gas installations in the Northern North Sea. Lophelia reefs are on the OSPAR List of Threatened and Declining Species and Habitats, as well as being an Annex II habitat under the EU Habitats Directive. Although Lophelia colonies on man-made structures are currently exempted from protection, their presence may facilitate the restoration of colonies elsewhere in the North Sea through increased connectivity with larval sources. Offshore installations are also known to be used by flat oysters (Ostrea edulis), edible sea urchins (Echinus Esculentus), blue mussels (Mytilus edulis), cod (Gadus morhua), and harbour porpoise (Phocoena phocoena), all of which are on the OSPAR List of Threatened and Declining Species. At the same time, various kinds of invasive species have been

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[24] Gass, S.E., Roberts, J.M. (2006). The occurrence of the cold-water coral Lophelia pertusa (Scleractinia) on oil and gas platforms in the North Sea: colony growth, recruitment and environmental controls on distribution. In *Marine pollution bulletin* 2006;52(5):549-59. Epub 2005 Nov 21.

[25] Thorpe, S. A. (2012). On the biological connectivity of oil and gas platforms in the North Sea. In *Marine pollution bulletin* 2012; *64*(12), 2770-2781.

[26] See Draft ISAB Science Day Presentation v3 on http://www.insitenorthsea.org/

found to thrive on oil and gas installations off the coasts of the US[27]. ***This fact gives rise to a devilish dilemma: whereas offshore installations may form a crucial stepping stone in the spread and survival of valuable species that are under pressure they might also form a similarly crucial stepping stone for invasive species to survive and spread. A solution may be found in partial removal or toppling of installations, as J.W. Coolen concluded that invasive species are primarily found in the intertidal zone of artificial reefs, whereas the deeper parts most resemble natural reefs.***

- From an ecological perspective, the particular species inhabiting a reef at any one time are less important than the community- and ecosystem-wide impacts driven by the physical habitat attributes (eg, nutrient and biomass production, or the provision of shelter and spawning places). From a regulatory perspective, however, it may be judicious to consider the current presence of specific species that are either protected, listed as threatened or declining, commercially important or – on the negative side – listed as invasive or potentially-invasive species.

Material and complexity of an installation:

- As described in §2.1 offshore installations are mostly built of steel and/or concrete. Of these two, **concrete most resembles the material of natural reefs and hence concrete parts of offshore installations in the North Sea have been found to resemble natural reefs more than steel parts[28].** Concrete also seems to have been used most often for the construction of artificial reefs in recent decades (see Annex 2 for an overview of Artificial Reefs in the OSPAR Region). Concrete installations are usually closed structures, where the sunlight cannot penetrate to the inside, and therefore function as a relatively smooth, solid rock in the middle of the sea. In the North Sea, concrete foundations have been used only for a very limited number of oil and gas installations, primarily in the Northern part, and for near-shore wind farms on shallow water.
- **Steel reefs (including oil and gas installations) have also been found to provide suitable habitat for invertebrate assemblages, including various coral species, sometimes even better than concrete[29].** Steel jackets for both oil and gas and wind installations are complex structures, involving numerous crossbeams and large spaces in between that allow light to penetrate. Hence, they are likely to support high reef-fish diversity and abundance and have also been found to do so in practise. On the other hand, they contain few spaces, suitable for small fish and invertebrates, at least until epifaunal (encrusting) communities develop[30]. Monopile structures, which are now used for 80% of offshore wind turbines in the EU and probably for an even higher percentage in the North Sea, in themselves are relatively uniform reef habitats, as they provide just a straight, smooth surface of steel as hard substrate with few types of microhabitats. Hence, monopiles

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27 Page, H. M., Dugan, J. E., Culver, C. S., & Hoesterey, J. C. (2006). Exotic invertebrate species on offshore oil platforms. *Marine Ecology Progress Series*, *325*, 101-107

28 Coolen JWP (2017) North Sea Reefs: Benthic biodiversity of artificial and rocky reefs in the southern North Sea. *PhD-thesis Wageningen University & Research, 203p*

29 Macreadie, P.I., Fowler, A.M. and Booth, D.J. (2011) Rigs-to-reefs: will the deep sea benefit from artificial habitat? *Front Ecol Environ 2011; 9(8): 455–461, doi:10.1890/100112*

30 Luckhurst, B.E. & Luckhurst, K. (1978). Analysis of the influence of substrate variables on coral reef fish communities. Mar Biol 40:317–23.; Hixon, M.A. and Beets, J.P. (1989). Shelter characteristics and caribbean fish assemblages: experiments with artificial reefs. In Bull Mar Sci 44: 666–80. And Claisse, J.T, Pondella, D.J. et al. (2014) Oil platforms off California are among the most productive marine fish habitats globally. www.pnas.org/cgi/doi/10.1073/pnas.1411477111

primarily add valuable reef habitat through concrete foundations and scouring protection.

- **Species use the installations in a variety of ways: some organisms settle on and colonise the installation – and thus form the basis for complex, local ecosystems – while others utilise these new reefs for shelter and/or feeding.**

5.2.2. Protection from trawling.

- As explained in chapter 2, offshore installations are surrounded by a safety zone i.e. fishing exclusion zone. These areas are essentially small Marine-Protected Areas (MPAs), yet it is unclear whether these areas exert significant influence on wider North Sea populations. **Of the experts we consulted, 81% believed that the no-fishing zones around offshore installations may be of significant importance to key species** (even though they account for <1% of the North Sea area) and 87% agreed that an **installation may add value even if it only attracts** fish if it is protected from trawling/fishing.
- **When an installation is fully removed, this safety zone i.e. fishing exclusion zone will also be removed** and the area reopened for all other human activities. **If a structure is (partially) left in place, it seems wise to maintain – or even enlarge – the exclusion zone as a safety measure. In practise, this does not always happen, though**, as fishermen are eager to regain any 'lost' fishing area. 82% of the experts we engaged, suggested that disused offshore **installations could effectively be used to protect valuable marine ecosystems** from trawling. This perspective is supported by several successful experiences using artificial reefs to protect sensitive areas from illegal trawling (see Annex 2).

5.2.3. Production of additional biomass

There is an **ongoing debate about the extent to which artificial reefs, including offshore installations really add value by producing additional biomass or simply attract various species from elsewhere.** Especially in the Gulf of Mexico, where artificial reefs are being heavily fished, this is a hot topic: if artificial reefs only attract fish, but don't add any new biomass, they may in fact have a negative effect by allowing fishermen to fish up fish very effectively around the reef. **In recent studies, it has been shown that offshore oil and gas installations can contribute to the production of additional biomass:** *"We found that oil and gas platforms off the coast of California have the highest secondary fish production per unit area of seafloor of any marine habitat that has been studied, about an order of magnitude higher than fish communities from other marine ecosystems."*[31]

The 'production vs. attraction debate' primarily concerns mobile species. Immobile species such as macro-algae, anemones, corals and to a lesser extent shell fish are regularly found on offshore installations and evidently do add to biomass as they cannot move.

Once an installation is removed, immobile species attached to the structure (i.a. additional biomass) are also removed. Mobile species can either stay or move somewhere else. In cases where these species' development is limited by available habitat, the loss of offshore installations may be fatal[32]. In all cases, mobile species will lose the protection provided by the safety zone around the installation.

[31] Claisse, J.T, Pondella, D.J. et al. (2014) Oil platforms off California are among the most productive marine fish habitats globally. www.pnas.org/cgi/doi/10.1073/pnas.1411477111

[32] Macreadie, P. I., Fowler, A.M. et al. (2011). Rigs-to-reefs: will the deep sea benefit from artificial habitat? In Front Ecol Environ 2011; 9(8): 455–461, doi:10.1890/100112

Noise and impacts on marine mammals

Studies of the impacts of offshore installations on marine mammals show that while offshore wind farms can have negative effects on marine mammals during construction, during operations, they can be at least as effective as existing marine protected areas in terms of creating refuges for benthic habitats, benthos, fish and marine mammals. The extent to which organisms benefit depends on the location of the wind farm and the level of imposed fishing restriction. For some species, negative effects have also been found on a local scale at other locations (e.g. Nysted wind farm)[33]. In the North Sea, harbour porpoises have been shown to make extensive use of offshore oil and gas installations as feeding stations[34]. However, to what extent these findings also mean that offshore installations benefit specific marine mammals on a population scale is still highly uncertain. It is equally uncertain, whether the eventual removal of these structures would have a positive or negative effect on marine mammal populations and whether decommissioned structures left in place would benefit marine mammals to the same extent as they do now if fisheries were allowed again within the safety zone.

What we do know, is that decommissioning activities (cutting and vessel movements) create similar negative impacts as the construction of offshore installations does. We also know that as safety zones are reopened to fishing, marine mammals lose some areas, where they can now forage without direct competition from fishermen. A more flexible approach to decommissioning will make it easier to assess the potential positive and negative effects on marine mammals on a case-by-case basis and to learn from experience over time, so that decommissioning choices can be adapted to new insights.

Chemical contamination

There is broad agreement between experts, that contaminated parts of an offshore installations should – as a matter of principle – always be removed to shore for proper waste handling. In line with this thinking, R2R programmes in the US only accept *clean* steel jackets.

The topsides of oil and gas installations contain chemicals that would have a negative effect on the marine environment and therefore should always be removed. In most cases, the jackets are made of clean, uncontaminated steel (or concrete). Storage tanks and the bottom part of concrete gravity-based structures may be contaminated by oil if they have been used for storage. This is the case, for example, with some of the installations in the Brent field, which will, by the way, not be removed, because of technical feasibility issues and safety risks, and for the Danish Siri platform.

As explained in §2 and 3, the seabed around oil and gas installations is often contaminated by so called drill cutting piles, which are huge mounds of gravel or sand mixed with chemicals that have been used as drilling fluid[35]. Drill cutting piles are primarily located in the Central and Northern North Sea, where currents and wave activity at seabed level are too weak to

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[33] Teilmann, J. & Carstensen, J. (2012) Negative Long Term Effects on Harbour Porpoises from a Large Scale Offshore Wind Farm in the Baltic—Evidence of Slow Recovery. Environmental Research Letters, 7 Avalilable from: http://www.scirp.org/(S(lz5mqp453edsnp55rrgjct55))/reference/ReferencesPapers.aspx?ReferenceID=1658011

[34] Todd, Victoria & D. Pearse, William & Tregenza, Nick & Lepper, Paul & B. Todd, Ian. (2009). Diel echolocation activity of harbor porpoises (Phocoena phocoena) around North Sea offshore gas installations. Ices Journal of Marine Science - ICES J MAR SCI. 66. 734-745. https://www.researchgate.net/publication/242093967_Diel_echolocation_activity_of_harbor_porpoises_Phocoena_phocoena_around_North_Sea_offshore_gas_installations

[35] For example, the drill cutting pile of the Murchison platform is has a measured height of 15.34 m and has been measured to cover an area of 6,840 m2 and have a volume of 22,545 m3. http://www.cnri-northsea-decom.com/pdf/decommissioning/Mgt-of-the-MUR-Drill-Cuttings-Pile.pdf

cause natural dispersal of contaminants. Daan et al. concluded that long-term biological effects of oil-based muds in the Southern North Sea are in general found in a zone with a radius of 200 m around the wells. Samples close to the rig (three years after drilling) showed a total absence of soil fauna. Unfortunately, these studies have not been repeated at a later stage, so there is very little (public) knowledge on how long it takes before contaminated seabed areas restore to their original state. With regard to Lophelia (which does not grow around, but on oil and gas installations) evidence of highly localised contamination from drill muds and cuttings has been observed by several studies.[36]

Experts we consulted do not feel certain that it is always the best environmental solution to remove drill cutting piles, because removal implies a significant risk of dispersal of contaminants into the water column and hence over a much wider area. In a report produced by Centre for Environmental Risk School at the University of East Anglia in 1999, it was concluded that the best environmental option, which was at that time technically feasible, was to leave drill cutting piles for natural degradation. This conclusion later was confirmed by a large study done by the UK oil and gas association (UKOOA) and seems to have become common practise since then, at least in situations where the footings of an installation are left in place.[37]

If a structure is fully removed, this implies contaminants in the seabed will soon be dispersed by trawlers once the safety zone is reopened to fishing activities. In cases where parts of an installation (e.g. footings) are left in place, drill cutting piles are usually left to decay by themselves through biological processes. There is substantial uncertainty about how long the seabed takes to recover. Recent studies by Gardline for BP, based on monitoring of the decommissioned North West Hutton installation, suggest that seabed recovery may be much faster than originally expected (decades instead of 500-1000 years) (Presentation by Katie Cross, Gardline, at NPF Decommissioning Conference 2015). However, we have found no peer reviewed scientific publications on this topic and especially comparative data are scarce, since there is no monitoring of seabed areas where installations are fully removed.

Emissions to air, energy use and loss of non-renewable resources

The energy requirements and associated emissions to air form important parameters in an environmental impact assessment of a decommissioning scenario. As energy requirements can be expressed as fuel requirements, saving energy means saving fuel. Taking an LCA perspective, the total energy consumed in a decommissioning process should include the theoretical amount of energy that is required to replace all materials that are not recovered (Erep). Figure 5.4 illustrates the comparison between leaving part of a structure on the seabed in comparison with a variant where that same structure is retrieved to shore for further recycling. If the actual energy consumption (Edir+Erec) is smaller than the energy required to reproduce that same amount of material from raw materials (Erep), then "recovery" performs better than "leave in place" in terms of energy use. However, when Edir + Erec > Erep the energy balance favours a leave-in-place scenario.

[36] Daan et al Gass & Murray (2006) Fosså et al., 2002

[37] Centre for Environmental Risk, University of East Anglia (1999) Drill Cuttings Piles in the North Sea: Management Options During Platform Decommissioning. Research Report No 31 http://www.offshorecenter.dk/log/bibliotek/cuttings.pdf

UKOOOA Drill Cuttings Initiative Final Report (2002) http://www.brasil-rounds.gov.br/round7/arquivos_r7/PERFURACAO_R7/biblio/UKOOAcascalho.pdf

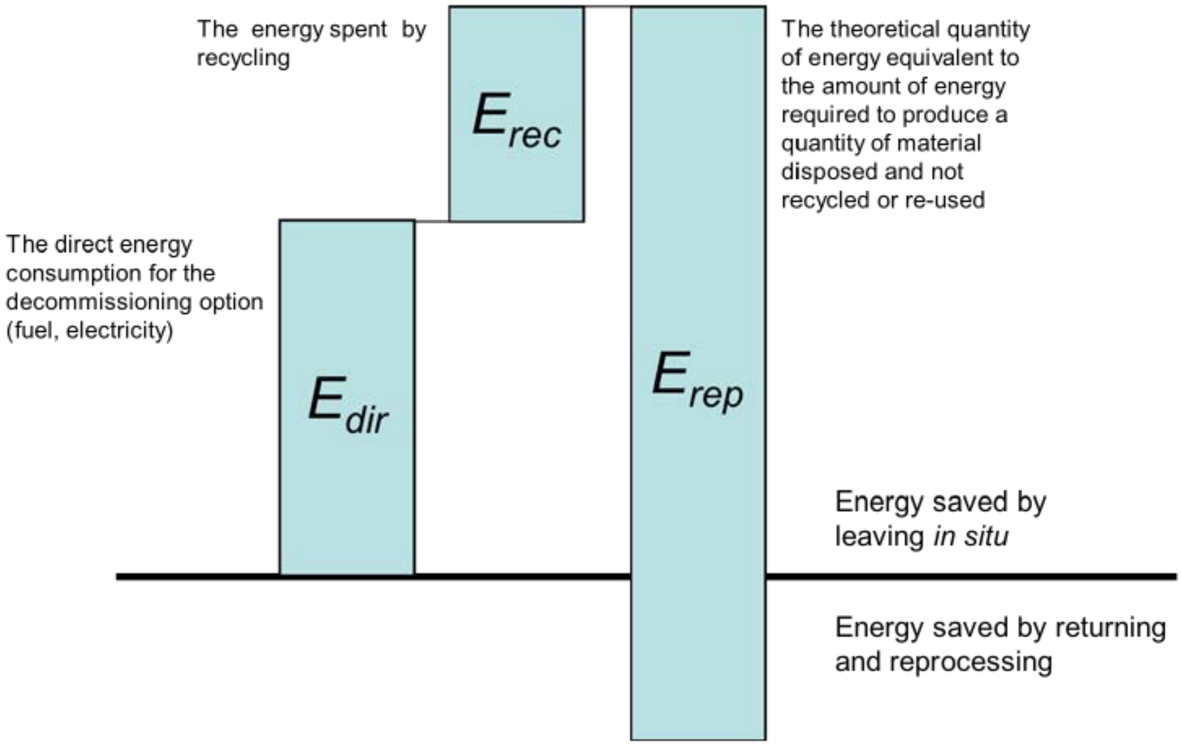


Figure 5.4. The three energy contributions in an LCA that determine which scenario is most energy-efficient. If Edir+Erec-Erep < 0 then energy is saved by recovery; otherwise, leave in place is preferred from an energy perspective. Source: IMSA Amsterdam (2011). Decommissioning of North Sea oil and gas facilities. An introductory assessment of potential impacts, costs and opportunities. Background report phase 1 Living North Sea Initiative

In decommissioning, direct energy consumption stems from dismantling, sea transport and onshore activities (demolition, onshore works and transport). The nature of the decommissioning process implies that the energy for transport movements is often 50% or more, and therefore might dominate the analysis.

Since most offshore installations in the North Sea primarily consist of high quality steel, the energy use related to the materials of the installation is highly dependent on the energy requirements for the production of steel. Since the steel from oil and gas installations - and probably also wind turbines - can be recycled for 98% or more[38], the recycling (Erec) and replacement (Erep) contributions are almost entirely determined by the energies required to produce steel. Edir is the decisive factor in judging decommissioning options from an energy perspective. According to the World Steel Association, secondary steel production, i.e. recycling from scrap, requires about half as much energy as primary steel production, depending on the specific process.

The emissions to air (CO2, So2, NOx) from offshore decommissioning are largely caused by fuel emissions by vessels. Generally, emission factors for transport (vessels, lorries) are larger than those required for material production. The recycling or primary production of metals takes place in energy efficient industries that often have several air emission control measures in place. The shipping sector, by contrast, is still relatively polluting, although new regulations increasingly limit also the emissions of vessels. Hence, emissions from direct energy use will weigh in more strongly than emissions related to material recycling or replacement.

[38] KLIF (2010) Decommissioning of offshore installations, Norwegian Climate and Pollution Agency, Oslo, February 2010, TA2643

Consequently, even if bringing an installation to shore for reprocessing saves energy, the assessment based on emissions may conclude that a leave-in-place scenario would be preferred (see for example Ekins, P., R. Vanner & J. Firebrace. (2006) Decommissioning of offshore oil and gas facilities: A comparative assessment of different scenarios in J. Env. Man. 79 (2006) 420-43).
In summary, energy use and emissions to air of different decommissioning options may vary substantially per installation, depending a.o. on location, removal techniques and efficiency and emission mitigation measures of vessels used. A flexible decommissioning approach would allow for specific assessments and evaluations for individual installations and hence presumably could result in an overall decrease of energy use and emissions to air. From a resource (circular economy) perspective, decommissioning options where recyclable material such as steel is left offshore inherently score worse than full removal options.

Long-term risks and legacy issues
In many debates on decommissioning regulations, the issue of long-term liabilities and risks tends to dominate and turn out decisive for which option is chosen. From the operator's perspective, long-term liability is primarily an issue of whether or not the operator remains responsible and liable for any incidents that might happen as a result of material being left offshore (see §4.2). Generally speaking, operators do not want to remain liable for something they are no longer actively involved with for many, many years. On the other hand, governments also do not wish to be liable for such material either and, following the polluter pays principle, this also may not seem fair. Consequently, liability considerations tend to favour full removal options.
However, the extent to which material left offshore is actually likely to cause environmental damage on the long term is highly uncertain. The major risks concern collisions with vessels, which may then leak pollutants, ghost-fishing from nets getting caught in the material and damage from material falling apart and on the seabed over time. The experts we consulted generally did not expect that these risks were likely to outweigh the potential benefits of leaving the reef habitat intact, but also indicated that this is a point of uncertainty. To a large extent, long-term risks and legacy issues should be manageable within a flexible decommissioning approach, if proper arrangements are made with regard to maintaining a safety zone around the structure, ensuring proper navigation marks and ensuring that some sort of 'reef foundation' or similar organisation is made responsible for maintaining and managing the artificial reef that the material has in fact become (in line with the OSPAR Guidelines for Artificial Reefs).

6. Conclusions

In the North Sea, there are now some 1,350 oil and gas installations, more than 27,000 shipwrecks and more than 2,300 offshore wind turbines. The number of wind turbines is growing with hundreds each year, forecasts predicting an additional 4,000-8,000 turbines by 2030 and up to 25,000 by 2050. Eventually the result could be that almost 8% of the North Sea area (57,000km^2) might be occupied by offshore energy installations by 2050 and that some 300-600 wind turbines would have to be built and decommissioned each year until 2050, while almost all oil and gas installations would have to be decommissioned within the same period of time. Next to these offshore installations, there are some 45,000 ship wrecks in the North Sea and more than 70 artificial reefs within the OSPAR area (of which at least 7 in Denmark). All these man-made structures – primarily made from steel and concrete -, mimic ecosystem functions of natural reefs in some way or other. Offshore installations differ from (most) artificial reefs, ship wrecks and natural reefs in the North Sea in that they pass all way through the water column, incl. the intertidal zone, while standing in the middle of the sea. Secondly, they are surrounded by a 500m safety zone, where a.o. fishing is not allowed for.

No assessments have been published on the cumulative effects of decommissioning in the North Sea (nor of the cumulative effects of the placement of thousands of new renewable energy installations). Hence, we can only provide a qualitative assessment of potential environmental effects of a more flexible approach to decommissioning in the North Sea.

- **Over time, offshore installations develop into artificial reefs, which may be of significant value to the ecosystem**, especially if they replace lost historical reefs, provide habitat for threatened or protected species, function as a stepping stone for larval exchange between natural reefs, provide food and shelter for mobile species/biomass or support important commercial species. Most of the experts consulted believe that valuable reef habitats should in principle be maintained and protected.
- **We seem to know more about what will happen to the ecosystem if we leave offshore installations in place** (established communities will develop further), **than we know about what will happen if we remove them** (established communities will disappear, which may possibly affect the wider ecosystem via related food webs and loss of connectivity).
- **There is a large degree of consensus among scientists that a more flexible approach to decommissioning could benefit the North Sea ecosystem**, especially if such an approach takes into account the role of individual installations within the wider network of reef habitats. Partial decommissioning options are seen to be at least as valid or even preferable to full removal options.
- **If partial decommissioning options are chosen, it is important to maintain or even enhance the safety zone around the installation.** Safety zones add ecological value by protecting the artificial reef from being damaged and protecting species around the reef from being caught by fishermen. Moreover, they reduce the risk of vessel collisions and snagging of fishing nets.
- **There is a strong need for practical experience and further research** on positive and negative effects of partial decommissioning options as compared to full removal, through **pilot projects** and through **modelling of cumulative effects**.
- In the table below, we **summarize the potential positive and negative effects** of introducing a more flexible approach to decommissioning in the North Sea. It is expected that **most of the negative effects can be mitigated** through improved EIAs, case-by-case measures and clear procedures for management of material left offshore.

Potential positive effects of flexile decommissioning	*Potential negative effects of flexible decommissioning*
General for all offshore installations	**General for all offshore installations**
Reduced loss of reef habitat, especially in Southern and Central North Sea	Lost opportunities for restoration of seabed to its 'original' (pre-placement) state
Protection of habitat for endangered species attached to offshore installations	Continued connectivity for invasive species (primarily intertidal zone)
Continued connectivity between natural and artificial reefs (offshore installations) for valuable species	Loss of non-renewable resources that could otherwise be reused or recycled (steel, copper, plastics, concrete)
Maintenance of valuable communities that have developed on man-made structures, including continued production of additional biomass	Loss of offshore space that can be freely used for any purpose (clean seabed)
Increased stability of ecosystem as artificial reef habitats are not continuously being removed and constructed	Increased long-term risk of damage due to vessel collisions with material left offshore
Continued (physical) protection from trawling (i.e. refuge, shelter and reduced seabed disturbance) around installations	Increased long-term risk of ghost fishing (by snagged gear)
Reduced impact of noise from decommissioning activities (vessels, cutting)	
Reduced negative impacts on coastal communities near decommissioning yards (pollution, space, odour)	
Reduced energy-use and emissions to air for removal, transport and onshore cutting of installations	
Reduced disturbance of seabed around offshore installations	
Specific for oil and gas installations	**Specific for oil and gas installations**
Reduced risk of resuspension of contaminants in seabed surrounding installations (during decommissioning and afterwards as a result of trawling)	
Specific for offshore wind farms	**Specific for offshore wind farms**
Incentive for eco-design of offshore wind farms (or at least removal of a possible incentive to minimize scouring protection and other elements that may improve ecosystem functions)	

Note: There is some disagreement as to whether 'loss of offshore space' is an environmental effect.

Annex 1. Expert Survey Methodology

Between April 6th and June 19th, 2017, we gathered survey responses from 200 experts from across the world, with a focus on the North Sea. Experts spanned academic, government and private organisations, and required a minimum of two scientific publications on offshore ecosystems or environmental impact assessment, or a minimum of 10 years professional experience in the case of non-academics. The list of experts was developed by A.M. Jørgensen, A.M. Fowler and J.W. Coolen using a database from a previous project on the decommissioning of oil and gas installations in the North Sea (the Living North Sea Initiative), a list of participants from the INSITE Science Day 2016 and list of participants from WINMON.BE (http://odnature.naturalsciences.be/winmonbe2013/participants).

We used a mixed-methods survey with 10 quantitative, categorical and open-ended questions and posted it on SurveyMonkey (https://nl.surveymonkey.com/r/GXMGBYG). The questions related to:

1) Country of work.

2) Areas of expertise.

3) and 4) Environmental criteria important for decommissioning decisions for offshore oil and gas installations in the North Sea (ranking 23 criteria and open question allowing addition of any other criteria).

5) Decommissioning options that should be considered for offshore oil and gas installations in the North Sea (14 options were listed, multiple choices were allowed).

6) and 7) Environmental criteria important for decommissioning decisions for offshore wind farms in the North Sea (ranking 23 criteria and open question allowing addition of any other criteria).

8) Decommissioning options that should be considered for offshore wind farms in the North Sea (12 options were listed, multiple choices were allowed).

9) Level of agreement with statements relating to their preference of decommissioning options, the interpretation and relative weighting of various environmental criteria (46 statements, one of 5 levels of agreement allowed).

10) Contact information of the respondent.

Respondents were allowed to skip questions or end the survey any time, allowing them to participate without leaving their contact details and to respond only to those questions on which they felt they had sufficient expertise.

Criteria presented in Questions 3 and 6 were based on Fowler et al. (2014), with some criteria added by researchers who organized the survey, to better match the North Sea region. Respondents were not allowed to rank two criteria equally, but could choose to rank fewer criteria, leaving the rest of the list with no score. Criteria were presented to respondents in a random order.

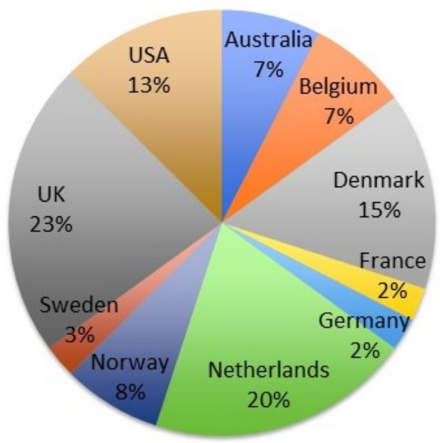
Responses were downloaded on June 19th, 2017.

Respondent characterization and relevance

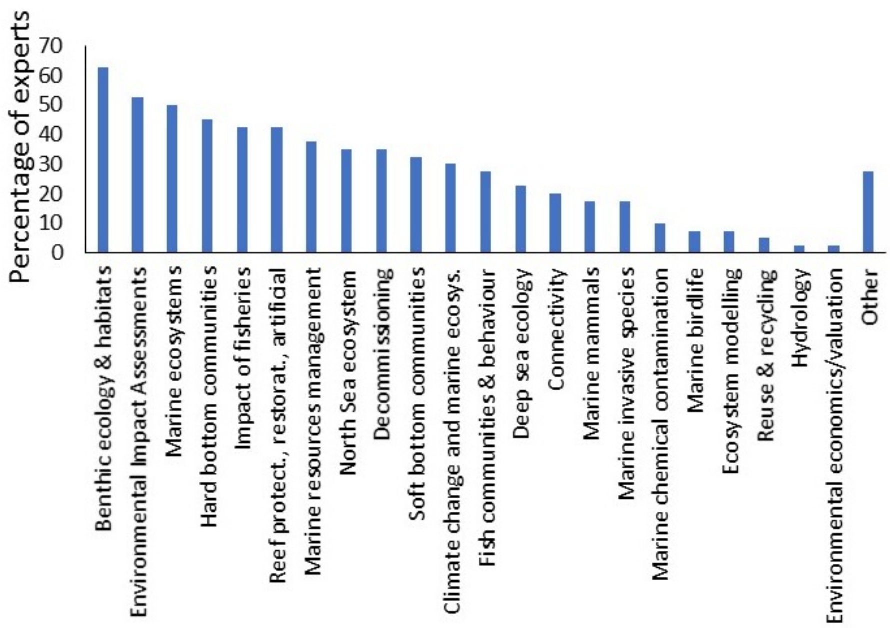
We downloaded 52 survey responses, comprising 26% of invited experts. We removed 12 responses, as they had only responded to the first two questions concerning country and area of expertise. Remaining experts were located in 10 countries and represented 34 organisations, 80% of which were in the North Sea region (Figure 1a). 29 experts were academics from independent research institutes, 10 were from private research and consulting organisations, and one was from a government agency.

Respondents represented more than 23 different areas of expertise (Figure 1b), with the majority having a background in benthic ecology and habitats, environmental impact assessments and general marine ecosystems. Expertise in connectivity, marine mammals, marine invasive species, or marine chemical contamination were indicated by 10-20% of respondents, while < 10% indicated expertise in marine birdlife, ecosystem modelling, reuse and recycling, hydrology, or environmental economics. See figures below.

a)



b)



Annex 2. Overview of Existing Artificial Reefs in the OSPAR Region

Author: Anne-Mette Jørgensen, Eco-Effective Strategies. May 1st, 2017.

Below, we provide an overview of (some) artificial reefs in the OSPAR region, based in the first place on "OSPAR Commission. 2009. Assessment of construction or placement of artificial reefs". The reefs mentioned in Appendix B of this assessment have been explored with Google search engine and available information added to the table. Also, reefs that were not mentioned in this report, but known to the author or which popped up during the Google search have been added.

Next to the OSPAR report, the following overview articles can be recommended. *Not* all the reefs mentioned in here have been added to the table.

Tessier, A, Francour, P., Charbonnel, E. et al. 2014. Assessment of French artificial reefs: due to limitations of research, trends may be misleading.

Fabi, G., Spagnolo, A., Bellan-Santini, D et al. 2011. Overview on Artificial Reefs in Europe.

Country	Location/name	Date	Purpose	Design & materials	Size	Monitoring progr. (length & focus	Results	Link/sources
Belgium	Thornton bank (in wind park)	2013	Protection and restoration of habitats i.r.t. offshore wind developments.	2 x 33 reef balls Also plans for a resting place for seals	unknown	Duration uncertain. Using sensors installed in nearby wind park. Focus on: Water quality, fish movements, porpoises/sea mammals and the use of the reef balls by various species (camera monitoring).	Tbd	http://www.vliz.be/nl/artificiele-riffen
DK	Vejle Fjord	2005 & 2013	Habitat enhancement, diving - snorkelling, education	2005: Sacks of blue mussel shells 2013: 100 tonnes rocks	2005: 0.2 km^2 (20ha) 2013: unknown	Unknown – some reporting in 2008, but not available online. 2013 reef will be monitored by a local high school.	Positive (according to news items); more fish, higher biodiversity.	
DK	'Blue Reef':	2008	Restoration of natural	Natural rocks from	45,000m^2 (4.5ha)	Baseline survey 2007. Biological surveys	Overall increase in biomasses of almost 6-8	http://naturstyrelsen.dk/naturbeskyttel

Country	Location/name	Date	Purpose	Design & materials	Size	Monitoring progr. (length & focus	Results	Link/sources
	Læsø Trindel (Northern Kattegat), 12 km offshore.		habitats and species of community interest	Norway		(colonisation) 2009, 2010, 2011. Repetition of 'baseline survey 2012. Focus on: Physical stability & structure, Development of biological community, incl. European lobster & fish on/around reef Change in food-web dynamics.	folds per m2 seabed at the two depth intervals of 5-6 m and 9- 10 m. The abundance of solitary species also increased considerably from 2007 to 2012 with a factor near 4 and 6, respectively, at the two depth intervals. Change in fish communities, with particular growth of juvenile cod.	se/naturprojekter/blue-reef/undersoegelser-investigations/
DK	Limfjord, Salling Aqua Park	2014	Diving (education)	Stone reef and various disused vessels and army tank after clean-up	Reef elements scattered over area of some 100 x 300m	Unknown	Unknown	http://www.sallingaquapark.dk/
DK	Ærøsund (South of Funen)	2014	Restoration of hard substrate habitat, diving reef (local economy & diving education) & educational	Disused vessel (ferry) after clean-up	Length 55.26m Width 9.32m Height 13m (6695m^3)	Started in 2014. No particular duration. Annual survey (video and diving) on colonisation of the wreck.	Rapid colonisation and sedimentation of lower deck. No scientific reports available (yet)	http://www.dyk-sydfyn.dk/40-about-m-f-%C3%A6r%C3%B8sund.html https://www.youtube.com/watch?v=p3W_4J2fZFw&index=1&list=PLK_xycf

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			activities.					Zm2PYWXd9xNCDkogbzRQFzDBfy&t=42s https://www.youtube.com/watch?v=NK_QSIWv9L8&index=2&list=PLK_xycfZm2PYWXd9xNCDkogbzRQFzDBfy
DK	Harbour of Copen-hagen	2016	Diving reef	Concrete vessel refurbished for the purpose	21m long, 7m wide, 3m high (441m^3)	Unknown	Tbd	http://www.tv2lorry.dk/artikel/dykkerentusiaster-jubler-koebenhavns-nye-skibsvrag-paa-plads-0
DK	Sønderborg, Als	2016, Ongoing	Restoration of natural habitats, improved water quality, diving opportunities.	Natural rocks (boulders) from local origin and from Sweden or Norway	13,400m^3 rocks of different sizes spread over 6 locations	Focus on: Fish stock analysis Harbour Porpoise visiting the reef Macroalgae populations & growth Estimates of oxygen production and N-fixation	Tbd	http://nst.dk/media/nst/Attachments/F_AlsStenrevKbhmarts2013_BoMammenKruse.pdf http://www.landbosyd.dk/nyheder/millioner-til-seks-nye-stenrev
France	Mimizan	1983, 1990-2006	Research and public awareness	1983: a combination of tyres	Spread over an area of	No consistent monitoring in early years. Regular dives between 2002 and	Data unpublished.	http://adremca.com/historique/

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			on the protection of the marine environment	(2,800), ropes and concrete blocks. 1990: 40 tonnes 1994: a barge (20 tonnes) 1996: 3 000 tyres 2002: 14 x 3.5tonne concrete blocks 2004: 142 tonnes 2005: 40 tonnes 2006: 51 tonnes	2ha (treated as a single reef)	2012.		
France	Capbreton Vieux Boucau Moliets	1999 – 2008 2001/2	Enhancement of local fisheries and research on protection and conservation of the marine	925 Concrete pipes (800 in 1999 and 125 in 2008) plus 3 Typi (concrete; 2.6mx4.6m)	3,775m^3 & 44m^3 800m^3	Unknown Reporting on measurements from diving and fish samples in 2007-2008.	Commercial fish species thriving. Biomass and species depend on types of reef.	http://www.aquitaine-landes-recifs.fr/tl_files/alr40/data/dossierpresentationALR2009angl.pdf

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			environment.	7 heaps of concrete pipes				
France	France Ile d'Ýeu – Le Croisic	2003	Experimentation on the durability of the structures and production	Concrete modules: i) Protection modules – 6m3 (13 tonnes) ii) Large modules – 156m^3 (57 tonnes) iii) Small modules – 5m^3 (3 tonnes).	3 areas of 500 x 1000 m (50ha).	2004-2006 (annual) & 2009, 2010 Focus on: Structural integrity Colonisation of structures	Small modules are stable, while large modules are weak (partially collapsed by 2010). Increased complexity and stability of reef ecosystems over time. Project is seen as successful in emphasising opportunities for biomass production and commercial species of artificial reefs and the importance of design and placement of artificial reefs.	http://www.corepem.fr/actions-et-projets/gestion-des-peches/recifs-artificiels/
France	Etretat	2008	Experimental reefs to evaluate marine resource enhancement effectiveness	169 concrete blocks (1.4m3) Exterior circle of 25 units Interior circle of 9 reefs of 16 blocks	450m^3 over area of 500 x 500 m (25ha)	5 years	Unknown	https://www.actu-environnement.com/ae/news/recifs_artificiels_etretat_5136.php4

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				1 large central module of reinforced concrete (54m3).				
DE	FINO 1 (North Sea, North of Borkum) FINO2 (Baltic, North of Rügen) FINO3 (North Sea/Wadden Sea, West of Sylt)	2003 2007 2010	Research into effects of offshore wind parks	3 research platforms with different structures, resembling offshore wind turbines	-	Ongoing since construction. Focus on: Bird strikes, The presence of porpoises, Benthic communities, The prevention of environmental damage associated with the collision of vessels.	FINO1: Fauna very similar to that of ship wrecks, but lower abundance than on highly fractured (complex) wrecks. Abundance on the platform was highest in complex parts of the structure (anchorage) in lower water levels.	http://www.fino-offshore.de/en/ http://epic.awi.de/32982/1/Krone13_ECSS125.pdf
NL	8.5 km offshore of Noordwijk aan Zee	1991	Research into changes in habitat and biodiversity	4 mounds of basalt rock Each mound 8 x 14 meters	Total 448m^2 (0.04ha)	Monitored between 1991–1996 (5 times a year) and revisited in 2001.	Biodiversity comparable with ship wrecks and much higher than on surrounding seabed. Substantial change in dominant species between 1996 and 2001. Reefs are disappearing into the sandy bottom	Van Moorsel, G.W.N.M & Waardenburg, H.W. 2001. Kunstmatige riffen in de Noordzee in 2001. De status 9 jaar na aanleg.
Norway	Risør (2	2002	Fish	'Runde	Each reef	2002-2005.	Similar to those of	https://www.ntnu.e

Country	Location/name	Date	Purpose	Design & materials	Size	Monitoring progr. (length & focus	Results	Link/sources
	units)		attraction, marine resource enhancement & research	reef': Concrete and plastic units And 'lobster houses'	unit has a diameter of 6m and upright height of 2.5m		Hammerfest Reefs. Though: experimental lobster houses turned out to become homes for lobster enemies rather than lobsters.	du/documents/919596/1265033033/Christie+presentation.pdf/414a8f3c-e150-4af1-b7c6-b28c58686448
Norway	Lofoten (2 reefs)	2004	Fish attraction	Concrete walls and pyramids with windows/ holes	Each group of walls and pyramids covers ca 50 x 50 m (0.25 hectares)	Uncertain; at least one visit after 10 years (2004). Focus on marine vegetation (kelp) and fish.	Rich growth of algae and high abundance of fish.	https://www.imr.no/filarkiv/2006/03/3.6_Kunstige_rev_paa_norskekysten.pdf/nb-no
Norway	Hammerfest (24 reef units/ 2 locations)	2006	Re-establishment and enhancement of kelp, other seaweeds & associated animals.	'Runde reef': Central cylinder of concrete with radiating polyethylene pipes	Each reef is 6m in diameter, and each group of 12 reef units covers ca 80 x 60 meters (0.48 hectares).	First inspection in 2006. 2007-2009; diving/video inspections 2-3 times a year. Focus on marine vegetation (kelp) and fish.	Rich growth of kelp and other marine vegetation; extensive use by juvenile fish	http://www.seacult.com/files/13.3%20Hammerfest%20Runde%20Reef%20Report%202009.pdf
Portugal	Faro and Olhão reefs,	1990	Experimental reefs to evaluate	Concrete lattice units and blocks		unknown	Unknown – clearly experienced as positive	

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	Algarve coast near Faro		ecological impacts, & effectiveness in terms of fish stocks and coastal resource management.					
Portugal	Ancão reef and other reefs along Algarve coast near Faro	1998-2001 and 2002-2003 2012	To increase and diversify fishing yield for commercial purposes, diving and research.	19,000 concrete modules. 4 naval vessels	35km2 (3 500 hectares)			http://www.oceanrevival.org/en/projecto/recifes-artificias.html http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1679-87592011000500015
Portugal	São Pedro do Estoril, Municipality of Cascais	?	Surf reef	Rock or sediment filled geotextile bags	?	Unknown	Seems to work well according to online surf spot recommendations.	https://www.researchgate.net/publication/257945441_AN_ARTIFICIAL_SURFING_REEF_IN_SAO_PEDRO_DO_ESTORIL_BEACH_PORTUGAL_NUMERICAL_AND_PHYSICAL_MODELING

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								_STUDIES
Spain	Pais Vasco	1960	Recreational diving	Disused steel vessel	unknown	unknown	Unknown	
Spain	Pais Vasco	2003	Recreational diving	Several disused steel vessels (after clean-up)		unknown	unknown	
Spain	24 reefs in various locations (Asturias, Cantabria, Galicia, Andalucia Cadiz, & Andalucia Huelva).	1986 - 2005	Mainly fisheries management (deterrent or production units, which may also serve to attract fish)	Mainly concrete units with dissuasive elements		unknown	unknown	
Spain	External waters of Huelva-Cadiz	2008	Fisheries protection and enhancement	2 polygons 9211.9 ha	2,257.7 ha	unknown	unknown	
Spain/UK	Bay of Gibraltar	1975 - 2013	Fisheries protection and enhancement Diving	Tyres, motor cars, navy vessels In 2013: 70 concrete blocks with metal sticks	?	unknown	unknown	http://www.helpinghand.gi/projects/2043-gibraltar-artificial-reef-project-a-first-in-europe

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Sweden	Gothen-burg	2003	Compensation for habitat loss and enhancement of living marine resources	Natural rock excavated during deepening of entrance to Gothenburg Harbour.	130 - 380 m and 4 - 14 meters high.	2002-2007. Focus on development of biological communities on the reefs & assessment of their effectiveness in terms of increasing productivity of particular species (lobster, brown crab, cod, saithe, pollack and whiting)	The monitoring programme showed that certain species - including lobster and commercial fish species such as cod - were strongly attracted to the reefs.. However, the monitoring period was too short to allow conclusions on increases in productivity. Negative influence on biodiversity on the reef due to heavy sedimentation & possibly lack of oxygen.	https://www.diva-portal.org/smash/get/diva2:879787/FULLTEXT01.pdf
Sweden	På, off the West-Coast of Sweden	2013	Habitat restoration and enhancement of living marine resources, especially lobster & particular fish species	Natural rocks (weighing ca 1 ton each), 15 concrete pipes constructed into pyramids, steel mesh mats with holes sutable for	Unknown	Unknown	Unknown	http://www.sportfiskarna.se/Om-oss/Aktuellt/ArticleID/4489

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				lobsters.				
UK	Poole Bay	1989	Research on use of waste from coal-fired power station in artificial reef construction	Purpose-built modules using stabilized waste from coal-fired power station	8 modules each 1m high and 4m diameter Total 50 tonnes	Focus on: Physical integrity Environmental acceptability of the material (heavy metals, epifauna) Biological colonisation Changes in infauna close to reefs Fisheries potential		
UK	Poole Bay	1998	Extension to the above research project using tyres and concrete in place of concrete and coal ash in artificial reef construction	Purpose built modules using scrap tyres and concrete	500 tyres	idem		
UK	Whitsand Bay, Cornwall	2004	Leisure diving/education & research. Linked to National Aquarium in Plymouth.	Decommissioned frigate (HMS Scylla); steel vessel after clean-up	Length: 113m, Weight 2300 tonnes	10-year monitoring programme looking at: Migration of Tributyltin (TBT) from the hull paint into the surround area, Changes in sedimentary processes as a result of the placement of the vessel	Increase in boat traffic in Whitsand Bay of between 200-300% in the first six months following placement -> additional local income. By 2009 Scylla hosted a 'mature steel wreck	http://www.divescylla.com/scylla-science

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						Colonisation of the wreck/reef. Latest formal monitoring report was published in 2007; in 2014 a presentation was given on the colonisation.	community'. >278 species have been recorded on or around Scylla ,incl. the nationally rare nudibranch, Trapania maculate. TBT has been found in biota samples collected from the reef. Hardly any colonization of areas treated with TBT. Extensive use for educational activities & research (modelling). By 2017, the wreck has deteriorated to an extent that divers are recommended to NOT dive inside the wreck.	
UK	Loch Linnhe - Scotland	2006	To facilitate research between artificial reefs and the environment , including potentially beneficial effects on fisheries and	30 reef modules, each of which consists of around 4 000 concrete blocks, some solid, some with	30 conical units of 10-15 m diameter, and 3.5-4 m high.	Baseline study in 2000-2001. Since 2006 active, multidisciplinary research programme, incl. both fundamental and applied research. The programme covers: environmental impacts; impacts on the local current regime; water flows around the reef and	Key impacts: Reduced current flow Reduction in the oxygen levels in the sediments at the edges of the reef Change in the biological community, with a decrease in species sensitive to low oxygen, and increase in those which are more tolerant of	http://www.sams.ac.uk/tom-wilding/artificial-reef/?searchterm=loch%20linnhe

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			local biodiversity. The long-term aim is to boost fish stocks by creating commercially viable man-made habitats	'caves'. Total weight ca. 6000 tonnes. The concrete contains a blend of cement and coal-ash (8%) & quarry dust. Blocks were tested prior to construction and shown to be physically robust and chemically inert.		associated sediment movements; an evaluation of the habitat complexity offered by the reef to crustaceans and fish of commercial importance (especially cod and lobsters); opportunities for seafood production; and comparison of productivity between natural and artificial reefs. Unclear whether it is still ongoing.	such conditions. Effects are more pronounced during summer and autumn, but are at all times limited to within 1 m of the edge of the reef.	
UK	Boscombe, Bournemouth	2006 (re-branding in 2014)	Surf reef (later diving reef & activity park)	Geotextile bags filled with gravel and sand	5450m^2	Unknown	Disappointing – little positive effect on surfing conditions	https://en.wikipedia.org/wiki/Boscombe_Surf_Reef