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Application of Ecosystem Services to support decision-making in OSPAR activities.

A case study of upscaling offshore wind farms in the North Sea region.

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List of abbreviations

Abbreviation	**Description**	**Definition**
ALARP	As Low As Reasonably Practicable	The level at which the costs are disproportionate to the benefits.
BTA	Bow Tie Analysis	Logical and coherent tool to identify, analyse, evaluate and identify management options for cumulative effects.
CICES	Common International Classification of Ecosystem Services	A common international classification scheme to identify ecosystem services.
DCS/SNS/CNS	Dutch Continental Shelf/Southern North Sea/Central North Sea	Regions in the North Sea.
EEA	European Environment Agency	Agency of the European Union, whose task is to provide sound, independent information on the environment.
EU	European Union	EU-27 countries[1].
ES	Ecosystem Services	The direct and indirect benefits that humans derive from ecosystems.
GES	Good Environmental Status	The environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive.
GHG	Greenhouse Gas	Any gas that has the property of absorbing infrared radiation (net heat energy) emitted from Earth’s surface and reradiating it back to Earth’s surface, thus contributing to the greenhouse effect.
IA2017	Intermediate Assessment 2017	Assessment of the marine environment in OSPAR region.
ICG-EcoC	Group on Cumulative Effects	Intersessional Correspondence Group Ecosystem Assessment Outlook - Cumulative Effects assessment (OSPAR).
ICG-ESA	Group on Economic and Social Analysis	Intersessional Correspondence Group on Economic and Social Analysis (OSPAR).
MA	Millennium Ecosystem Assessment	Assessment on the consequences of ecosystem change for human well-being to ensure sustainable use of ecosystems.
MAES	Mapping and Assessment of Ecosystems and their Services	Initiative of the European Commission, which aims to improve the knowledge and evidence base for biodiversity policy.
MSFD	Marine Strategy Framework Directive	Legislation in the EU that aims to protect more effectively the marine environment across Europe.
NECPs	National Energy and Climate Plans	To meet the EU’s energy and climate targets for 2030, EU Member States need to establish a 10-year integrated national energy and climate plan (NECP) for the period from 2021 to 2030.

[1] Since 31 January 2020, the United Kingdom is no longer a member of the European Union.

OSPAR	Oslo and Paris Conventions	The mechanism by which 15 Governments & the EU cooperate to protect the marine environment of the North-East Atlantic.
OWF	Offshore Wind Farm(s)	Wind farms in the marine area that generate renewable energy.
PBR	Potential Biological Removal	Level that is defined as the maximum number of animals, not including in natural mortalities that may be removed annually from a marine mammal stock while allowing that stock to reach or maintain its optimal sustainable population level.
QSR	Quality Status Report	Assessment by OSPAR on the quality status of the North-East Atlantic by joint monitoring and assessment.
RSC	Regional Sea Convention	Cooperation structure which aims to protect the marine environment and bring together Member States and neighbouring countries that share marine waters.
TEEB	The Economics of Ecosystems and Biodiversity	Global initiative focused on “making nature’s values visible”.
TEV	Total Economic Value	Tool to identify the economic value of an ecosystem service.
UNFCCC	United Nations Framework Convention on Climate Change	UN framework aiming to stabilize greenhouse gas concentrations.
WTP	Willingness to Pay	Amount a consumer is willing to pay for a good or service.

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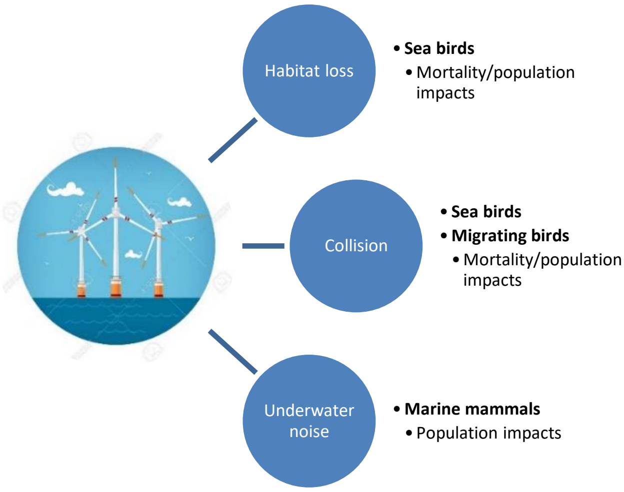
Executive summary

Introduction
The ambitious plans of the EU to combat climate change are taking form in renewable energy policies. They aim to decarbonise the energy system by upscaling the development of offshore windfarms (OWF). On the one hand, this is a positive development, as greenhouse gas emissions are reduced. On the other hand, the substantial increase in OWF may have a deteriorating effect on the marine ecosystem and its capacity to provide ecosystem goods and services that contribute to human well-being. Therefore, upscaling OWF needs to be sustainably managed. OSPAR protects the marine ecosystem in the North-East Atlantic. They carry out socio-economic assessments to capture the importance of persevering a healthy marine environment for human-wellbeing. However, a systematic approach to include ecological effects and the resulting socio-economic effects, is still missing. Therefore, the aim of the report is to explore whether linking the Bow Tie Analysis (BTA) to the concept of Ecosystem Services (ES) is of added value for decision-making within OSPAR activities, based on the case study of upscaling OWF in the North Sea region.

The report starts with describing the case study (chapter 2). Hereafter, the theoretical framework of the BTA is explained and applied to the case study (chapter 3). Then, the concept of ES is further elaborated, as well as the practical application to the case study (chapter 4). The BTA and ES are linked after separate analyses (chapter 5), which leads to valuation methods for the case study specific ES (chapter 6). The report closes with a discussion (chapter 7) and recommendations (chapter 8) for the proposed methodology and finally, the conclusion (chapter 9).

Case study
The EU aims to have a 32% share in renewable energy by 2030 and being energy neutral by 2050. These ambitious goals result in upscaling OWF in the North Sea. The North Sea is an extremely busy area where many activities already take place such as shipping, oil and gas exploration, sand and gravel extraction. The additional planned OWF in the North Sea may pressure the marine ecosystem in such a way that the capacity to provide ES may be disrupted. Already, several negative effects occur:



Additional OWF form a risk for these species and it is assumed that upscaling OWF will lead to declining or even disappearing populations.

Bow Tie Analysis

To assess what the risk of upscaling OWF is, the BTA can be used. This is a risk assessment tool that includes a hazard, a top event, causes, consequences and management measures that aim to reduce impacts of a certain risk. In the report, the risk of upscaling OWF is that populations will decline or disappear. The BTA showed that besides OWF, also other human activities also cause populations to decline. The different elements are summarized in the table below:

	Sea and migrating birds	**Harbour porpoise**
Hazard	Abundance/distribution of sea and migrating birds	Abundance/distribution of harbour porpoises
Top event	Abundance/distribution falls below baseline	
Causes	Habitat loss & collision (OWF)	Noise (OWF, fisheries, oil and gas, military activities, shipping)
	Bycatch (fisheries)	
	Biological disturbance (tourism & climate change)	
	Litter	Pollution (oil and gas)
		Habitat loss (oil and gas)
		Collision (shipping)
		Harmful substances (industry)
		Litter
Consequences	Losses to society	
	Change in fish stocks	
	Ecological regime shift in food web	
Preventative measures (OWF)	Site & time selection	Site selection
	Larger turbines; higher efficiency	Soft-start pile/alternative foundations
	Positioning	Sound systems
	Lighting	
	Deterrent devices	
Mitigation measures	Create new habitat	
	Improve habitat quality	
	Improve food supply	

Ecosystem Services

The losses to society from declining populations as a result of upscaling OWF can be expressed in adverse alterations in ES. The concept of ES shows the contributions of ecosystems to human well-being, allowing to make a connection between ecology and socio-economics. Several ecological functions can be divided in provisioning, regulating and cultural services. The following services are identified for the ecosystem components in the case study:

	Sea and migrating birds	**Harbour porpoise**
Expected to be relevant	Filtration/sequestration, scavenging, pollination and seed dispersal, pest and disease control, bird watching, scientific and educational, heritage/cultural and entertainment.	Maintaining nursery populations and habitats, gene-pool protection, sediment and fixing processes, climate regulation, scientific and educational, heritage/cultural and entertainment.
May be relevant	Maintaining nursery populations and habitats, gene-pool protection, sediment and fixing processes, climate regulation, aesthetic, symbolic, sacred and/or religious, existence and bequest.	Harbour porpoise watching, aesthetic, symbolic, sacred and/or religious, existence and bequest.

Linking BTA to ES

Linking the identified ES to the BTA shows the losses to society caused by placing OWF in terms of an adverse alteration in ES. Besides, also a favourable alteration in ES may occur, as fish stocks may increase. The analysis shows the importance of humans preserving a healthy marine ecosystem, as we depend on the services provided by ecosystems. Ensuring a sustainable marine ecosystem may be enabled by implementing the proposed management measures in the BTA.

Valuation of effects

To determine whether these measures are practicable, valuation of ES can be used to assess whether the costs of the measures are disproportionate to the benefits. These benefits arise from avoiding losing the identified ES. Indicators can be determined for the case study specific ES, which make the services measurable. Different monetary valuation methods can be used to value the ES for which the most appropriate technique needs to be chosen for each specific service.

Discussion and recommendations

The analyses of the BTA, ES and the integration of the methods, resulted in assessing the value added, the limitations and recommendations for these concepts. The table below summarizes the findings based on the application to the case study:

	BTA	**ES**	**BTA&ES**
Value added	Communication tool		Assessing socio-economic effects
	Explore management measures	Completeness	Explore risk scenarios
	Logical and coherent overview		
Limitations	Need for expert knowledge	Complex	Combining environmental, social and economic effects
	Simplification relations	Valuation pitfalls	
Recommendations	Expert group	Develop ES as communication tool	Use tool to develop research agenda: - Research: compensating measures, cumulative effects, future trends, integrated marine ecosystem assessment, ecological functioning. - Monitoring: actual numbers of mortality, behavioural changes, food web.
	Stakeholder participation	Multidisciplinary team	

There are several points for discussion on the case study as well. The table below summarizes the main implications encountered during the analysis of the case study, as well as recommendations for the case study.

	Implications	Recommendations
1)	Assumptions: upscaling OWF forms a high risk. Relative impact of windfarms not assessed.	Reduce ecological impacts: focus on implementing compensating measures.
2)	Uncertainties: uncertain relations in marine environment.	Precautionary measures: focus on precautionary measures.
3)	Effects: difficulty for ES capturing effects of degrading populations.	Enhance opportunities of OWF: focus on advantages involved with OWF.
4)	Analysis: incomplete marine ecosystem assessment.	Quantification: expand qualitative analysis to quantitative analysis.

Conclusion

Overall, integrating the concept of ES with the BTA captures the societal importance of implementing management measures to preserve nature. Since many different processes take place in the marine environment, both natural and anthropogenic processes, the relations are complex. The data requirements may undermine the usefulness of the method when effects are ought to be quantified. However, the qualitative assessment shows the importance of considering natural processes in decision-making. The BTA & ES are able to take the ecological and resulting socio-economic effects into account, stressing the importance of taking measures that can prevent or mitigate against the consequences. Even if OWF combat climate change, the negative effects on the marine environment need to be taken into account. It should be considered that mitigating climate change by placing OWF may result in unforeseen effects on biodiversity and the marine food web. By precautionary implementing measures, the development of upscaling OWF can continue to be positive and contribute to combatting climate change.

1 Introduction

1.1 Background

Currently, the European Union (EU) is developing ambitious plans to protect the Earth and find ways to ensure a healthy environment. A so called 'Green Deal' should lead to Europe being the first climate-neutral continent in the world[2]. One of the plans involve producing clean energy only (Van Slooten, 2019). Increasing the share in renewable energy sources is an important way of mitigating the effects of climate change. Besides reducing the reliance on fossil fuel sources, renewable energy also contributes to energy security, affordable prices, technological innovations and a potential leadership role for the EU (EC, 2018). To reach the targets set by the EU, countries need to make transitions in their energy production technologies. Wind energy is expected to play a big role in this transition, since it gives substantial opportunities in decarbonising the energy system (WindEurope, 2018). Therefore, countries surrounding the North-East Atlantic have plans for substantial upscaling of offshore windfarms (OWF) in the marine area (Matthijsen, Dammers & Elzenga, 2018; OSPAR[3]).

On the one hand, increasing the development of OWF contributes to mitigating climate change. On the other hand, it impacts the marine ecosystem. The Millennium Ecosystem Assessment (MA, 2005) defines an ecosystem as "*a dynamic complex of plant, animal, and microorganism communities and the non-living environment, interacting as a functional unit. Humans are an integral part of ecosystems*" (p. 49). Several studies have been carried out that evaluate the effects of OWF on the ecosystem (Boon et al., 2018; Degraer, Brabant & Rumes, 2013; Vaissière et al., 2014). Negative effects may occur, on for instance fish populations, the seabed, as well as on primary production and phytoplankton.

It is important to consider the negative effects, since humans make use of the goods and services that are provided by ecosystems, such as food and climate regulation. The concept of ecosystem services (ES) describes the flow of goods and services that are the constituents of human well-being (TEEB, 2010). The substantial scale-up of OWF may disrupt the ecosystem and its capacity to provide ES. Deterioration of the marine environment can lead to costs for society, as several economic sectors benefit from ES. In order to inform decision-making about human activities in the marine area, an ecosystem approach can be taken.

The ecosystem approach integrates environmental, social and economic aspects. According to the EC (2008), an ecosystem approach can be defined as "*management of human activities, ensuring that the collective pressure of such activities is kept within levels compatible with the achievement of good environmental status and that the capacity of marine ecosystems to respond to human-induced changes is not compromised, while enabling the sustainable use of marine goods and services by present and future generations*" (p. 24).

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[2] Mission letter Ursula von der Leyen to Frans Timmermans. *Executive Vice-President-designate for the European Green Deal.*

[3] https://www.ospar.org/work-areas/eiha/offshore-renewables

1.1.1 *Ecosystem approach in marine management*

An ecosystem approach can be used to inform decision-making about European seas (EEA, 2015). The European Environment Agency (EEA) has developed a framework (see figure 1) that illustrates how the approach is applied in marine management. Assessing the marine environment requires understanding of the marine ecosystem and its components. The link from the ecosystem to the socio-economic system is made by the concept of ES. The translation from the marine ecosystem to ES allows for integrating natural components in decision-making by valuing goods and services of nature that might not be represented in the market and by market prices (Ahtiainen & Öhman, 2013). Several (economic) sectors demand these goods and services, but the pressures of human activities impact the ecosystem condition. Applying ecosystem-based management can allow for finding optimal levels of preserving ecosystems and still profiting from them.

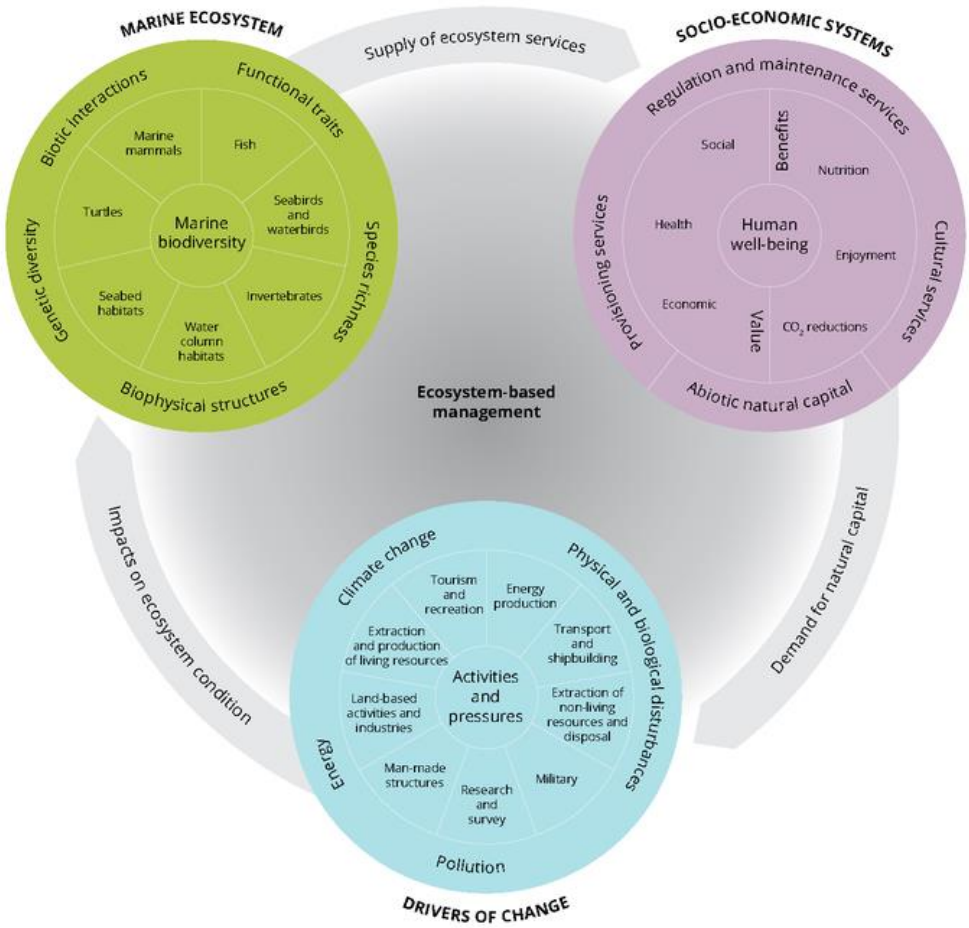

Figure 1: Applying ecosystem-based management in assessing the marine environment (EEA, 2015).

1.1.2 *MSFD and GES*

The European Marine Strategy Framework Directive (MSFD) that aims to protect the sea within European waters integrates the ecosystem approach. Each Member State is obliged to develop a marine strategy in order to reach Good Environmental Status (GES) by 2020. GES is defined by the European Commission (EC, 2008) as "*The environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive*" (p.25). Based on eleven descriptors, it can be qualitatively assessed whether GES is achieved (see box 1).

Box 1: : Eleven MSFD descriptors of achieving Good Environmental Status (EC, 2010).

Good Environmental Status is achieved when:

1. Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climate conditions.
2. Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystem.
3. Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock.
4. All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity
5. Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algal blooms and oxygen deficiency in bottom waters.
6. Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected.
7. Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems.
8. Concentrations of contaminants are at levels not giving rise to pollution effects.
9. Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards.
10. Properties and quantities of marine litter do not cause harm to the coastal and marine environment.
11. Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.

Several criteria and indicators are designed for the descriptors that allow Member States to report on the status of the marine waters. Indicators can measure or give an indication of the status of a descriptor, making it possible to set specific targets. According to Vrooman et al. (2019), GES is not expected to be achieved for most descriptors in the North Sea by 2020. Upscaling OWF puts additional pressures for achieving GES in the North Sea, stressing the importance of sustainable marine management.

1.1.3 OSPAR

The MSFD requires that neighbouring Member States cooperate if they share the same marine region. This cooperation is enabled by four cooperation structures, the Regional Sea Conventions (RSC). In an RSC, countries work together to develop a marine strategy. Under the MSFD, marine regions and sub-regions are developed (see figure 2) that are mainly within the boundaries of RSC. OSPAR, the Convention for the Protection of the Marine Environment of the North-East Atlantic, is the RSC that aims to protect the marine environment of the North-East Atlantic. This international cooperation of 16 Contracting Parties[4] in Europe monitors, assesses and reports the status of the ocean.

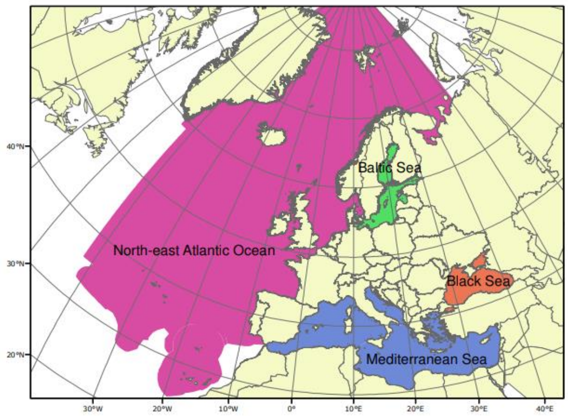

Figure 2: Marine regions under the MSFD (EEA, 2017).

Their marine strategy, the North-East Atlantic Environment Strategy, integrates the ecosystem approach in their objectives, meaning that human activities need to be managed in such a way that sustainable use of ecosystem goods and services is achieved (EC, 2019c; EC, 2019d). OSPAR assesses the marine environment by reporting the state of the waters in OSPAR region. In 2017, a report called the Intermediate Assessment (IA2017[5]) was published that aims to provide clear and up-to-date information to support decision-making. As a part of the IA2017, OSPAR carried out social and economic analyses that link human well-being to sustainable use of the marine environment. Socio-economic assessments of the marine environment support decision-making and inform policy.

One of the methodologies that can be used in socio-economic analyses is the concept of ES. The concept integrates environmental, social and economic aspects that can be taken into account in decision-making. According to the EEA, very few countries in the EU have used the concept of ES in socio-economic analyses (EEA, 2015). Thereby, the Bow Tie Analysis (BTA) can be used to assess cumulative effects in the marine environment. Combining the BTA with ES may be able to provide an understanding of ecological and economical effects. This methodology may be useful in various cases within OSPAR. Therefore, this report will use a case study to test whether the application of the BTA in combination with the concept of ES is useful to support decision-making of human activities in the marine environment.

[4] Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom, together with the European Union.

[5] https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/

1.2 Aim

The aim of this report is to determine whether the concept of ES and the BTA are useful to support discussions and decision-making in OSPAR activities. The concept of ES is assumed to contribute to understand the link between the state of the marine environment and human well-being. A relevant case study allows to evaluate whether the analysis of ES in combination with the BTA is of added value for the decision-making process. In this report, the expected increase in OWF in the wider North Sea area is used as a case study.

To evaluate whether the concept of ES and the BTA are useful to support decision-making within OSPAR, the following steps are taken:

1. Description of the case study (Chapter 2);
2. Incorporation of pressures and effects in Bow Tie Analysis (BTA) (Chapter 3);
3. Application of the concept of ES (Chapter 4);
4. Linking ES to the BTA (Chapter 5);
5. Valuation methods for the identified ES (Chapter 6);
6. Discussion about the usefulness of the BTA linked to ES decision-making (Chapter 7);
7. Recommendations for the application of the BTA linked to ES (Chapter 8);
8. Conclusion on the usefulness of the BTA linked to ES in decision-making (Chapter 9).

1.3 Methodology

To assess whether the application of the BTA linked to ES is useful to support decision-making, the report is developed step-by-step:

1. Description of the case study:

The case study is described in the context of current climate change mitigation strategies and the renewable energy policies that are developed by the European Commission. The study area of the case is determined to illustrate the size of OWF development and the geographical area. Additionally, studies that have researched the cumulative effects of OWF in the North Sea are briefly examined (Heinis, de Jong, von Benda-Beckmann & Binnerts, 2019; Van der Wal, Van Puijenbroek & Leopold, 2018).

2. Incorporation of pressures and effects in Bow Tie Analysis (BTA):

The BTA is applied to incorporate the causes and consequences due to upscaling OWF and possible other human activities. The BTA is used to provide an overview of the impacts of upscaling OWF. The tool can be helpful to find management options for cumulative effects (Judd, Wood & Lonsdale, 2017). For every ecosystem component that is deemed to be relevant for the case study, a BTA will be developed.

3. Application of the concept of ES:

A marine ES classification scheme is identified. The EEA (2015) has developed a specific marine ES classification scheme for the European marine environment, building on the CICES classification and other relevant literature (such as Böhnke-Henrichs et al., 2013; Maes et al., 2014). The scheme is critically evaluated by several criteria to assess whether the scheme is appropriate for the specific case study. Eventually, the scheme is used as starting point to identify ES for the case study.

4. Linking ES to the BTA:

The ES are integrated in the BTA for every ecosystem component that is deemed to be relevant for the case study. The BTA that are developed previously are used as a basis to link the identified ES to.

5. Valuation methods for the identified ES:

Valuation techniques for the identified ES are assessed. First of all, indicators are analysed, as well as economic and monetary valuation techniques. Several techniques that can be used for the relevant ES in the case study are proposed.

6. Discussion about the usefulness of the BTA linked to ES in decision-making:

Key discussion points are given based on the outcomes of the previously developed steps. It is discussed and evaluated whether the concept of ES and the BTA are useful to support discussions and decision-making in OSPAR activities. First, the methods of ES and BTA are discussed, whereby their added value and limitations are evaluated. Secondly, the outcomes of the case study are further evaluated.

7. Recommendations for the application of the BTA linked to ES in decision-making:

Key recommendations are given based on the outcomes of the previously developed steps. First, recommendations are given for the method used in the report. Thereby, several recommendations are given for future research and monitoring based on the case study. Eventually, recommendations are given for the case study.

8. Conclusion on the usefulness of the BTA linked to ES in decision-making:

Key conclusions are given based on the outcomes of the previously developed steps. It is determined whether the concept of ES and the BTA are useful to support discussions and decision-making in OSPAR activities.

2 Setting the scene

A recently published report of the United Nations (UNEP, 2019) shows that greenhouse gas (GHG) emissions are still rising and countries have difficulties to cut emissions. An international shift to sustainable systems is required. Globally, the total GHG emissions exist for its majority of CO_2 emissions that are related to energy use and industry (UNEP, 2019). In Europe, nearly 80% of the GHG emissions are energy related. As a result, the energy sector is undergoing a transition since large reductions can be achieved here (European Parliament, 2018). The EU wants to increase their share of renewable energy by upscaling the development of OWF. The North Sea in particular can play a big role in limiting GHG emissions and achieving sustainable energy supply (Matthijsen, Dammers & Elzenga, 2018). In this chapter, the energy transition is first described in a policy context. After this, the geographical location of the study area is set. Lastly, the focus of the case study is determined, based on the cumulative effects of OWF on specific ecosystem components.

2.1 Policy context

The Paris Agreement has been adopted in December 2015 and aims, according to the United Nations Framework Convention on Climate Change (UNFCCC) for: "*Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels*" (2015). Climate Action Tracker independently investigates whether the plans of governments are in line with the Paris Agreement and concludes that current measures and policies in the EU are not sufficient to reach the goals (Climate Action Tracker, 2019).

In 2009, a renewable energy directive has been designed (2009/28/EC), that aims to increase the share of renewable energy in the EU to 20% by 2020[6]. The dependence on fossil fuel sources should be reduced in this way (EU, 2009). To reach this target, Member States are required to develop national plans. In June 2018, the EU developed new ambitions for 2030 and 2050 (Directive (EU) 2018/2001). The EU has set a binding target to increase the share of renewable energy to 32% by 2030 (EC, 2018), aimed at reducing GHG emissions from the energy sector, contributing to the goals of the Paris Agreement. Additionally, Europe wants to have a leading position in the renewable energy transition (EC, 2018).

The directive is part of the 'Clean energy for all Europeans package', which requires countries to set 10-year National Energy & Climate Plans (NECPs) for 2021 to 2030. NECPs are aimed at achieving the energy union strategy, designed to provide consumers secure, sustainable, competitive and affordable energy (EC, 2019a). Progress reports to national targets need to be published, that allow for monitoring every two years. In June 2019, the EC has published their draft plans for implementation of the energy union strategy and 2030 goals. The plans are not yet ambitious enough to reach the climate and energy goals. However, the EU will provide recommendations for the draft plans that will show where more effort is needed to reach the goals. The leading role of Europe in the energy transition is carried on in the long-term vision of the EU. The vision aims to be energy neutral by 2050 (EC, 2019b).

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[6] According to Eurostat (last update: 07-02-2020), the share of energy from renewable sources in the EU-27 countries was almost 19% in 2018 (18,89%).

2.2 Study area

Over the past years, the number of onshore and offshore wind installations has increased significantly in order to decarbonise the energy sector (see figure 3). In 2017, both onshore and offshore installations have reached a record. The role of wind energy has become more profound over the past decade, since it has large potential to produce clean energy (Matthijsen et al., 2018). Wind energy is expected to contribute the most to reaching the renewable energy goals that are set by the EU. Only a small fraction of all wind energy is currently produced by offshore installations. Offshore wind installations have several advantages compared to onshore installations, since they are stable and abundant resources. OWF also have higher public acceptance (EC, n.d.).

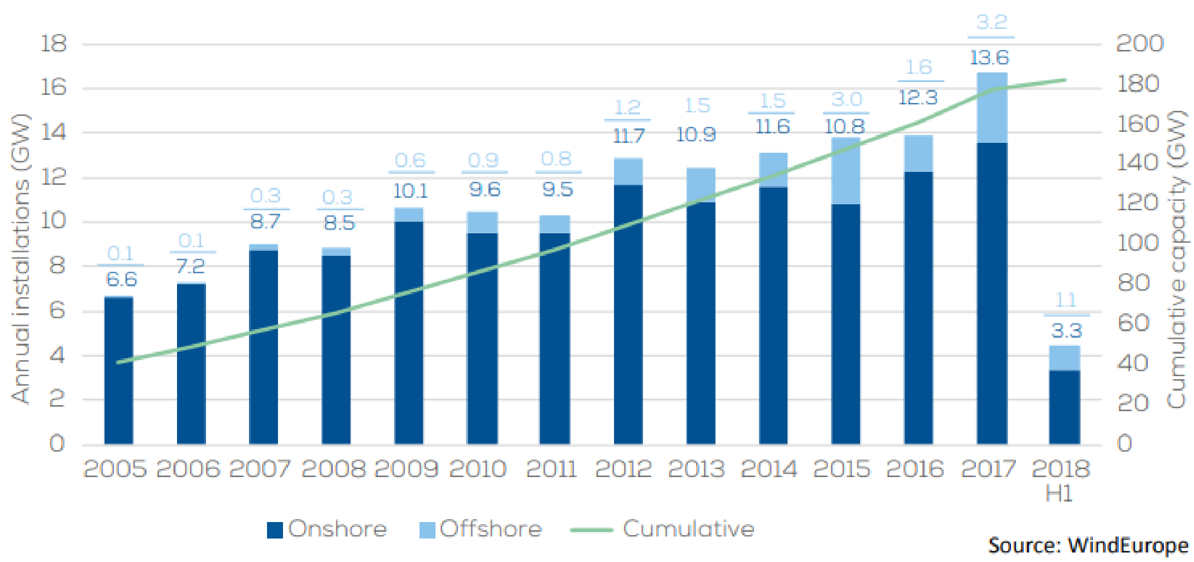


Figure 3: Wind energy gross annual and cumulative installations in Europe (WindEurope, 2018).

WindEurope (2018) expects that new records will be marked in 2019. Besides climate change mitigation, competition from the USA, China, Korea and Japan who are expanding their offshore installations, plays a role as well. Europe wants to retain the leadership status in the offshore wind industry (EC, n.d.). The UK, the Netherlands, Germany, Denmark, Belgium and France are expected to undergo the biggest increase in offshore wind installations in Europe. These countries (excluding France) are surrounding the North Sea[7], which is relatively shallow and therefore suitable for OWF. The North Sea region can play a big role in limiting climate change. Besides, the energy can be used directly in areas where the demand is high (such as the harbour of Rotterdam). Offshore wind is expected to cover 19% of all new wind energy installations in Europe (WindEurope, 2018).

[7] Countries bordering the North Sea: Belgium, Denmark, Germany, The Netherlands, Norway, Sweden, and the United Kingdom.

According to WindEurope (2019), 98% of the installed offshore cumulative capacity generated in Europe belongs to five countries. The UK (44%), Germany (34%), Denmark (7%), Belgium (6.4%) and the Netherlands (6%) generate most of the offshore installations within Europe. Spain, Finland, France, Sweden, Norway and Ireland have installations as well, but only account for 2% of the installed capacity. In figure 4, the share of offshore turbines are illustrated, both in percentages and MW of generated electricity. Thereby, the North Sea has the largest offshore capacity installed compared to the other sea basins in Europe. The North Sea accounts for 70% (12,938 MW) of the capacity, while the Irish Sea generates 16% (2,928 MW), the Baltic Sea 12% (2,218 MW) and the Atlantic Ocean 2% (413 MW) (WindEurope, 2019).

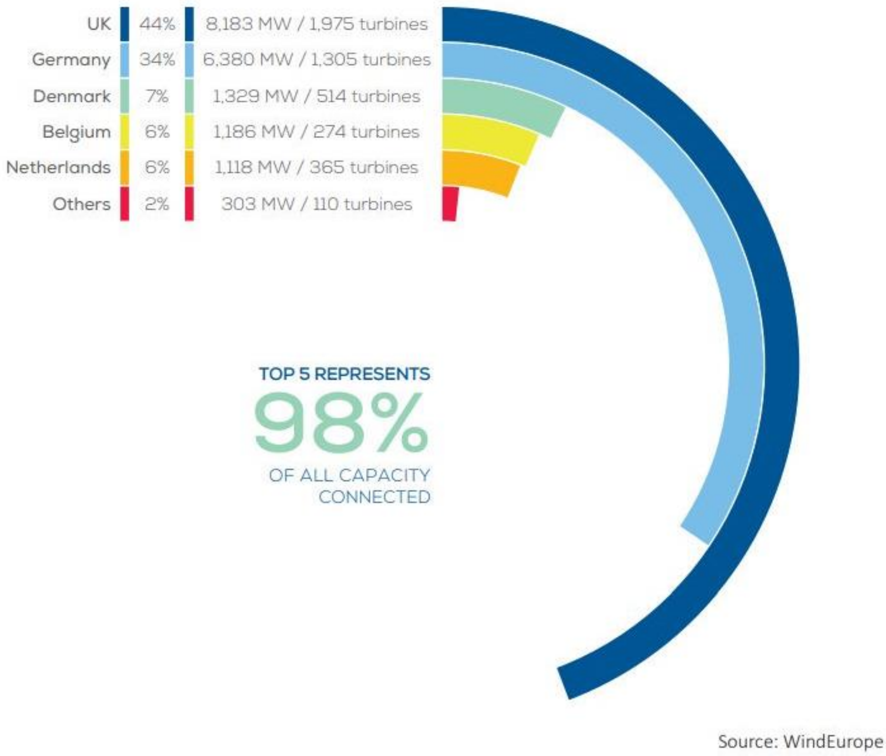


Figure 4: Cumulative offshore installed capacity (MW) and number of turbines per country (WindEurope, 2019).

Offshore wind parks in Europe are growing as a result of two effects. First of all, the number of turbines that are installed increases. Secondly, the wind turbines themselves are growing in size as well. Figure 5 shows the revolution of wind turbines that have grown in size continuously, leading to ever increasing energy yields. WindEurope (2018) expects that installed turbines between 2018 and 2022 are going to be even larger and more powerful. These turbines are expected to surpass the 9MW threshold, already 10MW turbines have been introduced. The energy efficiency of wind turbines increases when they grow in size, which results in lower costs. As seen in figure 5, the growth in wind turbines means larger rotor blades, thus a larger turning circle. Besides, while the efficiency of the turbines increases, the minimal distance between individual turbines increases as well, meaning less turbines per surface.

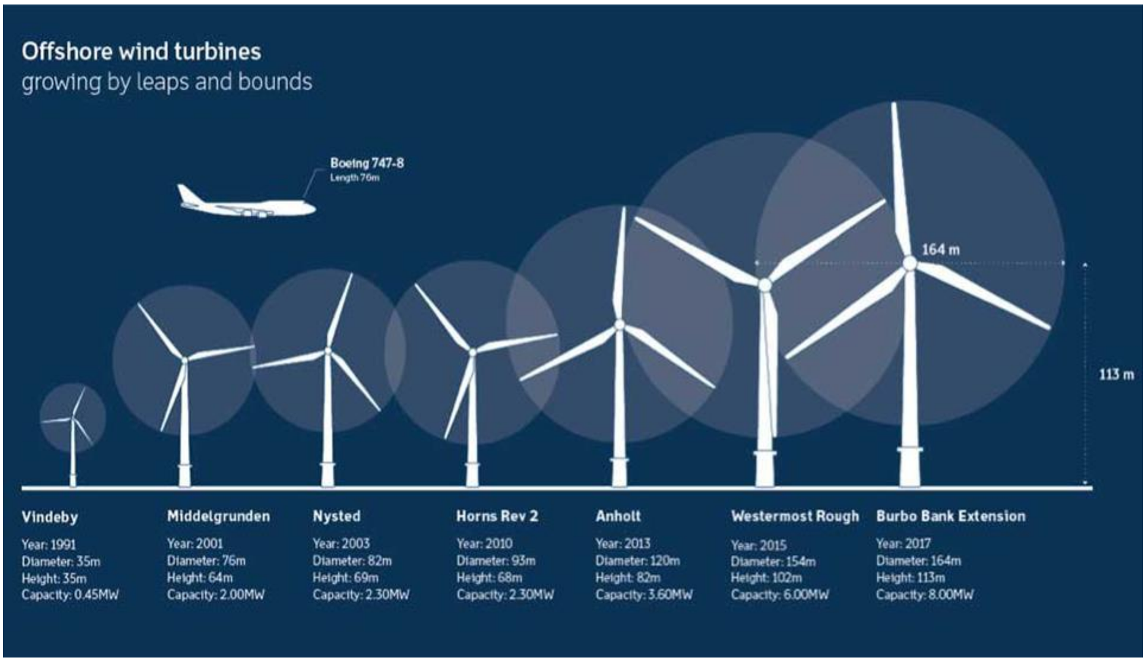


Figure 5: Offshore wind turbines, growing by leaps and bounds (Open Ocean, 2017).

The development of offshore renewables in the North-East Atlantic is recorded by OSPAR in their renewable energy database[8]. In this database, information is available that keeps track of the capacity of offshore installations from OSPAR Contracting Parties. Currently, the database contains information about Belgium, Germany, Spain, France, The Netherlands, Sweden and the UK. Information is available about operational, proposed and planned wind farms in the OSPAR marine area. From the database (2018) and WindEurope (2019) it is clear that the North-East Atlantic is mainly occupied by proposed and planned wind farms in the North Sea region.

The North Sea region is a busy marine area, containing many shipping routes, offshore oil and gas installations as well as sand and gravel extraction locations. The countries bordering the North Sea have to cooperate, since they share the marine area (Kafas et al., 2017). Figure 6 shows the area in the North Sea that will be occupied by OWF in 2050, based on estimations of the European Commission on installed capacity that is needed by 2050 (between 230 and 450 GW). The figure shows the area occupied by offshore wind only, thus other activities are not included. The figure illustrates the substantial scale of OWF in the North Sea, which is a part of the OSPAR region (Poland for instance is not part of OSPAR). Therefore, the study area of this case study is limited to the North Sea region.

[8] https://www.ospar.org/work-areas/eiha/offshore-renewables

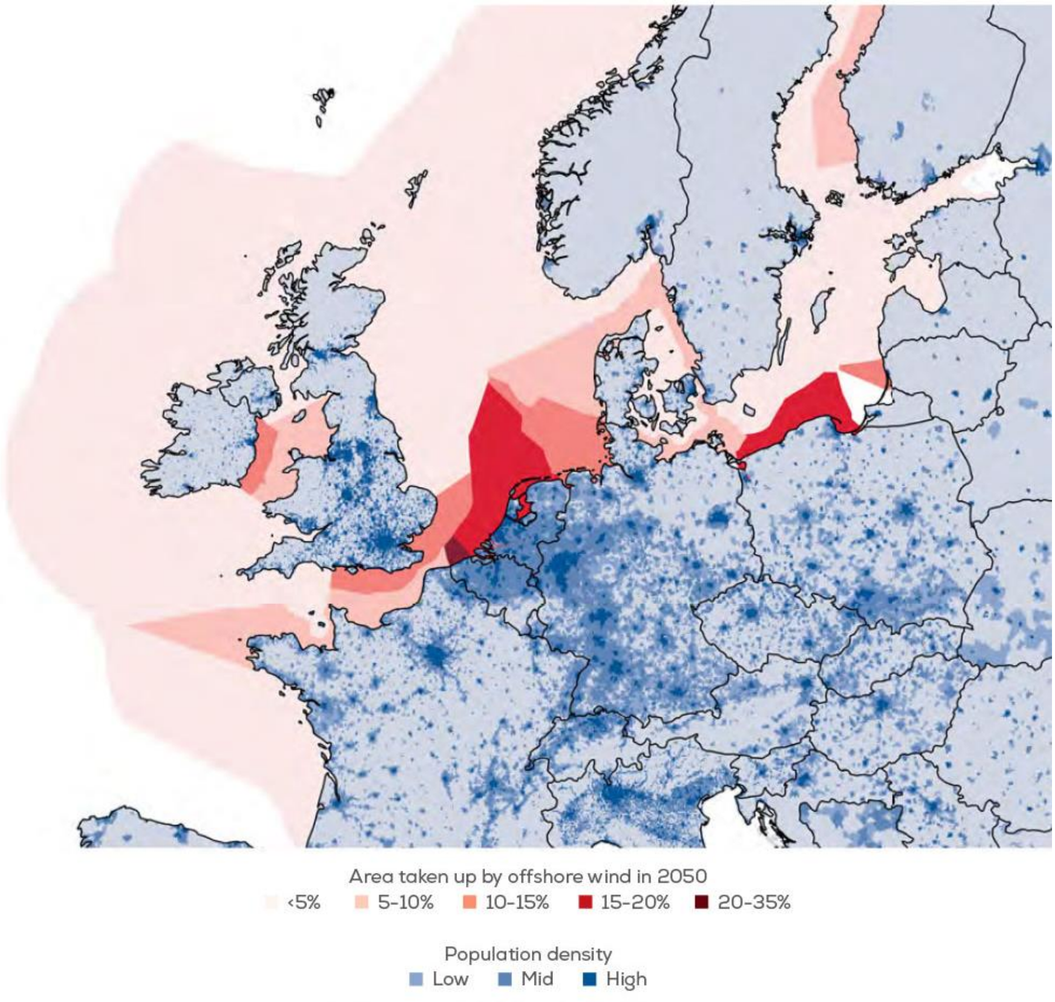


Figure 6: Area taken up by offshore wind in 2050 (WindEurope, 2019).

2.3 Impacts on the marine ecosystem

The placement of OWF in such a busy area as the North Sea brings risks and opportunities for the marine environment (see figure 7). Ecological impacts that occur underwater are for instance increased turbidity, increased sediment erosion and harmful impulsive noise during the construction of OWF. These effects impact species such as seabirds, marine mammals and fish, that live in the North Sea region. Operational wind turbines are a major concern for birds that collide with rotating blades. On the other hand, fish populations may be positively impacted, since fishery activities cannot take place in windfarm areas. An opportunity also arises for developing oyster reefs, which has already occurred at several North Sea OWF locations (Boon et al., 2018; Degraer, et al., 2013; Vaissière et al., 2014; Vrooman et al., 2019).

The study focusses on risks that OWF form for seabirds and marine mammals. These species are a part of the marine biological system in the North Sea, that are impacted by OWF. The existence of these populations is at risk, since they might be significantly negatively impacted by the substantial scale-up of OWF. In the MSFD, seabirds and marine mammals are included in the descriptor 'Biodiversity is maintained'. In the case of marine birds, it can be concluded that 1/3 of the populations are declining, 1/3 are stable and 1/3 are growing. The common seal for instance, has gotten the 'unfavourable' conservation status in the North East Atlantic (EEA, 2015). It is of great importance to look into these cases now, while measures can still be taken.

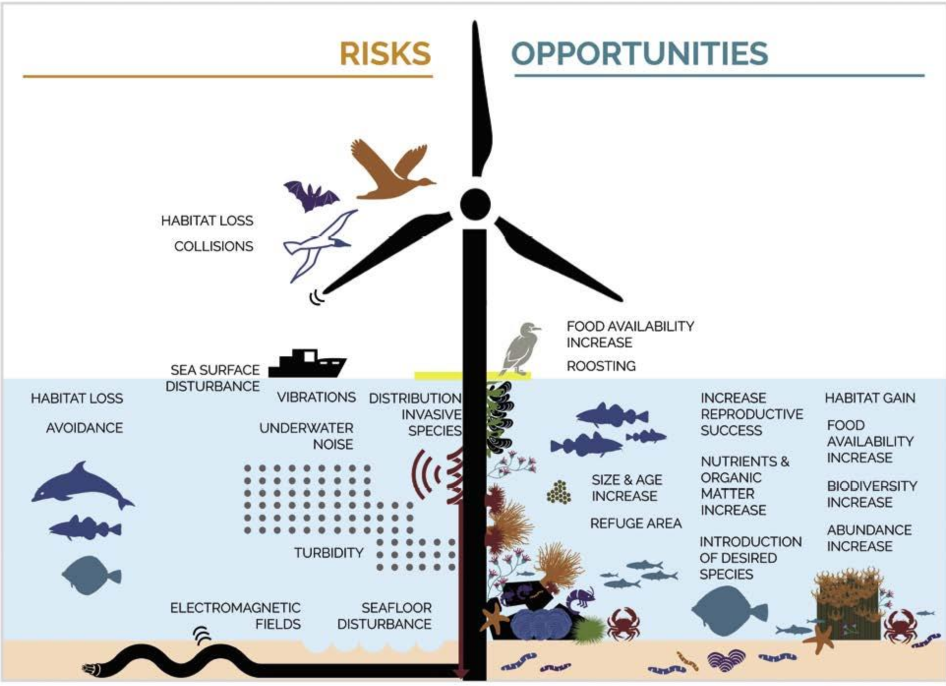


Figure 7: Risks and opportunities involved with OWF in the North Sea (Vrooman et al., 2019).

2.3.1 *Sea and migrating birds*

Sea and migrating birds are impacted by OWF in two ways: habitat loss and collision.

Habitat loss
One of the risks that occurs as a result of the increasing development of OWF is habitat loss. Habitat loss implies driving out species for which the North Sea is their habitat. Van der Wal, van Puijenbroek & Leopold (2018) have researched habitat loss of seabirds in the Dutch Continental Shelf (DCS) and in the Southern & Central North Sea (SNS & CNS) according to current plans of upscaling OWF. The study deals with cumulative effects of OWF, where all existing and planned wind farms are taken into account. Besides this, the impacts of shipping routes are considered as well (Leopold et al., 2014). Figure 8 shows the study area of Van der Wal et al. (2018), which includes the study area of the case study. Seabirds may avoid the areas where OWF are placed since they do not recognize this area as their natural habitat anymore. Deviating from their original route may result in a reduction of fitness and eventually death. Therefore, the scale-up of OWF may affect seabird populations and lead to population reductions (Van der Wal et al., 2018).

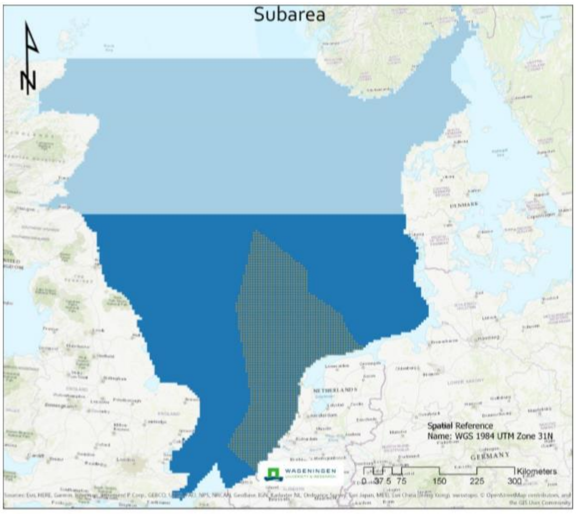


Figure 8: Study area including the Dutch Continental Shelf (orange), the Southern North Sea (dark-blue) and the Central North Sea (light-blue) (Van der Wal et al., 2018).

In the study of Van der Wal et al. (2018), five species of seabirds were identified as potential risk group of habitat loss. These birds are Divers (Red-throated- and Black-throated Diver), Northern Gannet, Sandwich Tern, Common Guillemot and Razorbill (see figure 9). The study estimated the mortality of these birds, also known as Displacement Mortality, based on the density of the population. The number of victims depends on several factors, such as population density and placement of OWF. Displacement Mortality occurs especially among the Common Guillemot and Razorbill. Upscaling OWF impacts the flying routes of birds, since more wind turbines will be placed and rotor blades are expected to increase. Based on the above results, it is assumed that upscaling OWF will result in higher mortality rates among seabirds as a result of habitat loss.

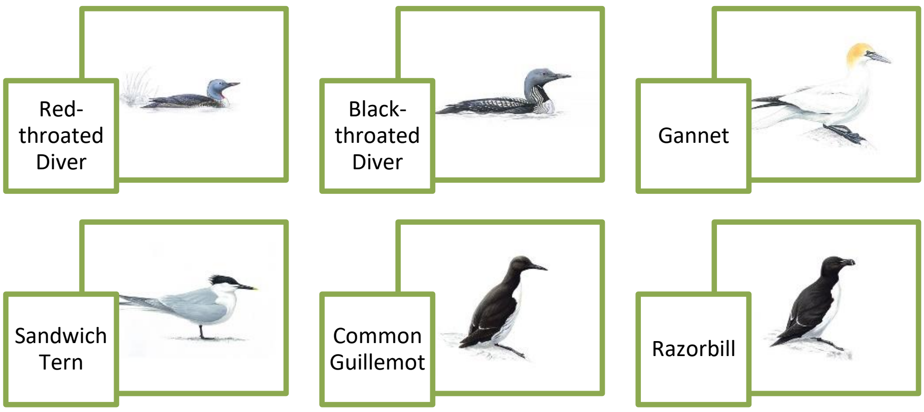


Figure 9: Seabird species that suffer from habitat loss (Adapted from the Royal Society for the Protection of Birds, 2019).

It is assumed that upscaling offshore windfarms in the North Sea will negatively affect populations of seabirds, since the substantial increase in the number and the size of wind turbines will lead to higher mortality rates due to habitat loss.

Collision

Besides habitat loss, another effect of OWF on seabirds is collision with rotating blades of wind turbines. Gyimesi, de Jong, Potiek & Rebolledo (2018) researched colliding species. The research is based on population density maps as well. In their study, the recent development plans for the North Sea are taken into account, as well as the increased size of the wind turbines. The study tests the impacts of OWF development against the Potential Biological Rate (PBR) to investigate whether the population losses are within limits in order to ensure sustainable population levels.

The victims amongst seabirds are Great Black-backed Gull, Lesser Black-backed Gull, Herring Gull, Black-legged Kittiwake, Great Skua, Northern Gannet (see figure 10). Besides seabirds that use the North Sea as their natural habitat, another kind of birds collides with the rotating blades as well. These birds are migrating species, such as the Tundra Swan, Brent Goose, Common Shelduck, Eurasian Curlew and Black Tern (see figure 11) that include the North Sea in their flying route. Collision of these birds with the rotor blades may result in mortality of sea and migrating birds, on top of the effects of habitat loss. Both seabirds and migrating species seem to collide with rotating blades, which may eventually lead to unacceptable population losses. Based on the results of the studies mentioned above, it is assumed that upscaling OWF results in higher collision rates with rotating blades, thus increased sea and migrating birds mortality due to collisions.

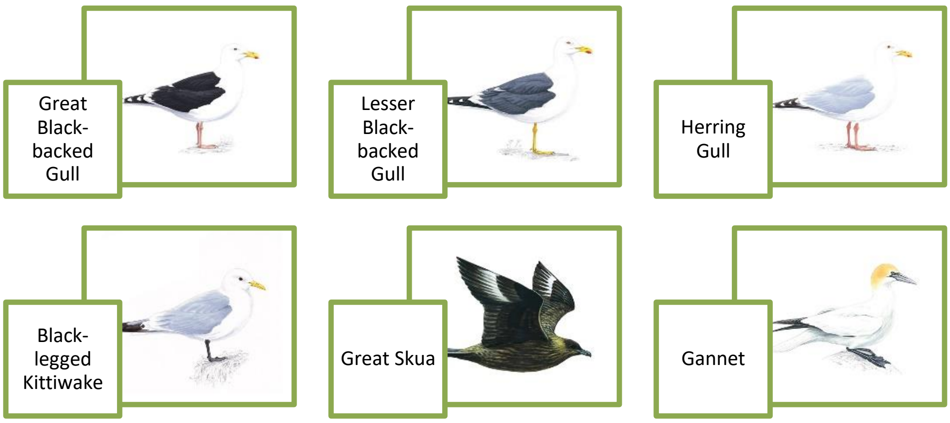


Figure 10: Seabird species that suffer from collision (Adapted from the Royal Society for the Protection of Birds, 2019).

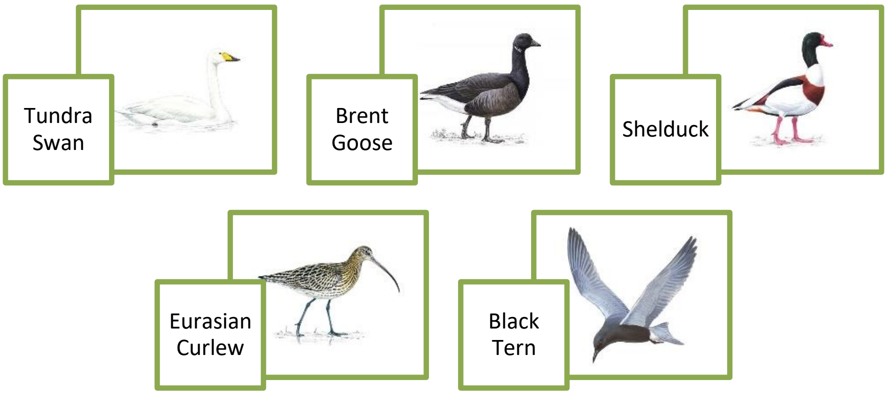


Figure 11: Migrating species that suffer from collision (Adapted from the Royal Society for the Protection of Birds, 2019).

It is assumed that upscaling offshore windfarms in the North Sea will negatively affect populations of sea and migrating birds, since the substantial increase in the number and size of wind turbines will lead to higher mortality rates due to collision.

2.3.2 Marine mammals

Underwater noise

Upscaling OWF does not only result in effects during the operation phase, but also during construction activities. Pile-driving for the foundation, as well as seismic data acquisition causes harmful impulsive underwater noise for several marine mammals. Continuous (ambient) noise is mainly caused by fisheries and shipping activities[9]. However, the production of continuous noise during the operational phase of wind turbines also influences the fitness of marine mammals (Vroomen et al., 2019). Heinis, de Jong, von Benda-Beckmann & Binnerts (2019) studied the possible effects of impulsive underwater noise on marine mammals, such as the harbour porpoise, grey seal and the common seal. Among marine mammals, harbour porpoises mainly uses the North Sea area as their natural habitat. Therefore, it is expected that this specie will be impacted the most. In the case study, the harbour porpoise will be included in further assessments (see figure 12).

[9] https://www.ospar.org/work-areas/eiha/noise

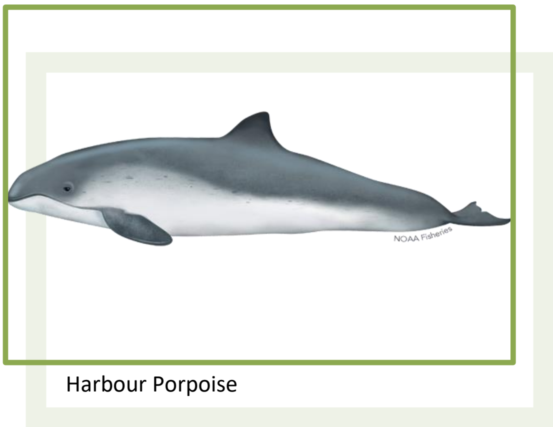


Figure 12: Marine mammal that suffers from underwater noise (adapted from NOAA Fisheries, 2019).

On the basis of the population density and the disrupted area, the number of disrupted animals can be calculated. Eventually, a calculation on the number of harbour porpoise disruption days can be made. Impulsive underwater noise impacts the marine mammals mainly during the construction phase by pile-driving, since the area cannot function as rest- and feeding ground anymore. This may impact the fitness of the animals and eventually the chance of survival and reproduction (Heinis et al., 2019). It is assumed that upscaling OWF leads to an increased number of disruption days and impacts the survival and reproduction of the harbour porpoise negatively. These effects are assumed to impact the population of the harbour porpoises negatively and may result in surpassing sustainable limits.

It is assumed that upscaling offshore windfarms in the North Sea will negatively affect the population of harbour porpoise, since the substantial increase in the number and size of wind turbines will lead to higher mortality rates due to impulsive underwater noise.

2.3.3 *Role in the marine food web*

Seabirds and harbour porpoises also play an important role in the marine food web. Every specie depends in a way on another specie for their survival, shown via prey-predator relations in food chains. Figure 13 illustrates a simplified food web, in which the dependence on the species is shown. Interactions in the food web are considered to be one of the main regulators of ecosystem dynamics. The importance of the functioning of food webs can be seen in the descriptors that are defined in the MSFD (descriptor 4). It may be difficult to classify and value the role of seabirds and harbour porpoises in the food web. However, it should be taken into account that upscaling of OWF may alter the population and thus the role in the food web. Even a small change in a population may lead to altering the food web and result in re-organisation, also called an ecological regime shift (EEA, 2015).

The effects that may occur due to upscaling OWF are assumed to influence the population densities of sea and migrating birds and harbour porpoises. As seen in the food web below, seabirds and harbour porpoises feed on fish. The survival of these species is dependent on fish stocks. It seems that there are concerns about the impact of seabirds on depleting fish stocks locally. This is also the case for marine mammals, since they can significantly affect fish populations (Bowen, 1997; Smith et al., 2011). If populations of seabirds and marine mammals decrease, fish stocks may change as a result.

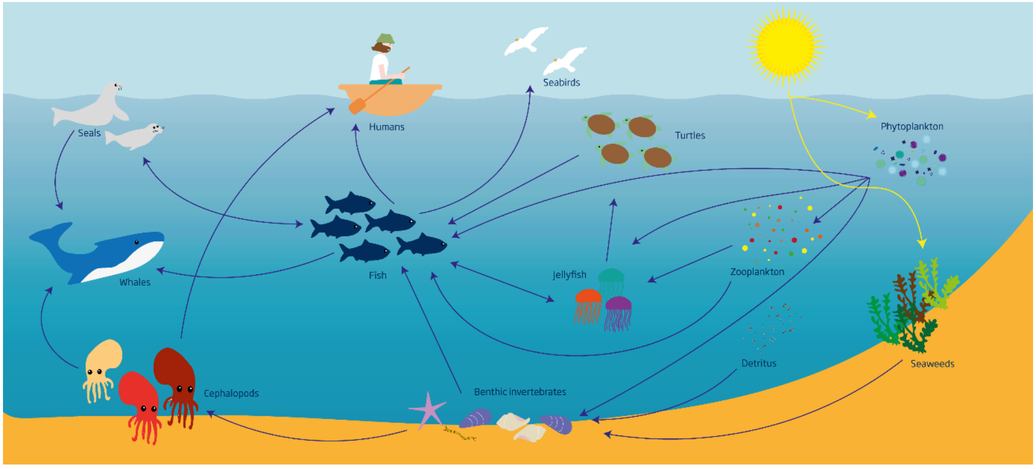


Figure 13: Simplified food web (WISE, 2019).

In addition, fishing activities are prohibited in wind farm areas (Degraer, 2013). This has another effect on seabirds and harbour porpoises as well, since they can be a victim of bycatch from fishing activities (Scheidat, Couperus & Siemensma, 2018). The harbour porpoise is especially vulnerable to harmful human activities, since they have a low birth rate amongst other things. Seabirds can also be accidently entangled in fishing gear, leading to injury and/or mortality (ICES, 2016). This means that upscaling OWF will not only lead to the prohibition of fishing activities in the areas of OWF, but also to a reduction in injuries and/or mortality among seabirds and marine mammals from bycatch.

2.4 Summarizing remarks

The EU wants to combat climate change by increasing the share of sustainable energy in the total energy mix. The countries bordering the North Sea are therefore planning and working on increasing OWF. Besides the number of turbines that are expected to increase, the turbines also grow in size to reach maximum energy yield. Recent studies show that OWF can form risks for several marine ecosystem components: seabirds suffer from habitat loss and collision with rotating blades; migrating birds suffer from collision; harbour porpoises are negatively impacted by impulsive underwater noise. It is assumed that upscaling of OWF will lead to a continuation of the above mentioned effects. This means that more OWF will result in declining or even disappearing population of sea and migrating birds and harbour porpoises. Figure 14 summarizes the effects on the different species. The next chapter will look into the consequences of the environmental effects, as well as the importance of OWF relative to other human activities.

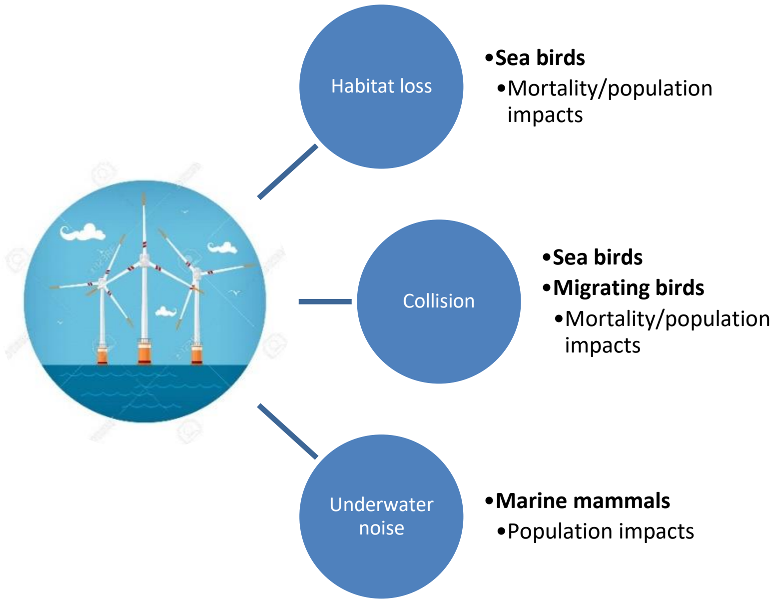


Figure 14: The effects of upscaling OWF in the North Sea region on birds and marine mammals.

3 Bow Tie Analysis

To visualise the effects and manage risks that are associated with substantial upscaling OWF, risk assessments can be used. According to the International Council for the Exploration of the Sea (ICES, 2014), "*Risk analysis is used to characterize the likelihood and magnitude of the ecosystem and socio-economic impacts, with additional consideration to existing regulations and policies used to manage the risks along the pathways of the causes and their effects*" (p.3). The Bow Tie Analysis (BTA) is a risk-assessment technique that is used in OSPAR QSR assessments to link the causes and consequences of pressures that may impact the marine ecosystem[10]. With this method, it can be reviewed what the risks are of upscaling OWF and evaluate which management measures can be implemented to reduce the impacts (ICES, 2014). In this chapter, the causes and consequences of human pressures on sea and migrating birds and harbour porpoises are analysed by using the BTA. First, the theoretical framework is explained. Afterwards, the BTA is applied to the case.

3.1 Theoretical framework

The BTA (figure 15) allows for a clear representation of causes and consequences that certain pressures may have on the marine ecosystem. According to Judd, Wood & Lonsdale (2017) it provides a "*logical and coherent tool to identify, analyse, evaluate and identify management options for cumulative effects*" (p.2). As shown in figure 15, the BTA got its name for being in the shape of a bow tie. Several elements need to be included to structure the BTA (see box 2). In the BTA, it should be clear what causes result in an undesired event, and what the consequences are of this event. Several management measures can be taken in order to prevent the event from happening or form a barrier for the consequences. On the left-hand side, the causes are shown, whereas the consequences are illustrated on the right-hand side. In the middle, the top event 'ties' the threats and the consequences together, which is the undesired event.

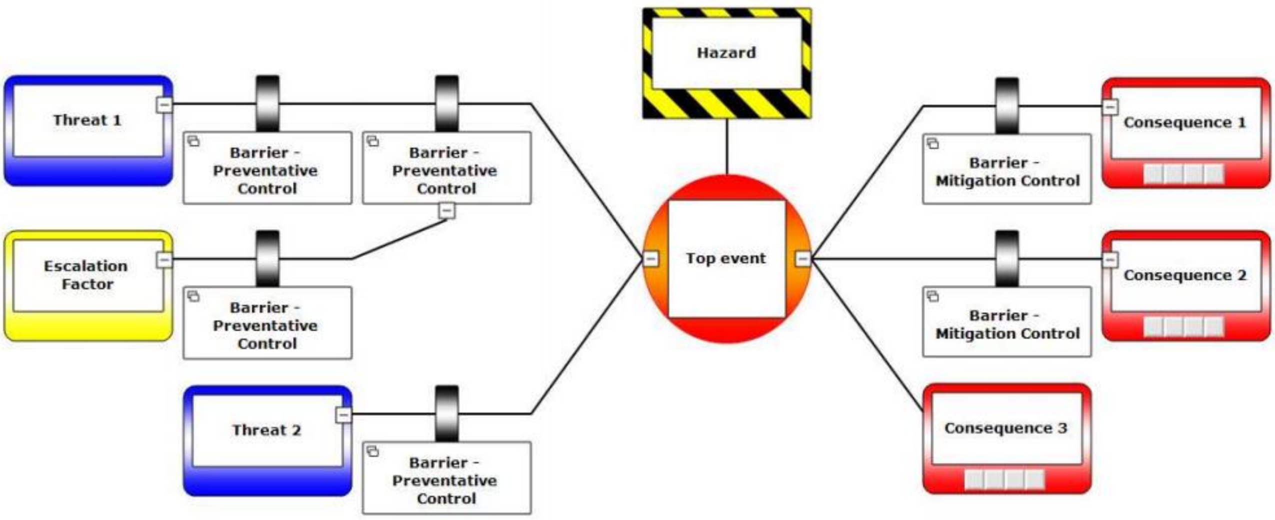


Figure 15: Bow Tie Analysis conceptual approach (Judd, Wood & Lonsdale, 2017).

[10]https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/chapter-6-ecosystem-assessment-outlook-developing-approach-cumul/

Box 2: Elements to structure a Bow Tie Analysis.[11]

1) **Hazard**: a state or activity of something which does not necessarily have to be something negative;
2) **Top event**: the undesired event, which happens when the control is lost over the hazard;
3) **Threats**: the possible causes that lead to the top event;
4) **Consequences**: the unwanted outcomes of the top event;
5) **Barrier**: controls/management measures that can be put into place that either prevent the top event to happen (Preventative control) or mitigate against the consequences (Mitigation control).
6) **Escalation Factor**: something that reduces the effectiveness of a measure.

The OSPAR Intersessional Correspondence Group Ecosystem Assessment Outlook – Cumulative Effects Assessment (ICG-EcoC) uses the BTA in their risk-based approach to determine the likelihood of pressures from human activities that may affect the achievement of GES (Judd & Wood, 2019).

The assessment is based on the following guiding question for the work of ICG-EcoC: "*In enabling the sustainable use of marine goods and services, what is the likelihood that the collective pressures from human activities will cause change capable of affecting the achievement of quality status (good environmental status) and how should these changes be managed?*" (Judd & Wood, 2019).

Judd & Wood (2019) propose a six-step process to be applied and presented in graphics:

1) **Identification of collective pressures:** Identify pressures from human activities that have the potential to collectively affect achievement of GES.
2) **Identification of effects:** Identify consequences of not achieving GES.
3) **Risk screening**: A 'risk' has been defined by the OSPAR Cetaceans Expert Group as (Judd & Wood, 2019): "*the likelihood of negative population effects resulting from the pressures of human activities, mediated through effects on individual mortality, health and/or reproduction*" (p. 9). Risk screening should identify the likelihood of human activities causing change capable of affecting GES, varying from low, high to medium.
4) **Management measures:** Measures to high-risk activities that should prevent unwanted change or mitigate the effects.
5) **Apply systems thinking:** Systems thinking is described in Judd & Wood (2019) as follows: "*Systems thinking enables a holistic way of conceptualising a problem. It moves us away from managing issues in isolation to consideration of the connectedness between issues to understand their collective impacts on the system as a whole. By taking a systems approach, we can identify trade-offs and synergies between such areas to design better solutions for the system*" (p. 12). By applying systems thinking, the complex relations between pressures and state are assessed (left hand-side of the BTA). Thus, the main causes, consequences and management measures of the pressures are developed in separate BTA to understand the holistic system. In this way, realistic and practical management measures can be developed (Judd & Wood, 2019).

[11] http://www.patientsafetybowties.com/knowledge-base/6-the-bowtie-method

6) **Analysis of collective pressures on quality status of cetacean abundance and distribution:** Consideration of data availability to determine how to analyse the relationships of cause-effect pathways.

In the following sections, these steps will be applied and described for the current case study of upscaling OWF.

3.2 Bow Tie Analysis – case study

It is expected that upscaling OWF will alter populations of sea and migrating birds and harbour porpoises negatively. However, there are other human activities that influence these populations as well. Together, these activities are expected to form a risk for society. The BTA should allow to link ecological effects with economic consequences in order to explore reasonable and practicable measures. Management measures are proposed that can be taken to reduce the risk of declining populations. The BTA identifies these elements in a coherent and logical matter. As there are two specific ecosystem components in the case study, there are two separate BTA. Before the BTA can be structured, the elements that need to be included in the analysis are listed in annex 1 & 2. The aim of the BTA is:

"To give an overview of the impacts of upscaling OWF in the North Sea relative to other human activities which altogether negatively influences populations of sea and migrating birds and harbour porpoises, causing change in benefits humans derive and how these changes can be managed."

The step process for the case study is adapted from Judd & Wood (2019) to be relevant for the case study. The following steps are included:

1) **Identify risk scenario**: The scenario for which the risk will lead to undesired outcomes.
2) **Identify collective pressures:** Identify pressures from human activities that have the potential to collectively impact populations.
3) **Risk screening:** Identify the likelihood of human activities negatively impacting populations.
4) **Identify effects**: Identify consequences of declining populations.
5) **Management measures:** Measures for high-risk pressures that should prevent unwanted change or mitigate the effects.
6) **Effectiveness measures screening:** Identify the effectiveness of measures, screening the effectiveness of the measure reducing the risk.

3.2.1 Sea and migrating birds

Step 1: Identify risk scenario

In the case study, there is a risk associated with upscaling OWF: decline in populations of sea and migrating birds. Therefore, the top event in the BTA is: "*abundance/distribution falls below baseline*", whereas the hazard is: "*abundance/distribution of sea and migrating birds".*

Step 2: Identify pressures

It should be assessed which human activities put pressure on the populations of sea and migrating birds to get an impression of the collective pressures from human activities. Recalling the effects that upscaling OWF has on sea and migrating birds, there can be assumed that due to collision and habitat loss the population of birds is negatively influenced. Besides upscaling OWF, bycatch from fishery activities, biological disturbance from tourism and climate change and litter negatively influences populations of sea and migrating birds. These collective human activities may cause the abundance/distribution of sea and migrating birds to fall below baseline. In this study, the effects of OWF will be further analysed. Figure 16 shows the drivers and pressures in the blue boxes that have an effect on the state, thus on the abundance/distribution of sea and migrating birds.

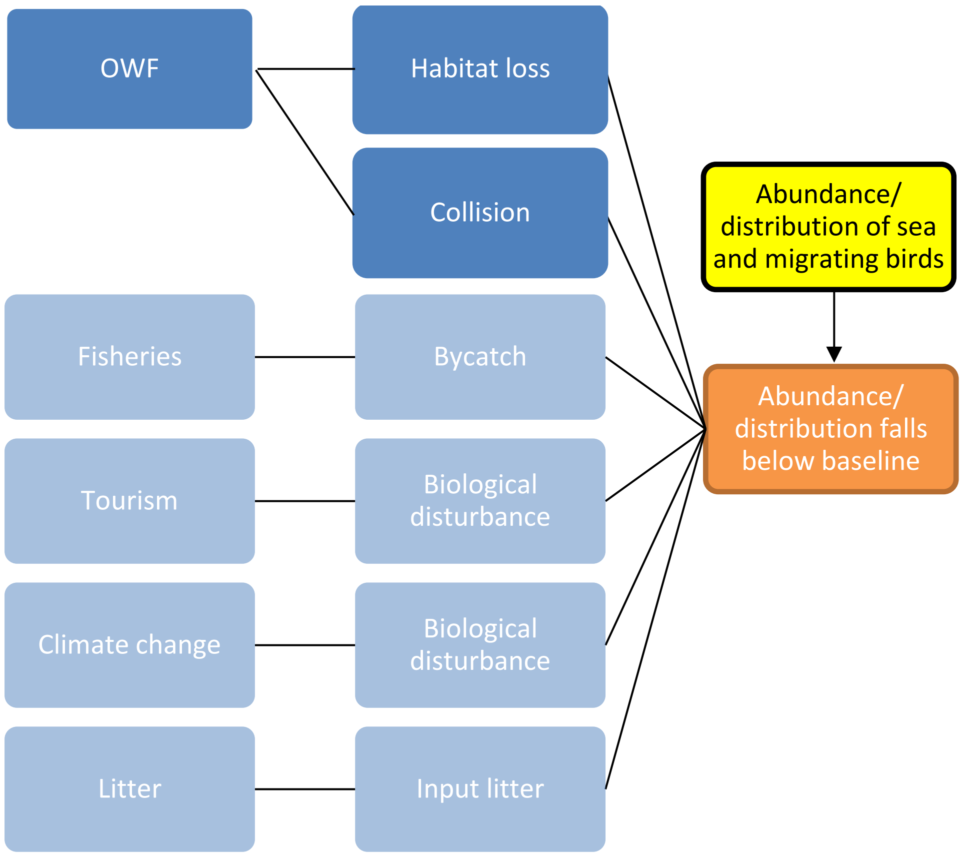


Figure 16: Pressures of human activities on the abundance/distribution of sea and migrating birds. Habitat loss and collision are identified as high-risk scenarios.

Step 3: Risk screening

In the previous steps, pressures from human activities have been identified. However, it is not clear what the likelihood of human activities causing change capable of impacting populations of sea and migrating birds is. The impact of every human activity relative to each other needs to be screened. This can range from low, medium to high. In the case study, it is assumed that the risks of OWF are high. Besides OWF, other pressures may have a substantial influence on populations as well. Risk screening is commonly executed by an expert group. Since this case study is analysing the risks of OWF, risk screening of other human activities has not been conducted. To give an impression of pressures that may be of high risk for seabirds, the EEA (2015) has identified the following main MSFD pressures for seabirds:

- Biological disturbance
- Physical loss
- Contamination by hazardous substances

Step 4: Identify effects

The consequences of the abundance/distribution of sea and migrating birds that falls below baseline needs to be assessed. The consequences are threefold. First of all, it is expected that population impacts will lead to losses to the society. Secondly, a decline in birds may change fish stocks, as birds feed on fish for survival. Finally, an ecological regime shift in the food web may take place. The human activities result in environmental, social and economic effects. Figure 17 shows the consequences resulting from the pressures from human activities when the abundance and distribution of sea and migrating birds falls below baseline. The lines with connecting red boxes illustrate the impact and response of the drivers and pressures that change the state.

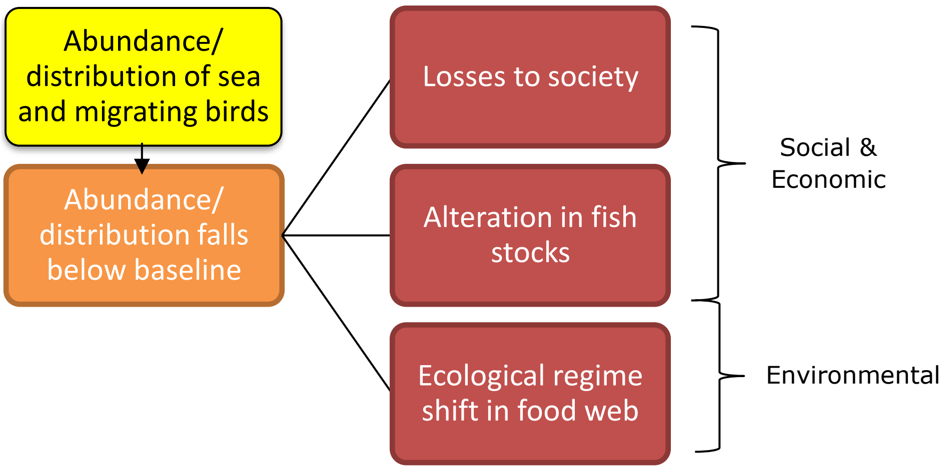


Figure 17: Consequences resulting from the pressures from human activities when the abundance and distribution of sea and migrating birds falls below baseline.

Step 5: Management measures

Several measures can be taken to prevent the population of birds from declining as a result of human activities, or mitigate against the environmental, social and economic consequences. Since this case study is analysing the potential consequences of OWF, the management measures are mainly focused on this activity. Other management measures that are included in the table in annex 1 are derived from additional literature and documents of the ICG-EcoC. These measures are mainly for illustration. This is not an exhaustive list. Figure 18 illustrates the management measures that could be implemented prevent the abundance/distribution of sea and migrating birds to fall below baseline.

There are various measures to prevent collision and habitat loss. Flying routes and habitats of birds should be taken into account when selecting a site for OWF, as well as nesting locations. When sites are selected that have a low density of birds populations, the effects of collision and habitat loss can be minimized. Turbines that are in an area of flying routes could be removed as well (Snyder & Kaiser, 2009). For collisions specifically, operating times of wind turbines can be adapted to mass bird migration periods. Larger wind turbines have a larger capacity and this will lead to less turbines being necessary to generate the same electricity. The turbines' blades can be positioned in such a way that impacts are minimized.

Additionally, lighting of the blades can be adjusted, as well as increasing the visibility of turbines by the use of UV-coating. Deterrent devices can be used to scare the birds when they are coming near to a wind turbine (Vrooman et al., 2019).

In figure 19, mitigation measures are presented that can mitigate against the consequences of the abundance/distribution of sea and migrating birds to fall below baseline. Populations of sea and migrating birds can be kept above baseline level when new habitat is created somewhere else or the quality of the habitat is improved. In this way, the birds do not have to suffer from reducing fitness and/or mortality when they avoid locations where human activities impact the habitat condition of birds. Increasing the food supply for birds in a specific area can result in more birds concentrating on that place and higher reproduction rates, thus increasing populations. Both the preventive and mitigative measures should result in lower or no impact on sea and migrating birds.

Step 6: Effectiveness of measures

The identified measures should prevent OWF impacting populations or mitigate against the consequences, may populations decline. The proposed measures should be measured in their effectiveness. For every measure, the risk reduction level and costs should be assessed. In this step, the concept of 'As Low As Reasonably Practicable' (ALARP) can be applied. A measure is ALARP, if the costs of the measure are disproportionate to the benefits.

Data requirements to assess ALARP:

1) Cost of measure;
2) Benefits of measure;
3) Risk reduction level.

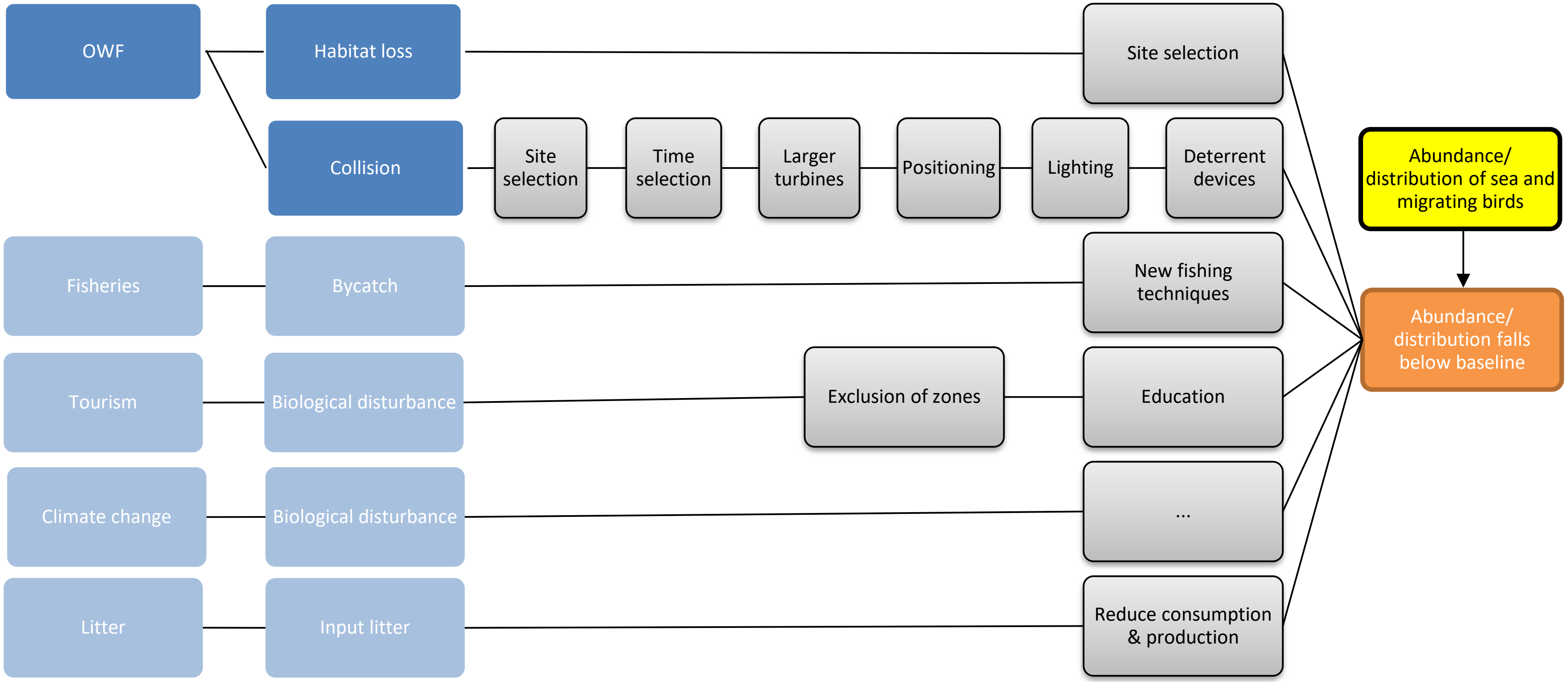


Figure 18: Management measures sea and migrating birds (preventive).

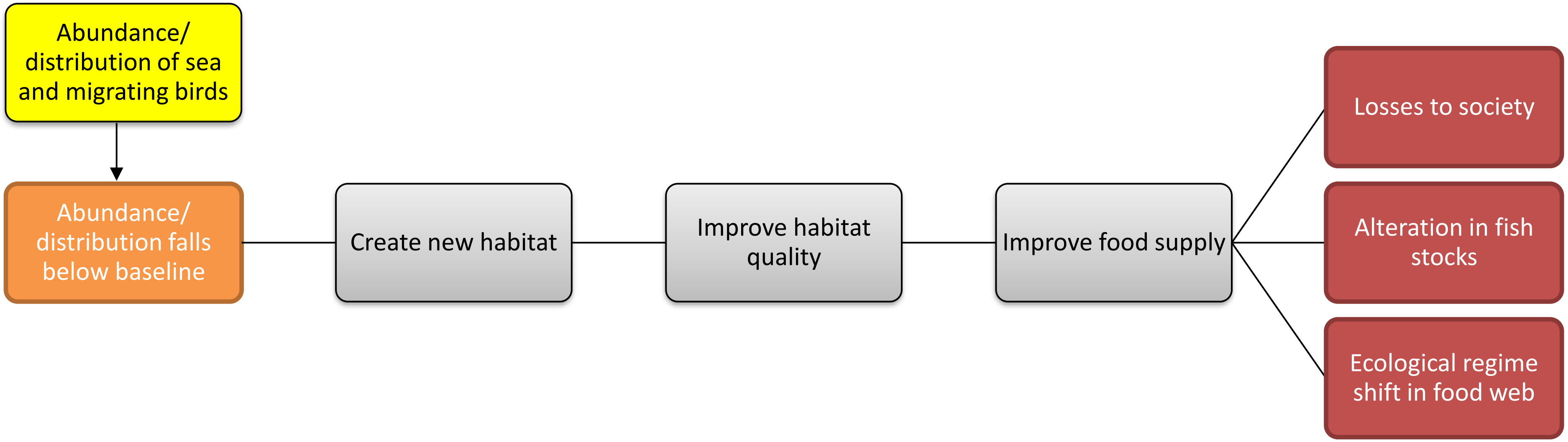


Figure 19: Management measures sea and migrating birds (mitigative).

3.2.2 Harbour porpoise

Step 1: Identify risk scenario

In the case study, there is a risk associated with upscaling OWF: declining populations of harbour porpoises. Therefore, the top event in the BTA is: "*abundance/distribution falls below baseline*", whereas the hazard is: "*abundance/distribution of harbour porpoises".*

Step 2: Identify pressures

It should be assessed which human activities put pressure on the populations of harbour porpoises to get an impression of the collective pressures from human activities. Recalling the effects that upscaling OWF has on harbour porpoises, there can be assumed that due to underwater noise during construction and (continuous) noise during operating OWF, populations of harbour porpoises are negatively influenced. Besides upscaling OWF, fishery activities, oil and gas exploitation, military activities, tourism, shipping, industry, litter and climate change drive pressures that negatively influence populations of harbour porpoise. These collective human activities may cause the abundance/distribution of harbour porpoises to fall below baseline. Figure 20 shows the drivers and pressures in the blue boxes that have an effect on the state, thus on the abundance/distribution of harbour porpoises.

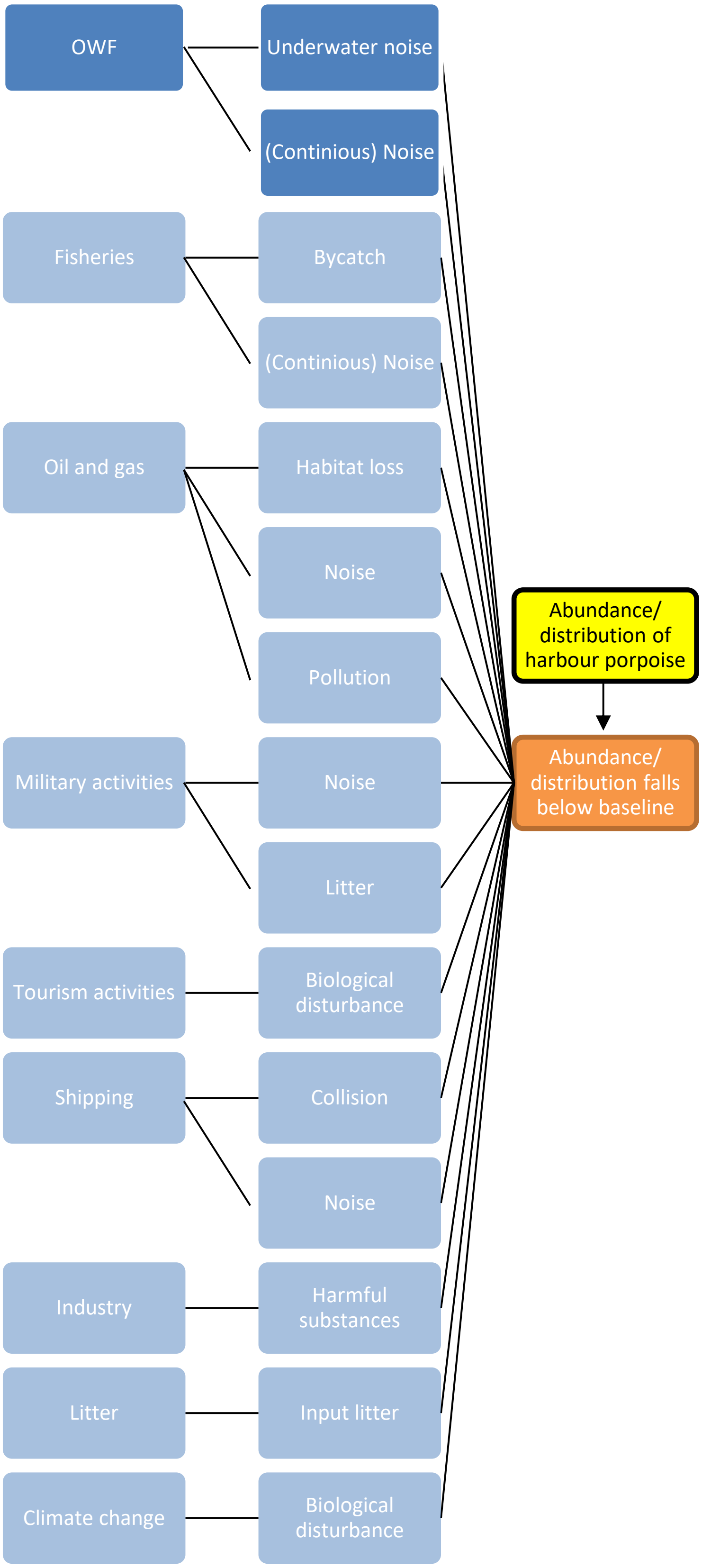


Figure 20: Pressures of human activities on the abundance/distribution of harbour porpoise.

Step 3: Risk screening

In the previous steps, pressures from human activities have been identified. However, it is not clear what the likelihood of human activities causing change capable of impacting populations of harbour porpoises is. The impact of every human activity relative to each other needs to be screened. This can range from low, medium to high. Besides OWF, other pressures may have a substantial influence on populations as well. Risk screening is commonly executed by an expert group. Since this case study is analysing the risks of OWF, risk screening of other human activities has not been conducted. To give an impression of pressures that may be of high risk for marine mammals, the EEA (2015) has identified the following main MSFD pressures for marine mammals:

- Biological disturbance
- Physical disturbance
- Contamination by hazardous substance

Step 4: Identify effects

The consequences of the abundance/distribution of harbour porpoises that falls below baseline needs to be assessed. The consequences are threefold. First of all, it is expected that population impacts will lead to losses to the society. Secondly, a decline in harbour porpoises may positively affect fish stocks, as harbour porpoises feed on fish for survival. Finally, an ecological regime shift in the food web may take place. The human activities result in environmental, social and economic effects. Figure 21 shows the consequences resulting from the pressures from human activities when the abundance and distribution of harbour porpoises falls below baseline. The lines with connecting red boxes illustrate the impact and response of the drivers and pressures that change the state.

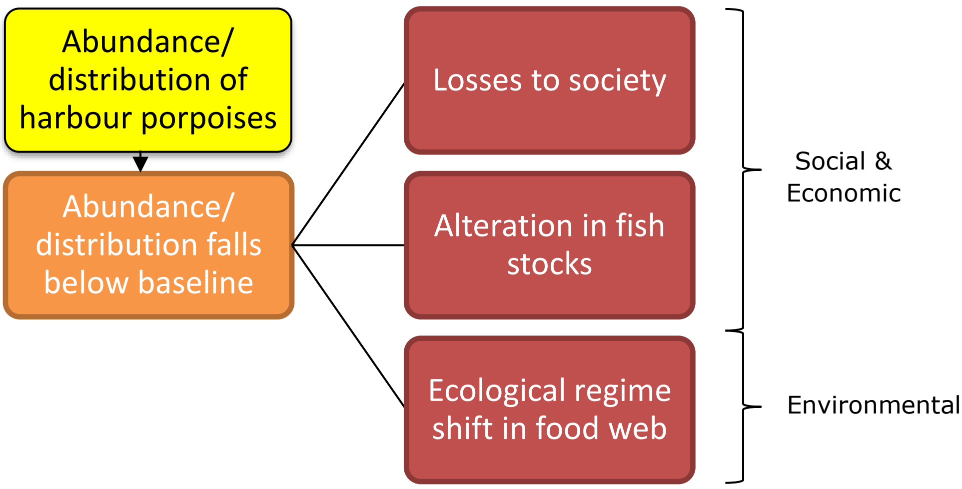


Figure 21: Consequences resulting from the pressures from human activities when the abundance and distribution of harbour porpoises birds falls below baseline.

Step 5: Management measures

Similar to sea and migrating birds, management measures are analysed in more detail around OWF, since the case study focuses on that specific human activity. Other management measures that are included in the table in annex 2 are derived from additional literature and documents of the ICG-EcoC. These measures are mainly for illustration and describe obvious measures. This is not an exhaustive list. Figure 22 illustrates the management measures that could prevent the abundance/distribution of harbour porpoises to fall below baseline.

Underwater noise negatively influences population of the harbour porpoises. A number of measures could be implemented to prevent the impact of underwater noise from OWF. First of all, sites can be selected for the placement of OWF that are not a part of the habitat of harbour porpoises in which case the sound does not influence the specie. Deterrent devices could be used to warn the harbour porpoise that they are approaching OWF. In this way, they can avoid the locations where noise will harm them. Currently, the construction of windfarms also uses a soft-start pile driving construction, where the noise is slowly increased, thus the impact of noise is minimalised. Alternative techniques may also be developed further in the future that produce less noise. Sound abatement systems such as bubble curtains reduce the noise during construction as well (Vrooman et al., 2019).

In figure 23, mitigation measures are presented that can mitigate against the consequences of the abundance/distribution of harbour porpoises to fall below baseline. Populations of harbour porpoises can be kept above baseline level when new habitat is created somewhere else or the quality of the habitat is improved. In this way, the birds do not have to suffer from reducing fitness and/or mortality when they avoid locations where human activities impact the habitat condition of birds. Increasing the food supply for birds in a specific area can result in more harbour porpoises concentrating on that place and higher reproduction rates, thus increasing populations. Both the preventive and mitigative measures should result in lower or no impact on harbour porpoises.

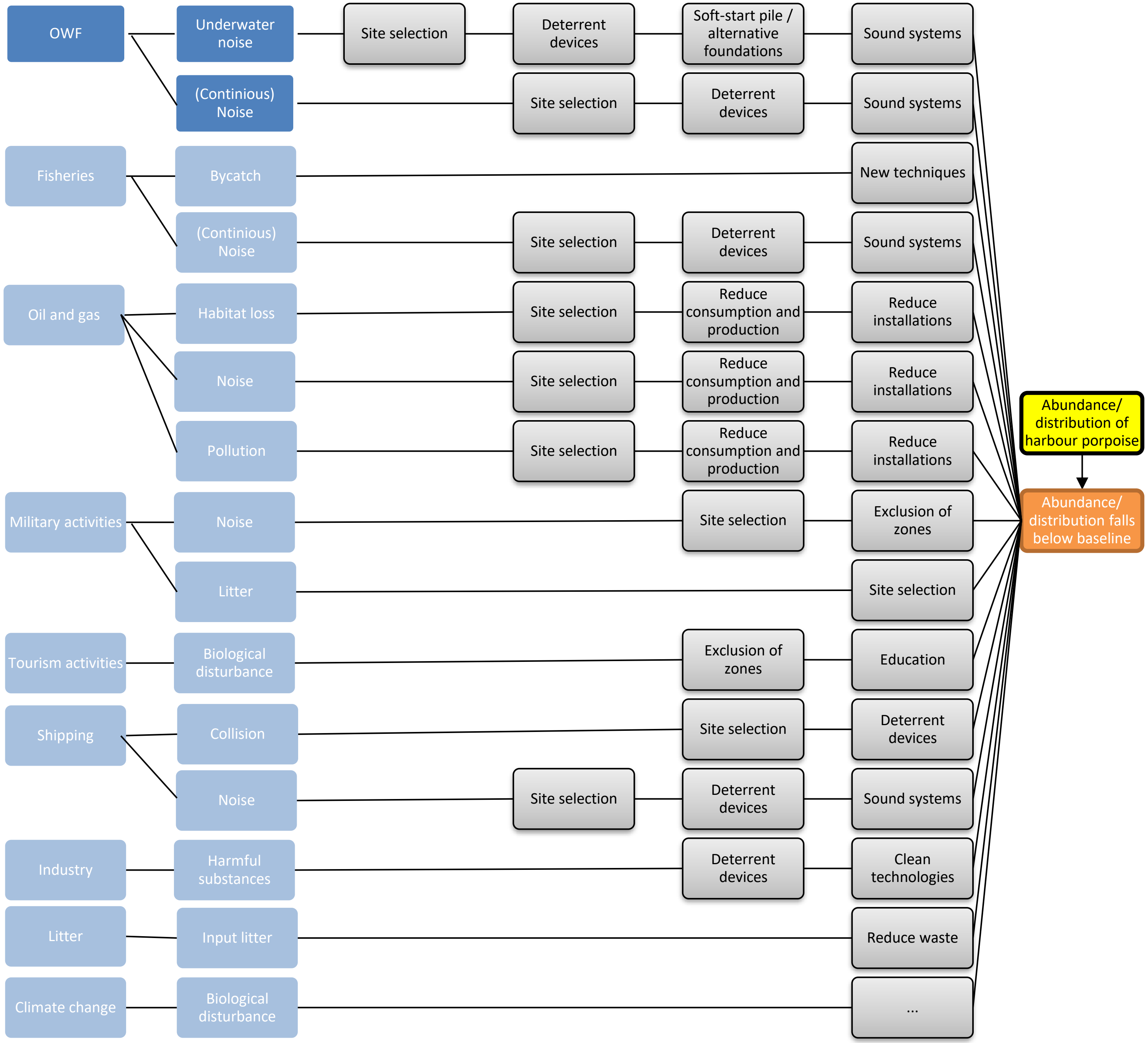


Figure 22: Management measures harbour porpoise (preventive).

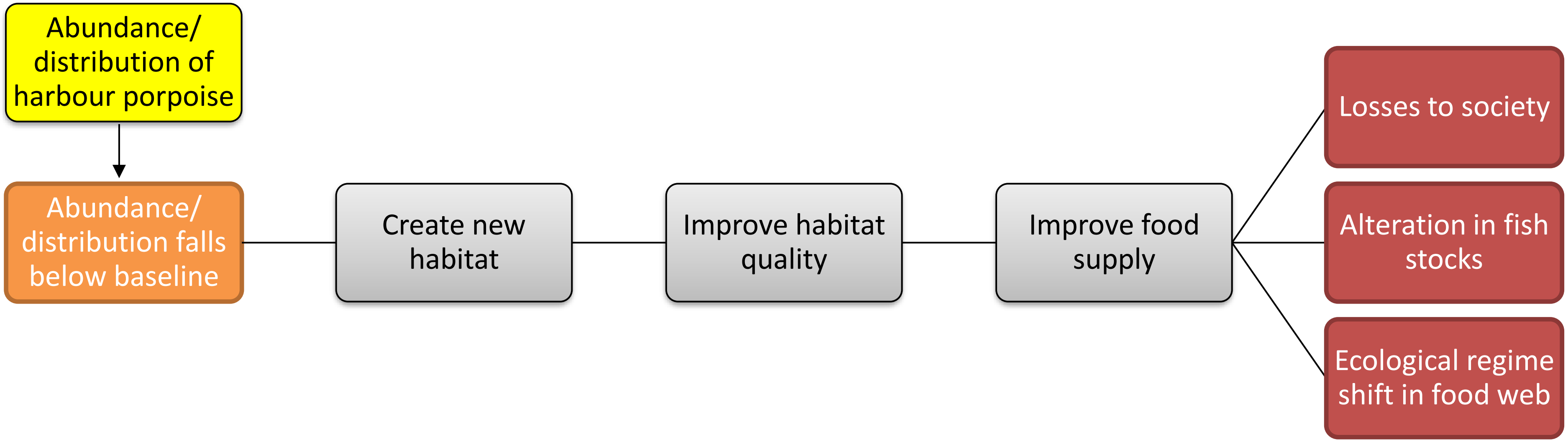


Figure 23: Management measures harbour porpoise (mitigative).

Step 6: Effectiveness of measures

The identified measures should prevent OWF impacting populations or mitigate against the consequences, may populations decline. The proposed measures should be measured in their effectiveness. For every measure, the risk reduction level and costs should be assessed. In this step, the concept of 'As Low As Reasonably Practicable' (ALARP) can be applied. A measure is ALARP, if the costs of the measure are disproportionate to the benefits.

Data requirements to assess ALARP:

4) Cost of measure;
5) Benefits of measure;
6) Risk reduction level.

3.3 Summarizing remarks

The BTA allows to explore the causes and consequences of the risk scenario: upscaling OWF in the North Sea. The BTA shows that besides upscaling OWF, other human activities in the North Sea may have a substantial impact on these populations as well. The identification of effects and consequences allows for the identification of possible relevant and effective management measures that can be either be preventive or mitigative. Since it is assumed that upscaling OWF is a high risk, measures are mainly proposed for the impacts of OWF in order to keep the populations above baseline level. However, if populations decline or even disappear, this is expected to have substantial impact on the society. These losses to society can be analysed by the concept of ES. The next chapter will elaborate on the ES that are provided by sea and migrating birds and harbour porpoises.

4 Ecosystem services

It is expected that upscaling OWF may lead to substantial losses for society, since there is a risk of populations of sea and migrating birds and harbour porpoises to decline or even disappear. The concept of ES can be used to make a translation from the ecosystem to the socio-economic system, in order to show the importance of a healthy environment for human well-being. Thereby, it may support effective management in the marine region. This chapter will first explain the theory behind the concept of ES. After this, an ES classification scheme is determined by critically evaluating available literature. On this basis, the ES that are supplied by sea and migrating birds and harbour porpoises will be identified. A qualitative description will allow for categorization of the different ES based on a scoring system. Eventually, the list of marine ES for the case study is presented.

4.1 Theoretical framework

According to The Economics of Ecosystems and Biodiversity (TEEB, 2010), ES can be seen as *"the direct and indirect contributions of ecosystems to human well-being"* (p.19). Figure 24 shows how ES connects the ecosystem to the economic system. ES is the flow of natural capital that contributes to human well-being (Van den Belt et al., 2017). Humans derive benefits from the ES provided. ES can be used as an instrument to qualitatively and/or quantitatively assess the importance of natural resources. In this way, it provides a tool to integrate natural aspects in decision-making (Braat & De Groot, 2012).

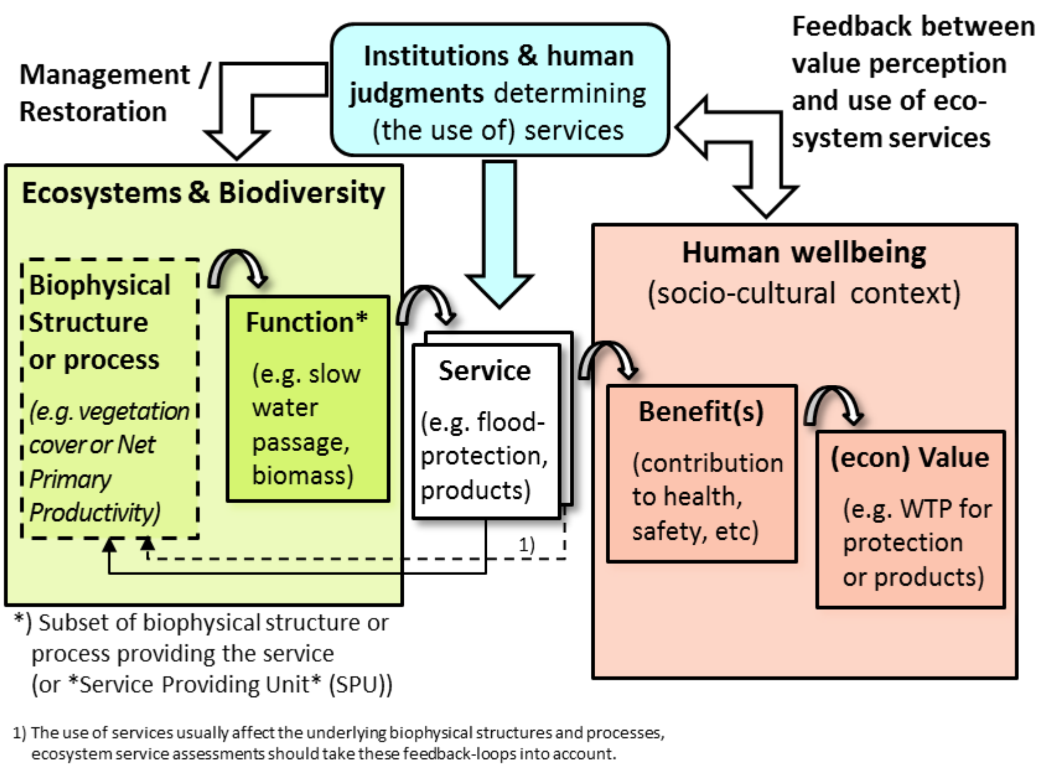


Figure 24: The Economics of Ecosystems and Biodiversity (TEEB) overview diagram (Braat & De Groot, 2012).

The ecosystem provides a variety of services, that can be classified in different categories. ES can be divided into provisioning, maintenance & regulating and cultural services. Provisioning services are tangible outputs derived from ecosystems. Maintenance and regulating services cannot be directly consumed but regulate the system, whereas cultural values can be obtained by interactions with the environment, such as recreational use (EEA, 2015). Applied to the context of this case study, the concept of ES is a method that can be applied to qualitatively and/or quantitatively value the services provided by sea and migrating birds and harbour porpoises.

4.2 Marine Ecosystem Services

In the case study, the increased demand for offshore renewable energy results in an enhanced human activity that impacts the ecosystem condition. The ecosystem components that are affected in this case are sea and migrating birds, as well as harbour porpoises. This report will focus on making a translation from the ecological effects to socio-economic impacts. Marine birds and harbour porpoises provide a variety of ES that can be divided into the above mentioned categories. These ES may change as a result of increased OWF. A marine ES classification scheme can be used to identify ES provided by sea and migrating birds and harbour porpoises.

The concept of ES is use in many different cases, which results in a wide variety of ES classification schemes. Generally, schemes are adapted to be adequate for the specific assessment. The most commonly applied schemes are those developed by the Millennium Ecosystem Assessment (MA), the Common International Classification of Ecosystem Services (CICES), The Economics of Ecosystems and Biodiversity (TEEB) and the Mapping and Assessment of Ecosystems and their Services (MAES). In the EU, CICES is used as a reference (EEA, 2015). MA and TEEB also include a fourth category, namely 'supporting services'. In CICES, this category is assumed to be incorporated in the other categories.

The main reason to use a marine ES classification scheme in the case study, is to provide a methodology to determine relevant ES. These can be further analysed, quantified and (possibly) monetized to support decision-making. A similar method is applied in the study of Norton, Hynes & Boyd (2018), who aim to value Ireland's coastal, marine and estuarine ES. In their study, the CICES classification functions as a basis and they carry out a quantitative analysis on all the ES identified to support decision-making and inform policy making. According to Norton et al. (2018), "*A thorough understanding of ecosystem functioning and how these functions provide benefits is needed in order to determine the change in service flow that might occur following a disturbance to an ecosystem*" (p. 3). A classification scheme allows for understanding which benefits are derived from the ecosystem. In this case, it will allow to assess which ES may change as a result of upscaling OWF.

Which ES classification scheme is most appropriate to use based on case-specific characteristics?

4.3 Criteria for the marine ES classification scheme

Following the recommendations of Veretennikov (2019): "*In order to integrate the ecosystem approach into OSPAR activities, it is first necessary to determine which framework will be most relevant for the North Sea marine services*" (p.15). It is not the aim of this report to design a completely new classification scheme. Therefore, existing schemes can be adapted and amended to fit the characteristics of the case study. It is necessary to develop criteria for the classification scheme to determine which scheme fits the specific characteristics of the case study. Based on Veretennikov (2019), the following criteria are used to determine the most relevant classification scheme:

Box 3: Marine ES classification scheme criteria (adapted from Veretennikov, 2019).

Criteria for the marine ES classification scheme:

- The scheme needs to be transparent and applicable across countries;
- The scheme needs to be relevant for the specific case study;
- The scheme needs to provide a clear overview of categories and classes;
- The scheme needs to be able to accurately evaluate the services present;
- The scheme needs to avoid the risk of double-counting.

The scheme in the report of the EEA (2015) will be used as a basis for the case study. This scheme can be found in figure 25. Based on the criteria in box 2, this scheme is deemed to be most appropriate for the case study. These criteria are substantiated below. The report of the EEA applies the concept of ES to improve management of the European waters. They assess ES that are provided by the marine ecosystem in Europe on the basis of several relevant sources. The scheme is adapted from CICES, as well as Maes et al. (2014). As Maes et al. (2014) developed a framework adapted from CICES as well, the CICES classification forms the basis for assessing marine ES in the EEA report. This means that the criteria are mainly critically evaluated for using CICES in assessing marine ES.

Marine ecosystem services		
CICES Section	**CICES Division**	**Summarised from CICES Group and Class**
Provisioning All materials and biota constituting tangible outputs from marine ecosystems. They can be exchanged or traded, as well as consumed or used by people in manufacturing.	*Nutrition* => All marine ecosystem outputs that are used as foodstuffs (seafood).	*Biomass from marine plants, algae and animals, and their outputs* • Wild capture seafood • In situ aquaculture seafood
	Materials => Marine biotic materials that are used in the manufacture of goods.	*Raw materials from marine plants, algae and animals, and their outputs* • Fibres and other materials for direct use or processing • Materials for agricultural and aquaculture use • Genetic materials for biochemical, industrial and pharmaceutical processes
Regulation and maintenance All the ways in which marine biota and ecosystems control or modify the biotic or abiotic parameters defining the environment of people (i.e. all aspects of the 'ambient' environment). These marine ecosystem outputs are not consumed, but they affect the performance of individuals, communities, and populations.	*Mediation of waste, toxicants and other nuisances* => Marine biota or ecosystems can mediate (neutralise or remove) waste and toxic substances that result from human activities. This mediation has the effect of detoxifying the marine environment.	*Mediation by marine biota (micro-organisms, plants, algae, and animals)* • Bio-remediation • Filtration/sequestration/storage/accumulation
		Mediation by marine ecosystems • Filtration/sequestration/storage/accumulation • Mediation of smells/noise/visual impacts
Regulation and maintenance (cont.) All the ways in which marine biota and ecosystems control or modify the biotic or abiotic parameters defining the environment of people (i.e. all aspects of the 'ambient' environment). These marine ecosystem outputs are not consumed, but they affect the performance of individuals, communities, and populations.	*Mediation of flows* => Marine biota/ ecosystem contribution to maintaining coastal landmasses and currents, reducing the intensity of floods, and keeping a favourable ambient climate.	*Mass flows* • Mass stabilisation and control of erosion rates • Buffering and attenuation of mass flows
		Liquid flows • Flood protection
		Gaseous/air flows • Ventilation and transpiration
	Maintenance of physical, chemical and biological conditions => Marine biota/ecosystem contribution to the provision of sustainable human living conditions.	*Life-cycle maintenance, habitat and gene-pool protection* • Seed and gamete dispersal • Maintaining nursery populations and habitats • Gene-pool protection
		Pest and disease control • Pest control • Disease control
		Soil formation and composition • Weathering processes • Marine sediment decomposition and fixing processes
		Water conditions • Chemical condition of salt waters
		Atmospheric composition and climate regulation • Global climate regulation by reduction of greenhouse gas concentrations • Micro- and regional climate regulation
Cultural Includes all non-material marine ecosystem outputs that have physical, experiential, intellectual, representational, spiritual, emblematic, or other cultural significance.	*Physical and intellectual interactions with marine plants, algae, animals, ecosystems, and seascapes* => Marine biota/ecosystem provision of opportunities for recreation and leisure as well as intellectual, emotional, and artistic development that can depend on a particular state of marine/coastal ecosystems (or where this can enhance it).	*Physical and experiential interactions* • Experiential use of marine biota (e.g. whale watching, snorkelling) • Physical use of marine ecosystems and seascapes (more sports-type activities such as sailing and leisure angling)
		Intellectual and representational interactions • Scientific • Educational • Heritage • Entertainment • Aesthetic
	Spiritual, symbolic and other interactions with marine plants, algae, animals, ecosystems, and seascapes.	*Spiritual and/or emblematic interactions* • Symbolic • Sacred and/or religious
		Other cultural interactions [18] • Existence • Bequest

Figure 25: Marine ES classification scheme (EEA, 2015).

- ✓ **The scheme needs to be transparent and applicable across countries.**

The CICES classification was developed to provide an international accepted standard classification. In practice, the scheme is applied to several studies. In Ireland for instance (Norton, Hynes & Boyd, 2018), the CICES classification serves as a basis for qualitatively and quantitively valuing coastal, marine and estuarine marine ES. In their study, CICES schemes are a proposed standard scheme to be applied, based on recommendations of the UN. Statistics Netherlands (CBS) also used the CICES scheme to assess ES from the Dutch North Sea (Graveland, Remme & Schenau, 2017). Hooper et al. (2019) state as well that CICES schemes are widely applied by academics as well as government agencies. It seems that the CICES scheme is transparent in use, as it is advocated to be used to inform management and has proven to be applicable in different countries as well.

- ✓ **The scheme needs to be relevant for the specific case study.**

CICES schemes are used as a reference at EU level, which makes it relevant to apply in the EU context. Since the case study is focussed around the marine area, the scheme needs to be applicable to marine waters, not (necessarily) the terrestrial area. Maes et al. (2014) has made a first attempt to amend the classification of CICES to be applicable to marine waters and concludes that the classification needs to undergo some changes. The EEA attempts to include these recommendations and to improve the work of Maes et al. (2014). According to the EEA (2015), it is the most adequate scheme to use in the EU marine context. Also, in a report of Statistics Netherlands (CBS), CICES schemes are used for natural capital accounting in the Dutch North Sea (Schenau, Rietveld & Bosch, 2019).

- ✓ **The scheme needs to provide a clear overview of categories and classes.**

Veretennikov (2019) states that a weakness of the CICES classification scheme is that it is not straightforward, in the sense that it does not provides a clear overview. Since the EEA has adapted the scheme from CICES, the scheme provides a clear overview for the different ES, including definitions and examples. As CICES is built upon the work of MA and TEEB, the scheme allows for comparison (Norton, Hynes & Boyd, 2018).

- ✓ **The scheme needs to be able to accurately evaluate the relevant ecosystem services present.**

According to Veretennikov (2019), "*The most appropriate classification of services is influenced by regional characteristics and the ability to accurately evaluate the services present*" (p.15). The scheme of EEA is composed on the basis of evidence of actual use in the EU, which proves the ability of the scheme to accurately evaluate the services. Thereby, it takes into account EU and global regulation on protection of several species, such as birds and mammals. It can also be seen in the studies of Ireland and the Netherlands that the CICES classification can be used in practice to evaluate marine services.

- ✓ **The scheme needs to avoid the risk of double-counting.**

One of the main challenges of using the concept of ES, is the risk of double-counting (Veretennikov, 2019). This can occur when the same function is included in more than one service. This is the case when supporting services are included in the categorisation. Supporting services do not directly provide benefits that humans derive from ecosystems, but they function as underlying natural processes (Norton, Hynes & Boyd, 2018). In the MA framework for example, double counting can be a problem since the MA framework includes supporting services. To illustrate what is meant by double-counting in the marine environment, nutrient cycling (supporting service) influences seafood provision (provisioning services). One should not add the value of the potential increase in fish production due to nutrient cycling to the value of the increased seafood provision, since that would be double-counting. CICES avoids this problem by excluding supporting services as a category.

4.4 The identification of ecosystem services

The EEA (2015) has identified ES that are provided by seabirds and marine mammals based on their marine ES classification scheme (see annex 3). In order to determine ES that are relevant for sea and migrating birds and harbour porpoises in the North Sea, the list of ES provided by the EEA will undergo a scoring assessment. Based on available literature, the ES are described and their relevance to the case is assessed. The scoring system shown in table 1 is used to determine the relevance of the ES for the case study, and if possible, their size.

> *The identified ES are susceptible to change when upscaling OWF.*

The ES will receive a '+' sign when according to the literature review, the ES is relevant for the case study. A '+-' sign indicates that the ES identified by EEA may be relevant for the case study. This is due to literature that studied a group of animals (such as water birds or marine mammals) instead of the specific species that occur in this report. It cannot be assumed that these services are provided by the specific species as well. However, lack of data availability does not automatically mean that the services can be neglected. Therefore, they are scored in this way to give weight to the services. A '-' sign means that the service is not relevant for the case study and/or too small to be of relevance. 'n/a' means that there was no information found in the literature. ES that are not relevant or where no information was available to make a judgement are not taken into account in any further assessment.

Table 1: Scoring system for identifying relevance of ES for the case study.

Score	Description
+	Relevant
+-	May be relevant
-	Not relevant
n/a	Not available/not applicable

4.4.1 Sea and migrating birds

The birds that suffer from effects of OWF can be divided in seabirds and migrating birds. The seabirds that suffer from habitat loss are Divers (Red-throated- and Black-throated Diver (together), Northern Gannet, Sandwich Tern, Common Guillemot and Razorbill). Suffering from collision occurs with seabirds Great Black-backed Gull, Lesser Black-backed Gull, Herring Gull, Black-legged Kittiwake, Great Skua, Northern Gannet and migrating birds Tundra Swan, Brent Goose, Common Shel Duck, Eurasian Curlew and Black Tern.

Table 2 shows the different ES that were identified by the EEA (2015) for water and seabirds in European seas. By reviewing literature, the ES and the relevance to the case study is described. In general, there is no substantial literature on the size of the ES provided by birds. However, by reviewing the available literature, it is possible to provide a distinction between services that are expected to be of relative importance, services that may be of importance, as well as services that may be neglectable for the case study.

Table 2: Scoring marine ES provided by sea and migrating birds in the North Sea region.

Class	**Description**	**Relevance to case study**	**Score**
Food (wild capture and related outputs).	According to Green & Elmberg (2014), 4.2 million shorebirds and ducks are hunted annually in the EU. In Europe, the Bird Directive is aimed at protecting wild bird species. It occurs that habitat loss is one of the main threats to birds. In Annex II of the Directive, a list is composed of 82 birds that can be legally hunted in the EU (EC, 2009).	The seabirds that are taken into account in the case study and suffer from habitat loss, are not included in this list, thus they cannot be hunted upon. However, several seabirds and migratory birds that suffer from collision are on the list. These are the great black backed gull, lesser black backed gull, herring gull, brent goose and the black tern (EC, 2009). As most of the birds are protected, the size of hunting for consumption is assumed to be neglectable.	-
	Eggs from birds can also be consumed as food, especially from geese and ducks (Green & Elmberg, 2014). While it is not allowed and recommended to pick eggs from nests, people can purchase goose eggs at the poulter, foreign supermarkets or from hunters. Duck eggs can be picked when they are unfertilized.	The consumption of goose and duck eggs is assumed to be small, due to the wide availability of chicken eggs in industrialized countries. It should be noted that only the Brent goose and the Common Shelduck are included in the case study from the families of goose and ducks. Egg consumption from geese and ducks of sea and migrating birds is assumed to be neglectable.	-
Fibres and other materials from plants, algae and animals for direct use or processing.	Waterfowl (such as ducks, geese and swans) provide feathers for insulation (Green & Elmberg, 2014). However, the down and feathers used in products such as pillows originate mainly from by-products from factories where birds are raised for meat and eggs (PETA, n.d.).	It is not common that wild birds in the North Sea region are targeted for the down and feather industry. This also accounts for grease that may be extracted from birds. This ES is assumed to be neglectable.	-
Genetic materials from all biota for biochemical, industrial and	n/a	n/a	n/a

pharmaceutical processes.			
Filtration/sequestration/ storage/accumulation by micro-organisms, algae, plants and animals.	Sea and migrating birds use the North Sea as flying route. These birds take nutrients from the shore to the coast. Gulls, geese and swans among others use the aquatic and terrestrial system to feed, which results in cycling from nutrients along these habitats. Geese can play a role in primary production as well. When acting as scavengers, birds also uptake nutrients from dumps and transfer them elsewhere (Green & Elmberg, 2014).	Sea and migrating birds in the North Sea cycle nutrients from terrestrial to aquatic systems and vice versa, however this is poorly studied and no data are available. According to Green & Elmberg (2014), this nutrient cycling may be able to cause major shifts in the trophic status of wetlands. The nutrient movement by scavengers if researched poorly as well, but is expected to be important and underappreciated (Wenny et al., 2011; Whelan, Wenny & Marquis, 2008).	+
Mediation of smells/noise/visual impacts.	Water birds act as scavengers, which indicates that they remove smells from dump sites or from corpses (Green & Elmberg, 2014; Wenny et al., 2011).	Smell mediation is a service that is provided by birds, however it is not clear what the size of the service is in the case study. There are currently no data available. The role of birds of being scavengers may be underappreciated, especially in scavenging carcasses (Wenny et al., 2011).	+
Pollination and seed dispersal.	Sea and migrating birds act as vectors of passive dispersal, and are just like terrestrial birds important for seed dispersal. Seed dispersal is considered the most important service provided by terrestrial birds (Sekercioglu, 2006; Wenny et al., 2011; Whelan, Wenny & Marquis, 2008). Over 920 birds pollinate a small percentage of plants Whelan, Şekercioğlu & Wenny (2015).	The role of sea and migrating birds in seed dispersal is understudied, however pollination and seed dispersal occurs. According to Whelan, Şekercioğlu & Wenny (2015), at least 33% of the birds disperse seeds, mainly terrestrial birds. The role of water birds is unknown, however waterfowl are certain to play a substantial role in the movements of seeds over long distances (Whelan, Wenny & Marquis, 2008). Sea and migrating birds are expected to play a substantial role in dispersal as well.	+
Maintaining nursery populations and habitats	Presence and activity of water birds can have positive effects on aquatic biodiversity. Birds have a crucial role in maintaining diversity on a local, regional and continental scale. Water birds can also play a role being a host for parasites, which may possibly contribute to the total biodiversity in the ecosystem (Green & Elmberg, 2014).	Small number of bird species and unknown amount of parasites (Green & Elmberg, 2014), but sea and migrating birds may play a role in maintaining nursery populations and habitats.	+-
Gene-pool protection	Water birds have a certain role in being passive dispersals, since they connect communities that live in isolated aquatic systems. In this way, they can maintain species and genetic diversity.	Gene-pool protection is provided by sea and migrating birds as well, however the specifics on their role are understudied but may be of relevance for sea and migrating birds.	+-
Pest control	Pest controls occurs as water birds control mosquitoes, that are major pests and vectors of disease. Water birds indirectly control pests in this way. Also, the larvae of mosquitoes are consumed by ducklings among other things. Water birds also spread parasites that results	The role of sea and migrating birds in pest control is understudied. However, as seabirds generally feed on fish (as well as their nestlings), there is no sufficient information to imply that sea and migrating birds provide pest control. Green & Elmberg (2014) suspect that the pest	+

	infects pests and reduces the abundance. Water birds can act as bioindicators for the ecological status of the ecosystem (Green & Elmberg, 2014; Wenny et al., 2011; Whelan, Wenny & Marquis, 2008).	control may be substantial in areas where there is no fish or in shallow water. Sea and migrating birds can act as bioindicators for the status of the marine ecosystem by monitoring.	
Disease control	As birds can carry many pathogens, they can serve as disease control if they are monitored. Wild migratory ducks have been used to analyse the avian influenza virus (AIV). The birds can be used to monitor the geographical scope of an outbreak (Green & Elmberg, 2014).	The role of sea and migrating birds in disease control is understudied. Besides wild migratory ducks that have been successfully used to monitor AIV, other birds may also function as disease control.	+
Marine sediment decomposition and fixing processes	Bioturbation of swans reduces methane due to increased oxidation of sediments. Breeding colonies can influence the soil chemistry and nitrogen cycling (Green & Elmberg, 2014; Wenny et al., 2011).	No sufficient information can be found that bioturbation also occurs with other birds besides swans. However, soil chemistry and nitrogen cycling by breeding colonies may be relevant for sea and migrating birds.	+-
Chemical condition of salt waters	n/a	n/a	n/a
Global climate regulation by reduction of greenhouse gas concentrations.	Swans feed on submerged macrophytes that reduce the production of methane by bioturbation (Green & Elmberg, 2014).	There are no data available on the size of methane that is reduced. No sufficient information can be found that bioturbation also occurs with the other birds, however it may be relevant for the group of sea and migrating birds in the case study.	+-
Experiential use of marine biota	On site bird watching.	In the North Sea region, bird watching occurs for example on the Wadden Islands. Bird watching tourism in the EU is a growing market, mainly in the UK and the Netherlands. Also the largest bird organisation is located in the UK (The Royal Society for the Protection of Birds), with more than 1 million members. The Dutch bird organisation has 141,000 members (CBI, 2017).	+
Scientific & Educational	Sea and migrating birds are a matter of subject in science, such as this report itself.	Sea and migrating birds have a role in science, but no data are available. A review in literature databases shows approximately 40,000 hits on 'seabirds' (Google Scholar: 110,000; WUR library: 13,978; Scopus: 14,000; JSTOR: 11,143) and approximately 56,000 hits on 'migrating birds' (Google Scholar: 153,000; WUR library: 45,320; Scopus: 3,000; JSTOR: 21,250). Hits include articles, books and journals. The research (and call for research) shows that the sea and water birds plays a substantial role in science.	+

Heritage, cultural	Values from swans for instance can be reflected through artistic and historic importance (Green & Elmberg, 2014).	The role of sea and migrating birds in heritage or cultural aspects is understudied. However, the public values seeing birds in wintering sites for example. Therefore, there are actions to protect populations. This has led to several international conservation guidelines, like the Bird Directive in the EU, showing the importance of birds for the public.	+
Entertainment	Off-site entertainment, indicating for instance the appearance of sea and migrating birds in the media.	The role of sea and migrating birds in off-site entertainment is understudied. A search on 'seabird' on Google News results in 191,000 hits, and 'migrating birds' 52,600 hits showing the relevance in the media.	+
Aesthetic	Terrestrial and water birds are used for taxidermy, which can be considered art. Feathers of terns have been used in clothing in several fashion items as well (Green & Elmberg, 2014).	The role of sea and migrating birds having aesthetic value is understudied however it may be relevant.	+-
Symbolic	Birds used in symbols.	Swans for example are used in symbolic of the Lutheran church in the Netherlands. The role of sea and migrating birds in symbols is understudied, but may be relevant.	+-
Sacred and/or religious	Birds that have spiritual, ritual identity.	Gulls for instance can have spiritual meaning, in the sense of reflecting freedom and living in the moment, as well swans that can have religious meaning. Swans for example also have artistic and religious importance through history (swans and royalty).	+-
Existence	The value described to knowing that sea and migrating birds exist, even if people will never see them.	Data are not available, however the occurrence of sea and migrating birds indicates that there can be an existence value ascribed.	+-
Bequest	The value described to knowing that future generations will have the option to enjoy sea and migrating birds.	Data are not available, however the occurrence of sea and migrating birds indicates that there can be a bequest value ascribed.	+-

4.4.2 *Harbour porpoises*

Marine mammals that suffer from effects of underwater noise from OWF are the harbour porpoise, grey seal and the common seal. As stated before, the harbour porpoise is expected to be impacted the most by underwater noise and therefore assessed in the case study.

Table 3 shows the different ES that were identified by the EEA (2015) for marine mammals in European seas. By reviewing literature, the ES and the relevance to the case study is described. In general, there is no substantial literature on the size of the ES provided by harbour porpoises. Especially since they are a part of groups in research, such as marine mammals in general or cetaceans. However, by reviewing the available literature, it is possible to provide a distinction between services that are expected to be of relative importance, services that may be of importance, as well as services that may be neglectable for the case study.

Table 3: Scoring marine ES provided by harbour porpoises in the North Sea region.

Class	**Description**	**Relevance to case study**	**Score**
Fibres and other materials from plants, algae and animals for direct use or processing.	In EEA (2015), raw material is identified as an ES by marine mammals. It is not clear from the literature what raw material is provided by marine mammals.	In Europe, seal products are not allowed on the market and no other raw materials from seals or the harbour porpoise can be identified.	-
Pollination and seed dispersal.	n/a	n/a	n/a
Maintaining nursery populations and habitats	Grey whales restructure part of benthos habitats, that may be of influence on preserving habitat for primary prey. According to Bowen (1997): "*There is evidence that the abundance and distribution of marine mammals can have important effects on the structure and function of some ecosystems*" (p. 272).	Literature focusses on marine mammals in general, however as the harbour porpoise is a marine mammals, this service is expected to be relevant for them as well. A better understanding of the role of marine mammals in marine ecosystems needs to be developed.	+
Gene-pool protection	Cetaceans have been researched on the factors that shape genetic diversity.	Literature focusses on cetaceans (whales, dolphins and porpoises) showing which factors shape genetic diversity, indicating that there is a large gene-pool (Vachon, Whitehead & Frasier, 2018).	+
Pest control	n/a	n/a	n/a
Disease control	n/a	n/a	n/a
Marine sediment decomposition and fixing processes	The movement of marine mammals through the aquatic system results in nutrient cycling from the deeper ocean upwards. Large cetaceans may also play a role in transferring nutrients downward after death (Bowen, 1997; Roman & McCarthy, 2010).	Literature focusses on marine mammals or cetaceans in general, not specifically on harbour porpoises. However, as marine mammals play a substantial role, harbour porpoises are expected to play a substantial role in transferring nutrients as well.	+
Chemical condition of salt waters	n/a	n/a	n/a
Global climate regulation by reduction of greenhouse gas concentrations.	Marine mammals can enhance primary productivity, as whales and seals are responsible for nitrogen. According to Roman & McCarthy (2010), "*Whales and seals may be responsible for replenishing 2.3×104 metric tons of N per year in the Gulf of Maine's euphotic zone, more than the input of all rivers combined*" (p. 1).	Literature focusses on marine mammals or cetaceans in general, not specifically on harbour porpoises. However, they play a substantial role in recycling nitrogen, which is expected for harbour porpoises as well.	+
Experiential use of marine biota	Seal watching occurs in the North Sea region, for instance at several spots along the Dutch coast. Like bird watching, people go to the Wadden Islands to spot common seals. Grey seals can be spot all along the UK coast. Harbour porpoises can be spotted for example along the coast in Scotland.	In this case, marine mammal watching also includes watching harbour porpoises. There specific relevance in this activity is unclear, however it may be relevant.	+-
Scientific & Educational	Marine mammals are a matter of subject in science, such as this report itself.	The role of harbour porpoises in science specifically is assumed to be small as most research is around marine mammals. A review	+

		in literature databases shows approximately 5,000 hits on 'harbour porpoise' (Google Scholar: 17,500; WUR library: 1,711; Scopus: 1,300; JSTOR: 944). Hits include articles, books and journals. The research (and call for research) shows that the harbour porpoise plays a substantial role in science.	
Heritage, cultural	The role of harbour porpoises in heritage or cultural aspects.	The role of harbour porpoises in heritage or cultural aspects is understudied. However, the harbour porpoise is protected in the EU under the Habitats Directive and more conservation sites are assigned in the UK for instance. This shows the importance of harbour porpoises for the public.	+
Entertainment	Off-site entertainment, indicating for instance the appearance of harbour porpoises in the media.	The role of harbour porpoises in off-site entertainment is understudied. A search on 'harbour porpoise' on Google News results in 36,500 hits, showing the relevance in the media.	+
Aesthetic	The role of harbour porpoises in art.	Harbour porpoises having aesthetic value is understudied. However, marine mammals (mostly seals) can have aesthetic value for being a symbol for a clean world in mascots or stuffed animals. Harbour porpoises may also play a role.	+-
Symbolic	Harbour porpoises that are used in symbols.	The role of harbour porpoises in symbols is understudied. Marine mammals, mostly seals, can be a symbol for protection. Harbour porpoises may also play a role.	+-
Sacred and/or religious	Harbour porpoises that have spiritual, ritual identity.	Dolphins can have spiritual aspects as they stand for knowledgeable species. Harbour porpoises specifically may have spiritual, ritual identity.	+-
Existence	The value described to knowing that harbour porpoises exist, even if people will never see them.	Data are not available, however the occurrence of harbour porpoises indicates that there can be an existence value ascribed.	+-
Bequest	The value described to knowing that future generations will have the option to enjoy harbour porpoises.	Data are not available, however the occurrence of harbour porpoises indicates that there can be a bequest value ascribed.	+-

4.5 Summarizing remarks

The concept of ES allows for linking ecology to economy in order to integrate natural elements in decision-making. ES can be divided in several categories, for which a marine classification scheme can serve as a tool to identify ES. Based on several criteria concerning regional characteristics and applicability, the scheme of the EEA is considered to be the most appropriate. This scheme is used to identify ES for the case study. Moreover, sea and migrating birds and harbour porpoises contribute to human well-being via the ES they provide. Upscaling OWF is assumed to alter populations of seabirds and harbour porpoises in the North Sea. As seen in the BTA, this means losses to society since the ES cannot be provided anymore. The application of ES to the case study provides an understanding of the importance of taking measures to protect the marine environment. The judgement of the relations is challenging, however it was possible to distinct neglectable, relevant and possibly relevant ES. The next chapter will incorporate the ES in the BTA to show the losses to society in terms of ES.

5 The Bow Tie Analysis and Ecosystem Services

Upscaling OWF is a risk for populations of sea and migrating birds and harbour porpoises in the North Sea. Management measures can be implemented to prevent or mitigate against the consequences. However, upscaling OWF may result in populations to decline or even disappear. This will have social, economic and environmental consequences. The importance of preserving the marine environment for human well-being is shown by the concept of ES. The previous chapter identified ES that are provided by sea and migrating birds and harbour porpoises. This chapter integrates the concept of ES in the BTA to show what the ecological effects of OWF mean for society.

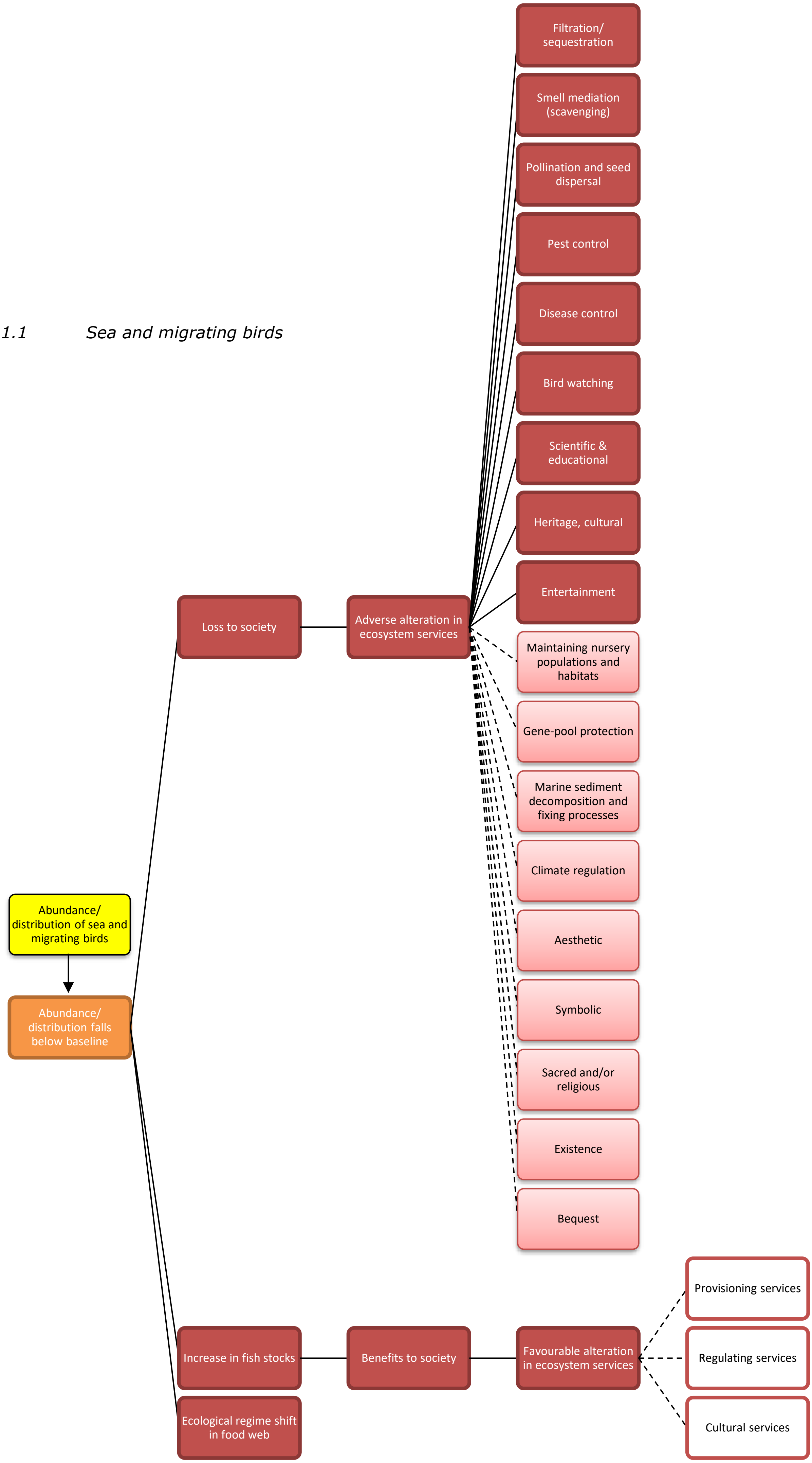
5.1 Case study

Upscaling OWF may lead to populations of sea and migrating birds and harbour porpoises to decline or even disappear. This results in losses to society, that can be indicated by an adverse alteration in ES. The figures below show the losses to society in terms of ES integrated in the BTA. In the BTA, the ES are shown that were identified in the previous chapter. In the dark-red boxes, the ES are shown that are expected to be of substantial relevance to the case study. The light-red boxes are the services that may be relevant for the case study, based on available literature. First, the BTA for sea and migrating birds is shown (section 5.1.1) and hereafter the BTA for harbour porpoises (section 5.1.2).

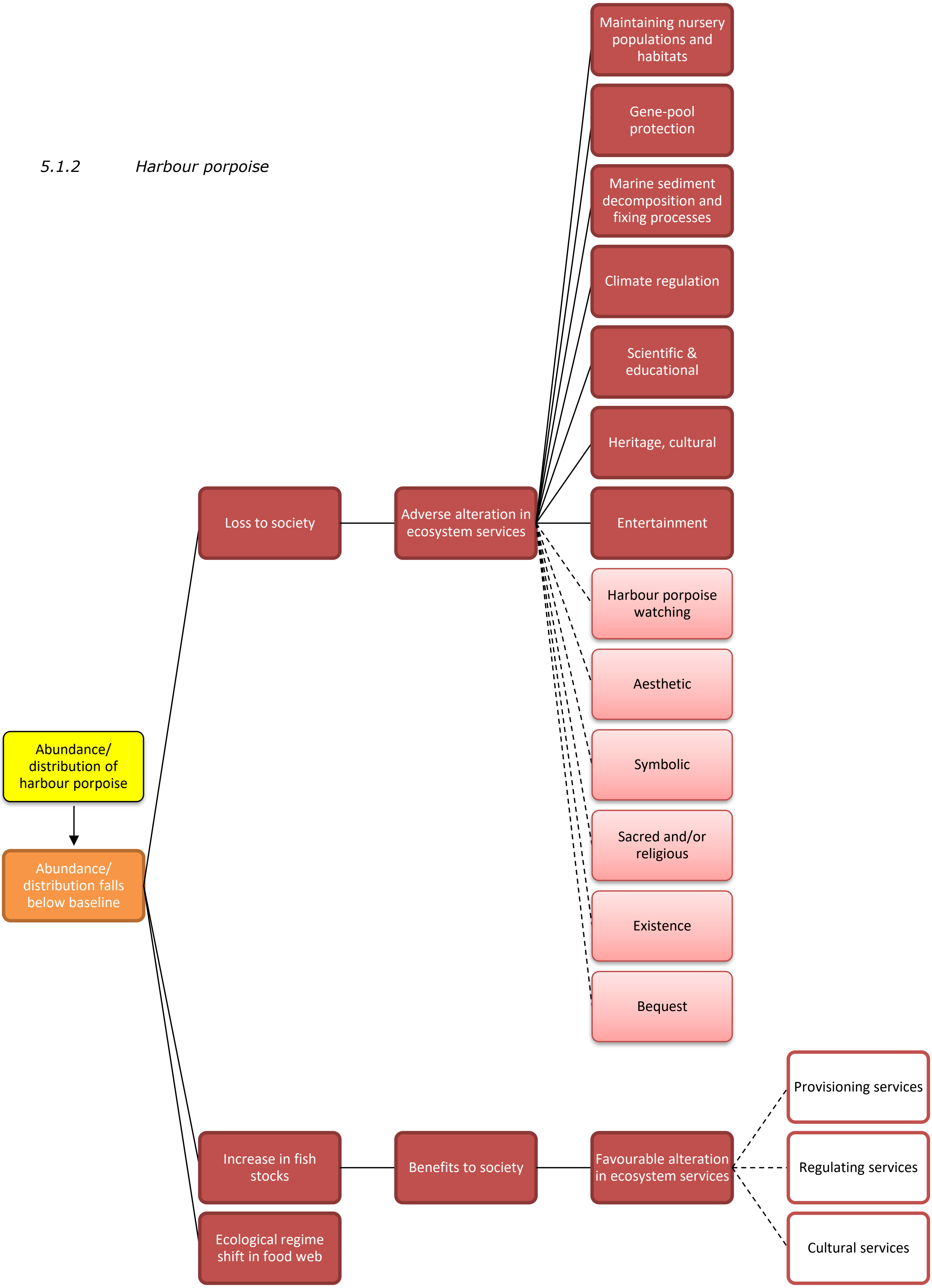
Besides the losses to society, a change in fish stocks may appear as well. The change may be a local increase in fish stocks, which may lead to a favourable alteration in ES. For this consequence, ES can be identified as well that represent the benefits to society when populations of sea and migrating birds and harbour porpoises declining. The EEA (2015) has identified ES for fish in European seas, that cover all fish species including commercial stocks. While it is beyond the scope of this report to undergo a critical evaluation of the ES provided by fish in the North Sea specifically, the list by the EEA provides an impression of ES provisioning by fish. The EEA has identified the following ES provided by fish:

- **Provisioning**: Seafood (wild capture, and related outputs); Fibres and other materials for direct use or processing; Materials for agricultural and aquaculture use; Genetic materials for biochemical, industrial, and pharmaceutical processes;
- **Regulating**: Filtration/sequestration/storage/accumulation of wastes and toxicants by biota; Seed and gamete dispersal; Maintaining nursery populations and habitats; Gene pool protection; Disease control and Pest control; Decomposition and fixing processes; Chemical condition of salt waters; Global climate regulation by reduction of greenhouse gas concentrations.
- **Cultural services**: Experiential use of marine plants, algae, and animals; Physical use of marine ecosystems and seascapes (including leisure fishing); Scientific, educational, heritage, entertainment, aesthetic, symbolic, sacred/religious, existence, and bequest interactions.

5.1.1 Sea and migrating birds



5.1.2 Harbour porpoise



5.2 Summarizing remarks

Integrating the concept of ES in the BTA shows the interaction between ecological, social and economic effects. The combination of the BTA with ES shows the losses to society of an ecological effect caused by human activities. There are several uncertain relations, however the identification of ES made it possible to distinct ES that are neglectable for the case study, ES that are expected to be of substantial relevance and ES that might be of relevance. This provides insights in the social consequences of the risk of upscaling OWF. The measures that are proposed in the BTA should prevent of mitigate against the consequences of declining or even disappearing populations. Implementing measures should avoid losing ES provided by sea and migrating birds and harbour porpoises. The valuation of ES can be used to assess whether the costs of proposed measures outweigh benefits of avoiding the losses to society.

6 Valuation of effects

Human activities such as upscaling OWF result in pressures that form a risk for the survival of populations of birds and harbour porpoises. Declining or disappearing populations lead to losses for society in terms of ES, since they cannot be provided anymore. However, preventive and mitigative measures can be implemented that should lower the impact of OWF. In order to evaluate the benefits of implementing those measures, the ES need to be valued. This chapter will focus on providing valuation methods for ES. It is not the aim of this chapter to provide monetary values, however possible methods are proposed. First, indicators are identified. After that, a tool for economic valuation of ES is assessed and finally, methods for the identified ES are proposed. In this way, the economic impact of upscaling OWF can becomes clear, which can be taken into account in decision-making.

6.1 Theoretical framework

6.1.1 Indicators

Indicators can be identified to make the ES measurable. Indicators can be useful to assess the changes in ES that may occur as a result of human activities (Hattam et al., 2015). Thereby, they allow for assessing the importance of an ES and can be a reference point for monetary valuation (Böhnke-Henrichs et al., 2013). Indicators help to understand the relevance of the ecosystem components to human well-being and help support decisions in marine management (Veretennikov, 2019).

The difficulty arises when the set of indicators for the identified ES need to be determined as many different indicators exist in literature. The indicators should provide a description of ES and allow for understanding of ecosystem functioning. There are several criteria that an indicator should meet: **measurability** (data availability to measure and quantify), **sensitivity** (ability to detect change is ES over time), **specificity** (ability to display change in management), **scalability** (applicability in different spatial scales) and **transferability** (applicability in other studies) (Hattam et al., 2015; Norton et al., 2018; Veretennikov, 2019). According to Veretennikov (2019), indicator selection should be specific for each case that works with ES.

6.1.2 Economic valuation

The identified ES provide an understanding of the benefits that humans derive from sea and migrating birds and harbour porpoises. Commonly, ES are not valued in such a way that they are comparable to other economic services or capital. This leads to a risk of giving too little weight to ES in decision-making (Costanza et al., 1997). Therefore, the identified ES have to be valued in economic terms (Börger et al., 2014). According to Lopes & Videira (2013) among others, economic valuation of ES has its limitations and an interdisciplinary approach needs to be taken. This approach should integrate knowledge from ecology, society, sociology and economics.

As many environmental resources do not have an economic value on the market, it is difficult to include ES in economic choices (Ledoux & Turner, 2002). However, the absence of a market value does not imply that these environmental services do not have a value (Silvis & Van der Heide, 2013). The value of ES is commonly assessed by the framework of Total Economic Value (TEV). In this framework, monetary and non-monetary aspects are taken into account (Grant, Hill, Trathan & Murphy, 2013; Veretennikov, 2019).

Figure 26 illustrates the TEV framework, showing the division into use and non-use values. Use values are split into several different values. The benefits human derive though use values can be divided into direct use values (e.g. food, timber, recreation), which are marketed goods and services that are directly received and indirect use values (e.g. climate regulation, nutrient cycling). Direct use values can be split into non-consumptive use values (e.g. recreation, research) which are not traded in the market and consumptive values (e.g. seafood). Consumptive goods are marketed, representing scarcity through market prices. Indirect use values are related to values that are derived from services that support the ecosystem (Silvis & Van der Heide, 2013).

Non-use values have an immaterial character as they are independent of the use of an ecosystem. They can be divided into existence and bequest value which are not reflected by market prices either (Veretennikov, 2019). According to Silvis & Van der Heide (2013), *"non-use values may include the option value, quasi-option value, existence value, bequest value and philanthropic value"* (p. 43). The option value described the certainty of the good being available for use in the future (Pascual et al., 2010). The quasi-option value is related to a delayed improved situation, describing protection. The philanthropic value describes the satisfaction of people knowing that a service is available for the current generation (Silvis & Van der Heide, 2013). On the basis of the TEV framework, values can be attached to the different ES.

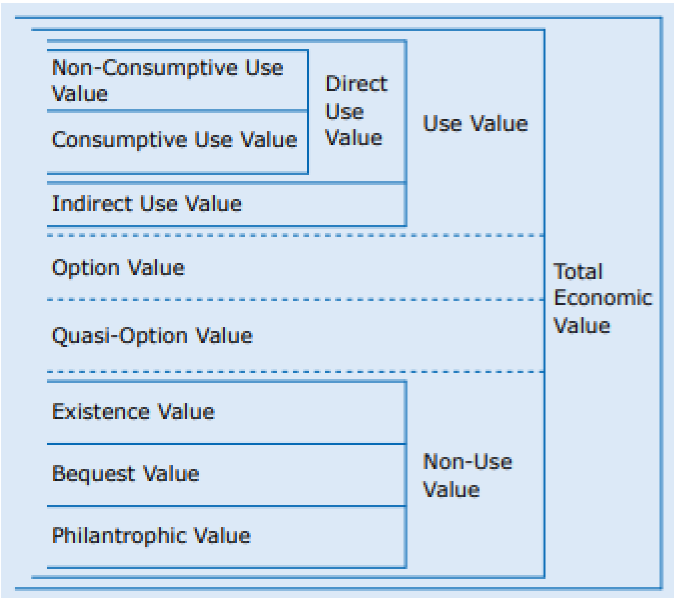


Figure 26: The framework of Total Economic Value (TEV) (Silvis & Van der Heide, 2013).

6.1.3 *Monetary valuation*

In order to underline the importance of preserving ES to society, they may be represented in monetary terms. However, it seems that this can be quite challenging and several techniques are proposed for each type of ES category. Table 4 shows the different methods that can be used. First of all, the monetary value of marketed goods and services can be derived from the market, for instance based on market prices. Cost approaches represent the costs derived from replacing the environmental service. Revealed preference methods use regression analyses to analyse the price for an ES. Stated preference methods use questionnaires to estimate the Willingness To Pay (WTP), mostly used to estimate non-use values (Silvis & Van der Heide, 2013; Veretennikov, 2019).

Table 4: Ecosystem services valuation techniques (Roebeling et al., 2019).

Catgory	Technique	Description	Marine ecosystem service example where used
Revealed WTP (direct market)	Market price	Market prices stemming from a normal production process	Capture fisheries, seaweed harvesting
	Production function	Values how changes in the quantity or quality of the ecosystem affects ES and ultimately the costs of production of the final benefit	Water quality in an estuary, filtration services provided by oyster reef in a bay
Imputed WTP	Damage cost avoided	Value of an asset is equivalent to the value of the economic activity or assets that it protects	Protection of coastal property from storm surges
	Replacement cost	Value is based on the cost of replacing the environmental function	Coastal defence
	Substitute cost	Value of a non-marketed product is based on the market value of an alternative product providing the same or similar benefits	Waste water treatment
Revealed WTP (surrogate market)	Travel cost	Inferred from the cost of travel to a site (i.e. expenses and value of time incurred)	Marine and coastal recreation use
	Hedonic pricing	Value of goods is based on the value of individual components	Sea view premium in property prices
Stated WTP	Contingent valuation	Survey technique asking a representative sample of individuals how much they are willing to pay to prevent loss of, or to enhance, an environmental good or service	Protection of a marine species or habitat, marine non-use values
	Choice experiments	Asking respondents to select their preferred package of environmental attributes at different prices and then inferring specific component values	Climate regulation, potential use of marine genetic materials
Transfer of values	Benefits transfer	Values estimated in one context and location are used to estimate values in a similar or different context and location	All of above

For the different marine ES, different valuation techniques can be used. The valuation methods in table 4 are possible methods of valuing services that for instance have a market (market price technique) or no market (travel cost method). Therefore, table 5 shows the suitability of the different valuation methods for the categories of ES. On this basis, techniques can be chosen that can be appropriate to quantify ES.

Table 5: Suitability of valuation methods for the categories of ecosystem services (Silvis & Van der Heide, 2013).

Method	Ecosystem service category		
	Provisioning	**Regulating**	**Cultural**
Market prices	+	+/-	+/-
Cost approaches	+	+	-
Revealed preferences	+/-	-	+
Stated preferences	-	-	+

6.2 Case study

6.2.1 *Indicators*

As it is not the aim of this study to determine new indicators, indicators are proposed below based on relevant literature. Table 6 shows potential indicators for the previous identified ES provided by sea and migrating birds and harbour porpoises. For some ES, there could be no indicators identified in the reviewed literature (n/a). If the service is provided by sea and migrating birds or harbour porpoises alone, there is a '(SMB)' or '(HP)' behind the services respectively.

Table 6: Potential indicators for ES in the case study (adapted from Böhnke-Henrichs et al., 2013[12]; EC, 2019b[13]; Hattam et al., 2015[14]; Maes et al. (2016); Norton et al., 2018[15]).

Ecosystem service	**Indicators**
Filtration/sequestration/ storage/accumulation by micro-organisms, algae, plants and animals (SMB)	- Nutrient load to coast (ton/a)
Mediation of smells/noise/visual impacts (SMB)	n/a
Pollination and seed dispersal (SMB)	n/a
Maintaining nursery populations and habitats	- Submerged and intertidal habitats diversity (no.) - Oxygen concentration (%) - Turbidity (%) - Species distribution (km2/ha) - Abundance and richness – at age (ton/a) - Extent of marine protected areas (km2/ha) - Nursery areas (km2/ha) - Number of species (species richness)

[12]The study of Böhnke-Henrichs et al. (2013) is analysed, as they have extensively reviewed more than 145 marine valuation studies

[13]The indicators originate from the guidance report of the EU that is based on MAES classification (2016). They aim to guide the application of ES in decision-making and have identified ES and indicators based the main ecosystem types.

[14]Hattam et al. (2015) identified specific indicators for the case of the Dogger Bank based on indicators selected during an interdisciplinary expert workshop.

[15]Norton et al. (2018) is included as their set of indicators, since it is one of the most comprehensive lists in the literature. Thereby, they have carried out a quantitative study on Ireland's marine ES based on these indicators, showing practical applicability of ES.

	- Number and diversity of species using the area for nursery or reproduction (abundance/m2 and species diversity)
Gene-pool protection	- Genetic diversity per population - Diversity of species and sub-species, phylogenetic distance, Biodiversity Intactness Index (BII)
Pest control (SMB)	- Presence (no.) - Distribution (km^2) of alien species
Disease control (SMB)	n/a
Marine sediment decomposition and fixing processes	- Nitrogen removal (%) - Water residence time (months) - Depth/water residence time (m/year)
Global climate regulation by reduction of greenhouse gas concentrations	- C stock (tonC) - C sequestration (tonC/a) - pH - blue C (tonC) - PP (ton C/year)
Experiential use of marine biota	- Extent of marine protected areas (km^2/ha) - Presence of ionic/endangered species (no.) - In-water activities occurrence (no.) - Recreation trips (no/year) - Visits of an area (no.) - Days used for particular activity per person (no.) - Overnight stays (no.) - Hotel rooms in a region (no.) - Square feet of beach/beach day - Amount of Catch rate pf target fish species - Visitors per season (no.) - Boats involved in trips (no.) - Dive operators offering trips (no.)
Scientific & Educational	- Scientific studies (no.) - Documentaries, educational publications (no.) - Visits to scientific and artistic visits exhibits (no.) - Amount of time (# of person days) spent in education about, research regarding, or individual learning about an ecosystem/specie - Number of students in marine-related courses/number of papers related to research at a certain site
Heritage, cultural	- Households that consider an area or aspects of an area of cultural heritage (no.) - Number of marine-related protected structures, marine museum visits, number of activities or festivals related to the marine - Species, habitats or ecosystems that is being or can potentially form the core or contribute to a cultural custom, rite or way of life
Entertainment	- Documentaries, educational publications (no.) - Visits to scientific and artistic visits exhibits (no.) - Amount of time (# of person days) dedicated to creation of culture, art and design per area per year - Species, habitats or ecosystems that have or can potentially inspire any piece of artwork
Aesthetic	- Square feet of beach/beach day - Beach day

	- Increased value in house prices, increased prices in hotel rooms - Uniqueness of a site (1/number of sites with similar features) - Abundance of key species of individual interest (count data) - Area of biotopes of key interest to individuals
Symbolic	n/a
Sacred and/or religious	- Amount of time (# of person days) dedicated for formal religious ceremonies that involve coastal/marine environments per year - Species, habitats or ecosystems that is being or can potentially be worshipped or be of significance to a religious belief
Existence *Bequest*	- Extent of marine protected areas (km^2/ha) - Presence of ionic/endangered species (no.)

6.2.2 *Economic valuation*

Economic valuation of ES can be useful to assess whether the proposed measures in the BTA are proportional to the benefits. In the case study, the identified ES for sea and migrating birds and harbour porpoises exist of regulating and cultural services. These services can be related to the different values in the TEV framework. Table 7 shows the type of values that can be linked to ES, helping to determine valuation techniques.

Table 7: Economic Values case study (adapted from Silvis & Van der Heide, 2013).

Ecosystem services		**Economic values**			
Category	**ES case study**	**Direct use**	**Indirect use**	**Option value**	**Existence & bequest value**
Regulating	Filtration/sequestration (SMB); Mediation of smells/noise/visual impacts (SMB); Pollination and seed dispersal (SMB); Maintaining nursery populations and habitats; Gene-pool protection; Pest control (SMB); Disease control (SMB); Marine sediment decomposition and fixing processes; Global climate regulation by reduction of greenhouse gas concentrations. Maintaining habitats; gene-pool protection.		x	x	
Cultural	Experiential use of marine biota; Scientific & Educational; Heritage, cultural; Entertainment; Aesthetic; Symbolic; Sacred and/or religious; Existence; Bequest.	x		x	x

6.2.3 *Monetary valuation*

In order to estimate the monetary value of the identified, techniques should be chosen that can appropriately estimate values. Table 8 shows methods that can be used to value the identified ES for the case study.

Table 8: Valuation techniques for the ES in the case study (adapted from Roebeling et al., 2019; Silvis & Van der Heide, 2013).

Ecosystem services

Category	**ES case study**	**Valuation method**
Regulating	Filtration/sequestration (SMB); Mediation of smells/noise/visual impacts (SMB); Pollination and seed dispersal (SMB); Maintaining nursery populations and habitats; Gene-pool protection; Pest control (SMB); Disease control (SMB); Marine sediment decomposition and fixing processes; Global climate regulation by reduction of greenhouse gas concentrations. Maintaining habitats; gene-pool protection.	- Market price - Production function - Substitute cost - Benefit transfer - Damage cost avoided - Replacement cost
Cultural	Experiential use of marine biota; Scientific & Educational; Heritage, cultural; Entertainment; Aesthetic; Symbolic; Sacred and/or religious; Existence; Bequest.	- Market price - Production function - Travel cost - Contingent valuation - Choice experiments - Benefits transfer - Hedonic pricing

6.3 Summarizing remarks

Since upscaling OWF negatively impacts populations of sea and migrating birds and harbour porpoises, this affects the provision of ES. Valuation of the services can show the socio-economic impacts of the development of upscaling OWF. In order to assess the size of the ES, indicators were proposed. Thereby, several economic and monetary valuation methods are proposed. The valuation of the ES provided by sea and migrating birds and harbour porpoises gives an indication of the economic losses that are involved with upscaling OWF in the North Sea region. The management measures that are proposed in the BTA, should limit the impacts of declining populations, thus avoid losing the ES provided by these populations. Thereby, the valuation of ES shows the benefits of implementing measures that can reduce the impacts of upscaling OWF.

7 Discussion

The previous chapters focussed on the application of the BTA in combination with the concept of ES to support decision-making within OSPAR. The plans for upscaling OWF in the North Sea to combat climate change have been used as a case study to explore the added value of the methodology. After elaborate analyses of the BTA and ES, this chapter will evaluate the methods, focussing on their value added, as well as their limitations. After this, the results of the case study are discussed. The discussion is based on the challenges encountered during the execution of the report, as well as discussions with several parties who are working with the BTA or ES.

7.1 Method

7.1.1 Bow Tie Analysis

Value added:

1) Communication tool

In the BTA, both anthropogenic and natural relations can be taken into account, dependent on the aim of the BTA. Especially in case of marine management, the BTA is able to provide an overview of all the different pressures on the marine environment. There are still many uncertainties in this field, but the BTA is able to at least qualitatively include pressures from human and natural activities. Since the natural system is complex itself, one BTA can be chained to other bow ties to show the underlying causes and consequences that may lead to a change in the state of the marine environment.

2) Explore management measures

Besides the causes and consequences, the BTA assesses the management measures that can be taken in order to prevent or mitigate against the consequences of an unwanted event. It gives the opportunity to explore options for decision-makers and shows the different possibilities to reduce impacts. The effectiveness of these measures can be screened, evaluating how far the risk may be reduced.

3) Logical and coherent overview

In order to incorporate environmental information in decision-making, it can be challenging to capture the essence of the problem as the system is complex. The BTA allows to visualise the information in such a way that it provides a clear overview. The relations between causes and consequences become clear. In this way, the BTA becomes accessible for people without a thorough understanding of the complex system.

Limitations:

1) Need for expert knowledge

In order to construct the BTA, it is necessary to gather all kinds of information that needs to be well understood. There should be information on the multiple causes, consequences and measures concerning the change in the state of the marine environment. Understanding this information is the basis of the BTA, which can be challenging. Additionally, it can be time and money consuming as well, especially since there are many uncertainties on the effects on the marine ecosystem.

2) Simplification relations

The BTA allows to construct cause-effect relations (in the marine environment) in a logical and coherent matter. However, natural systems are complex and interconnected. The BTA may oversimplify the cause-effect relations and their feedbacks and/or trade-offs. There may be several feedbacks in the system that cannot be shown in (chained) bow ties. Additionally, future trends and developments are not taken into account in the bow tie, as it explores a possible risk scenario.

7.1.2 Ecosystem Services

The value added:

1) Communication tool

The concept of ES links ecology to economy. ES can be used as a communication tool to make people aware of the dependence of humans on nature. It shows the importance of conservation policies and helps decision-makers to implement measures. Since ES shows the economic benefits from healthy ecosystems, it implies that ecosystem degradation will lead to costs to society, calling for sustainable management.

2) Completeness

The concept of ES aims to capture all the different elements in an ecosystem (component) that contribute to human well-being. Since the list of services is elaborate, every function is analysed. ES can be used as a tool to ensure that all the functions are taken into account, enabling a better understanding of ecosystem functioning.

Limitations:

1) Complex

For the application of ES, it is necessary that an ecosystem (component) is fully analysed in order to assess which ES are provided. A thorough understanding of the ecological functioning is necessary, especially for assessing regulating services. The tool is mainly used by economists to value a certain type of ecosystem. Understanding the links between services is even for ecologists challenging and there are lots of uncertainties. Uncertain relations may be used as an argument to exclude certain ES, which results in an incomplete picture. The complex character of the concept and the uncertainties make the application time and money consuming.

2) Valuation pitfalls

In general, there are many discussions about the valuation of ES. Besides valuing ES being challenging, deriving a (monetary) value for a service may stop the thinking. Natural processes are continuously moving and changing, which can hardly be described by a specific value. If an ES is quantitatively assessed and included in a CBA, it may easily be assumed that this value correctly represents the value of nature. However, the story behind the number may be neglected.

7.1.3 Linking BTA to ES

<u>The value added:</u>

1) Assessing socio-economic effects

With the BTA alone, collective pressures are assessed that lead to an unwanted event. From here, consequences of these risks are analysed. However, it is not clear what the impact will be on the economy and which sectors it may affect. By integrating the concept of ES in the BTA, the socio-economic impacts of the risk become clear. Using the BTA in combination with ES is useful to systematically assess what certain high risk scenarios mean for society. The impact on ES shows the costs of degrading ecosystems. The proposed measures in the BTA can be weighed to the benefits associated with ES. These benefits are reflected by the ES provided by the ecosystem (component) that is defined as hazard in the BTA. It provides an understanding of the societal importance of implementing measures to preserve nature by taking ES into consideration.

2) Explore risk scenarios

The BTA provides an understanding of the causes that might lead to an undesired event, as well as the consequences when this event takes place. Linking the BTA to ES shows the societal impact of the risk and helps to support discussions. As the BTA is able to analyse risk scenarios, ES can help evaluating whether the risk is acceptable or not. May the ES that are impacted be non-substantial, thus may the societal impact be small, it can help evaluate whether taking measures is necessary.

3) Combining environmental, social and economic effects

The concept of ES is anthropogenic, thus only the impact for human well-being is assessed. The environmental effects can be included in the BTA as well, either as causes or consequences. By chaining separate bow ties, the underlying cause-effect relations of the elements in the bow tie can be assessed. In this way, environmental, social and economic effects are linked.

7.2 Case study

7.2.1 Implications

1) Assumptions

In the case study, it is assumed that upscaling of OWF will lead to a population decline in sea and migrating birds and harbour porpoises. Thereby, OWF are assumed to form a high risk for these species. The actual impact of additional windfarms is not assessed by the BTA and ES in this report, since a risk scenario is analysed. In the BTA, several other pressures are identified that cause the populations of sea and migrating birds and harbour porpoises to decline. As it is assumed in the case study that upscaling OWF forms a high risk for these populations, the impact of OWF relative to the other pressures has not been critically assessed.

A recently published report commissioned by Rijkswaterstaat[16] assessed the relative impact of offshore wind compared to other pressures in the marine environment on key species (sea birds and harbour porpoises). The largest pressure pathway has been assessed for the current state, but also for future scenarios (2023 and 2030). For the scenarios, the following pressures are identified to have the largest impacts:

Sea birds

- Present day
  - Prey availability effects due to climate change;
- Future scenarios
  - Climate change.

Harbour porpoise

- Present day
  - Bycatch from fisheries;
  - Noise levels and displacement from fisheries;
  - High levels of non-impulsive noise from shipping.
- Future scenarios
  - Bycatch from fisheries.

The pressures above do not mention OWF as an expected biggest threat. However, the effects of OWF are mentioned as being potential localised impacts for sea birds. Thereby, OWF may also cause permanent underwater noise for harbour porpoises. It is currently only assessed as a pressure during the construction phase. However, the substantial scale of the future windfarms may cause continuous noise during the operation phase as well.

2) Uncertainties

The BTA and the concept of ES require information and data about several uncertain relations. Identifying ES may be uncertain for several ecosystems (and their components). This makes it difficult to judge whether the risk is acceptable or not and what measures should be taken. Especially valuing ES to weigh them against the costs of measures, uncertainties in the ecological functioning may undermine discussions. However, these uncertain relations will give implications for every tool used. Therefore, this is an implication for the case study rather than for the method used.

3) Effects

The negative effects of OWF are currently occurring for sea and migrating birds and harbour porpoises. As identifying ES for the species seems challenging, this might undermine the actual impact of declining populations on biodiversity and the food web. Besides, the ES that are identified in the case study do not make a distinction between individual species or populations. Several services may be dependent on a combination of species. Therefore, it can be challenging to inform a specific decision on the analysis. The fact that there are already negative effects occurring, might be sufficient to form a decision on. The focus should be on compensating measures that need to be implemented.

[16] https://northseaportal.eu/publish/pages/144481/assessment_of_relative_impact_of_anthropogenic_pressures_on_marine_species.pdf

4) Analysis

The case study used in the report analyses two specific ecosystem components. These species are a part of the food web and contribute to the lively biodiversity in the marine ecosystem. They can be considered to be 'at the end of the chain', as these species do not directly provide services (for instance the provision of seafood by the marine ecosystem in the North Sea area).

8 Recommendations

The previous chapter focussed on the strengths and weaknesses of the method applied to the case study, as well as several implications for the case study itself. In this chapter, recommendations are given based on the application of the tools to the case study. First, several recommendations are given for the method used. After this, recommendations are given for research and monitoring based on the outcomes of linking the BTA to ES. Finally, recommendations are given for the case study specifically.

8.1 Method

8.1.1 Bow Tie Analysis

1) Expert group

The BTA should be structured within an expert group, where the complex cause-effect relations can be assessed. Thereby, the expert group can screen the risks and give weights to the different pressures identified in the bow tie. In this way, it can become clear which pressures may have a more profound impact relative to others.

2) Stakeholder participation

Management measures that are developed in the BTA to reduce impacts should be assessed together with stakeholders. For instance, energy suppliers should have a stake in exploring possible measures as well.

8.1.2 Ecosystem Services

1) Develop ES as communication tool

Use the concept of ES as a communication tool by improving the qualitative story. ES can be powerful in decision-making when the qualitative importance of preserving nature becomes clear. Quantifying ES may not always be necessary to stress human dependence on healthy ecosystems. ES contributes to the awareness of people/decision-makers of the importance to implement (precautionary) measures, especially because several negative impacts of OWF are already occurring.

2) Multidisciplinary team

The analysis of ES requires understanding ecological functioning. People from different disciplines should be included to capture all the services. Combining ecological and economic knowledge is necessary to get a full picture of the possible ES provided by an ecosystem (component).

8.1.3 Linking BTA to ES

Linking the BTA to ES showed that there are several knowledge gaps. The analysis can be used to develop a research agenda and to prioritize what needs to be researched and/or monitored in the (near) future:

<u>Research</u>

1) Compensating/mitigation measures

Upscaling OWF contributes to combatting climate change, which has a high priority on many political agendas. These windfarms will be developed on a large scale in the (near) future, so the focus has to be on compensating/mitigation measures that can reduce the impacts of OWF.

Prioritize research on investigating possible measures (and their effectiveness) that compensate/mitigate impacts of:

a. Collision;
b. Habitat loss;
c. Underwater noise.

2) Cumulative effects

In the marine ecosystem, many activities are taking place at the same time. The pressures caused by the activities altogether influence the ecosystem. Therefore, it is necessary that research is done to the impact of cumulative effects, instead of specific pressures. The ecosystem (component) experiences effects from the cumulative pressures, not specifically from one activity. Data collection on cumulative effects and methodologies should be adequately assessed at an international level.

3) Future trends

The plans for upscaling OWF are known, which allows for developing scenarios for areas of the sea that will be occupied by offshore wind. However, the future trends and developments of the other activities in the marine ecosystem should be researched as well. These trends of pressures should be integrated in a cumulative assessment, where different scenarios (and their impacts) can be assessed.

4) Integrated marine ecosystem assessment

Sea and migrating birds and harbour porpoises are ecosystem components in the entire marine ecosystem in the North Sea. OWF have effects on other components as well. Therefore, it is recommended that further research is developed that focusses on the marine ecosystem as a whole, looking at services that are provided by an area, such as the North Sea.

5) Ecological functioning ecosystem components (sea and migrating birds and harbour porpoises)

The identification of ES for the ecosystem components is the case study seemed difficult, since there is a lack of research to the ecological functioning of the specific species in the case study. Thereby, it is also not clear what the size of the possible services is. Therefore, it is recommended that further research is developed on:

a. Relations between ecosystem components and human well-being;
b. Size of ecosystem services provided.

<u>Monitoring</u>

1) Actual numbers of mortality

According to the research used in this report, there are already negative effects occurring on sea and migrating birds and harbour porpoises. These species need to be monitored as the windfarms are expanding.

Keep track of ongoing developments:

a. Number of colliding sea and migrating birds (and the effect on populations);
b. Mortality as a result of habitat loss among sea and migrating birds (and the effect on populations);
c. Mortality as a result of noise among harbour porpoises (and the effect on populations).

2) Behavioural changes

Keep track of ongoing developments in behavioural changes of sea and migrating birds and harbour porpoises. Sea and migrating birds and harbour porpoises may adapt their behaviour in the (near) future to the OWF. Therefore, it should be monitored if and how these populations adapt to changing habitats.

3) Food web

The marine ecosystem is an open system where species are connected with each other in a food web. There are possibly several trade-offs and feedbacks in the marine food web that occur. For instance, if populations of sea birds decline, this may lead to a local increase in fish stocks and an increase in harbour porpoises (and vice versa). Besides, when areas of OWF are closed for fishing activities, this may lead to increasing fish stocks and increasing populations of sea birds and harbour porpoises. These possible feedbacks and trade-offs need to be monitored.

8.2 Case study

1) Reduce ecological impacts

The method is useful to explore possible measures to manage the risks. For instance, linking the BTA with ES does not show the impact of additional windfarms in the North Sea, but explores the risks associated with the additional windfarms. Especially since the OWF will be built in the (near) future and negative effects are already occurring, the focus should be on implementing compensating/mitigation measures.

2) Precautionary measures

As the North Sea is one of the busiest seas, the biodiversity in the marine ecosystem is negatively impacted by the combined activities. However, the exact impact of the collective pressures is unknown. According to the EEA (Korpinen et al., 2019), effects of degradation are reversing at locations where management measures are adequately implemented. The improvement in the state of the seas can be linked to European and international management. This calls for implementing precautionary measures, which could decrease the pressure on the marine ecosystem.

With respect to the large scale implementation of wind farms, precautionary measures should be taken that lower the impact on the state of the marine ecosystem. The analysis shows that there are several measures that can be taken. If these precautionary measures are taken, the negative impacts of large scale implementation of OWF can be combatted. In this way, the development of OWF has potential to provide opportunities. Also in protected areas, precautionary measures can provide opportunities for OWF and may increase social acceptance.

The measures that can be implemented:

- New foundation and installation techniques (including deterrent devices and sound systems);
- Habitat restoration/creation;
- Low-emission vessels;
- Spatial protection measures;
- Site and time selection (including adjustments to mass migrations and foraging locations).

3) Enhance opportunities of OWF

First of all, OWF are built because they reduce the reliance on fossil fuels and combat climate change. This positive development should be continued by taking (precautionary) measures that limit ecological risks. In addition to compensating/mitigation measures, advantage of OWF should be taken by enhancing the opportunities involved with OWF (for instance developing oyster reefs or restoring the seabed by prohibiting fishing activities).

4) Quantification

The methodologies applied to the case study have resulted in a qualitative analysis of the effects. Before, recommendations are given for research and monitoring to obtain quantitative information. To use the methodology in the report for a quantitative analysis, the following data are required:

- Population densities in North Sea region (to assess relative and absolute impacts);
- Actual impact of OWF on populations (to assess the size of the impact);
- Risk of OWF relative to other activities (to evaluate whether the risk is acceptable or not, and whether measures are necessary to be implemented);
- Risk reduction rate measures (to assess the effectiveness of the measures);
- Costs of measures;
- Value of populations by:
    - Assessing size of identified ES (by using indicators);
    - Assessing economic value of ES (by estimating WTP).

9 Conclusion

The EU has set ambitious goals to combat climate change in the coming decades. By increasing the share in renewable energy, the EU aims to reduce the reliance on fossil fuels. Energy production from wind sources is enhanced by upscaling OWF in the North Sea as OWF are able to produce renewable energy on a large scale. However, the substantial scale-up of OWF forms a risk for maintaining a healthy marine ecosystem. OSPAR ensures a healthy marine environment in the North-East Atlantic and explores methods on how to incorporate ecological effects and the resulting socio-economic effects in decision-making. Therefore, the BTA in combination with the concept of ES is applied to a case study to explore the usefulness of the method. The report aims to determine whether linking the BTA to ES is useful to support discussions and decision-making in OSPAR activities.

The BTA identifies the complex relationships between causes and consequences of a risk scenario in a clear and visual way. The BTA is able to explore possible management measures that can be taken to prevent an unwanted event to take place or mitigate against the consequences. As a basis, a thorough understanding of the system is needed, which requires input from experts and an interdisciplinary approach. Besides, stakeholders should be involved to explore measures that are executable. This is important for constructing a BTA that assesses cumulative effects. The application of the case study shows that the risk of upscaling OWF in the North Sea pressure populations of sea and migrating birds and harbour porpoises, resulting in changes in the food web and losses to the society.

The losses to the society are assessed by the concept of ES. ES describe the benefits that humans derive from ecosystems, linking ecology to economy. ES shows the societal dependence on natural resources and can be used as a communication tool to stress the importance of conservation policies. ES creates awareness and analyses all ecosystem functions that can be classified. This detailed analysis asks for interdisciplinary knowledge and may be time consuming due to the complexity. Uncertainties in the ecological functioning of sea and migrating birds and harbour porpoises made it challenging to identify ES for the case study. The relevant ES were identified, which show what the impact on human well-being is when populations decline.

The BTA shows the different activities that pressure the marine environment. Initially, this may be seen as a problem for nature. However, incorporating the concept of ES shows in what way the society will suffer from a deteriorated marine ecosystem. The integration of the BTA and ES is useful to support decision-making, since it shows the societal importance of implementing measures, as humans depend on healthy (marine) ecosystems. Additional OWF are going to be built in the near future to tackle one of the biggest problems humans are facing now, for which the scale will be substantial. However, several negative effects are already occurring. Therefore, decision-makers should focus on compensating measures that minimise ecological impacts, so the development of OWF can continue to be positive. These measures should compensate for human-induced pressures in the seas. The challenges remain understanding the complex system and finding a balance between preserving a healthy ecosystem and making use of the services provided by nature.

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Annex 1: Elements BTA sea and migrating birds

Activity[17]	Characteristics	Pressures	Preventive barriers	Event (state change)	Mitigation/recovery barriers	Consequences
Offshore windfarms	Avoidance of windfarms	Habitat loss	Site selection[18]	Marine bird population	Creating new habitat; improving habitat quality; improve food supply; OSPAR recommendations	Adverse alteration in ES (cost to society); adverse alteration in biodiversity
	Operating windfarms cause collisions	Collision	Site selection; stop operation during mass migration; larger turbines, greater capacity; blades' positioning; lighting; deterrent devices[14]	Marine bird population		Adverse alteration in ES/biodiversity
Fisheries activities	Fishing activities cause bycatch	Marine bird bycatch	Change techniques for longline and trawl fisheries[14]	Marine bird population		Adverse alteration in ES/biodiversity
Tourism activities	Disturbance by increased number of boats or people approaching too closely; especially in summer	Biological disturbance	Exclude tourism in environmentally important areas (breeding/migration)[14]; education for tourists	Marine bird population		Adverse alteration in ES/biodiversity
Climate change	Long-term	Biological disturbance		Marine bird population	Paris Agreement	Adverse alteration in ES/biodiversity
Litter	Especially areas that are close to	Input litter	Reduce production and consumption of	Marine bird population	Clean-up actions; OSPAR recommendations	Adverse alteration in ES/biodiversity

	densely populated areas		environmentally persistent waste[19]			

[17] Adapted from Wood, D. (2019). B14: Update of summary of activities and pressures & ICES (2014). Report of the Joint Rijkswaterstaat/DFO/ICES Workshop: Risk Assessment for Spatial Management (WKRASM), 24–28 February 2014, Amsterdam, the Netherlands. ICES CM 2014/SSGHIE:01. 35 pp. Retrieved from http://ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/SSGHIE/2014/WKRASM2014.pdf.

[18] Vrooman, J., Schild, G., Rodriguez, A.G., van Hest, F., 2019. North Sea wind farms: ecological risks and opportunities. North Sea Foundation, Utrecht, the Netherlands.

[19] Dias, B. D. S. (2016). Marine debris: understanding, preventing and mitigating the significant adverse impacts on marine and coastal biodiversity. *CBD Technical Series,* (83).

Annex 2: Elements BTA harbour porpoises

Activity[20]	Characteristics	Pressures	Preventive barriers	Event (state change)	Mitigation/recovery barriers	Consequences
Offshore windfarms	Construction of windfarms	Underwater noise	Site selection; deterrent devices; soft-start pile driving construction; sound abatement systems[14]	Harbour porpoise population	MSFD; OSPAR recommendations	Adverse alteration in ES/biodiversity
	Operating windfarms	(Continuous) noise	Site selection; deterrent devices; sound abatement systems[14]	Harbour porpoise population		Adverse alteration in ES/biodiversity
Fisheries activities	Operating windfarms	(Continuous) noise	Site selection; deterrent devices; sound abatement systems[14]	Harbour porpoise population		Adverse alteration in ES/biodiversity
	Fishing activities cause bycatch	Marine bird bycatch	Change techniques for longline and trawl fisheries[14]	Harbour porpoise population		Adverse alteration in ES/biodiversity
Oil and gas[21]	Exploration and extraction	Habitat loss	Site selection; reduce oil and gas production and consumption; reduce number of installations	Harbour porpoise population		Adverse alteration in ES/biodiversity
	Exploration and extraction (seismic surveys;	Noise	Site selection; reduce oil and gas production and consumption; reduce number of installations	Harbour porpoise population		Adverse alteration in ES/biodiversity

[20] Adapted from Wood, D. (2019). B14: Update of summary of activities and pressures & ICES (2014). Report of the Joint Rijkswaterstaat/DFO/ICES Workshop: Risk Assessment for Spatial Management (WKRASM), 24–28 February 2014, Amsterdam, the Netherlands. ICES CM 2014/SSGHIE:01. 35 pp. Retrieved from http://ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/SSGHIE/2014/WKRASM2014.pdf.

[21]https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/pressures-human-activities/trends-discharges-spills-and-emissions-offshore-oil-and-gas-inst/

	explosions; sonar sources)					
	Exploration and extraction	Pollution	Site selection; reduce oil and gas production and consumption; reduce number of installations	Harbour porpoise population		Adverse alteration in ES/biodiversity
Military activities[22]	Flying practice routes and boats for shooting activities	Noise	Site selection; exclude military activities in important areas (breeding/migration)[14]	Harbour porpoise population		Adverse alteration in ES/biodiversity
	Munition in the sea from shooting activities	Litter	Site selection	Harbour porpoise population	Clean-up actions; MSFD; OSPAR recommendations	Adverse alteration in ES/biodiversity
Tourism activities	Disturbance by increased number of boats or people approaching too closely; especially in summer	Biological disturbance	Exclude tourism in environmentally important areas (breeding/migration)[14]; education for tourists	Harbour porpoise population	MSFD; OSPAR recommendations	Adverse alteration in ES/biodiversity
Shipping	Collision with boats	Collision	Site selection; deterrent devices	Harbour porpoise population		Adverse alteration in ES/biodiversity
	Motorised shipping	Noise	Site selection; deterrent devices; sound abatement systems	Harbour porpoise population		Adverse alteration in ES/biodiversity

[22] https://www.noordzeeloket.nl/functies-gebruik/militair-gebruik/

Industry	Especially areas that are close to industrialised areas	Harmful substances	Deterrent devices; clean production technologies	Harbour porpoise population	Cleaning actions; MSFD; OSPAR recommendations	Adverse alteration in ES/biodiversity
Litter	Especially areas that are close to densely populated areas	Input litter	Reduce production and consumption of environmentally persistent waste[15]	Harbour porpoise population	Clean-up actions; MSFD; OSPAR recommendations	Adverse alteration in ES/biodiversity

Annex 3: Marine ES supply seabirds and marine mammals

[23]***Ecosystem service***	**Division**	**Group**	**Class**	**Seabirds**	**Marine mammals**
Provisioning: *All materials and biota constating tangible outputs from marine ecosystems. They can be exchanged or traded, as well as consumed or used by people in manufacturing.*	**Nutrition:** All marine ecosystem outputs that are used as foodstuffs.	Biomass from marine plants, algae and animals, and their outputs.	Food (wild capture and related outputs).	✓	
	Materials: Marine biotic materials that are used in the manufacture of goods.	Raw materials from marine plants, algae and animals, and their outputs.	Fibres and other materials from plants, algae and animals for direct use or processing.	✓	✓
			Genetic materials from all biota for biochemical, industrial and pharmaceutical processes.	✓	
Regulation and maintenance*: All the ways in which marine biota and ecosystems control or modify the biotic or abiotic parameters defining the environment of people (i.e. all aspects of the 'ambient' environment). These marine ecosystem outputs are not consumed, but they affect the performance of individuals, communities, and populations.*	**Mediation of waste, toxics and other nuisances:** Marine biota or ecosystems can mediate (neutralise or remove) waste and toxic substances that result from human activities. This mediation has the effect of detoxifying the marine environment.	Mediation by marine biota (micro-organisms, plants, algae, and animals).	Filtration/sequestration/ storage/accumulation by micro-organisms, algae, plants and animals.	✓	
		Mediation by marine ecosystems.	Mediation of smells/noise/visual impacts.	✓	
			Pollination and seed dispersal.	✓	

[23] This scheme is based on the EEA marine ES classification scheme and a marine ES scheme provided by the European Commission (2019) who developed guidance on integrating ecosystems and their services into decision-making in the EU. Both the EEA and EC used the CICES classification as reference. Note: non-relevant ES are not shown.

	Maintenance of physical, chemical and biological conditions: Marine biota/ecosystem contribution to the provision of sustainable human living conditions.	Life-cycle maintenance, habitat and gene-pool protections.	Maintaining nursery populations and habitats	✓	✓
			Gene-pool protection	✓	✓
		Pest and disease control	Pest control	✓	✓
			Disease control	✓	✓
		Soil formation and composition	Marine sediment decomposition and fixing processes	✓	✓
		Water conditions	Chemical condition of salt waters	✓	✓
		Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations.	✓	✓
Cultural: *Includes all non-material marine ecosystem outputs that have physical, experiential, intellectual, representational, spiritual, emblematic, or other cultural significance.*	**Physical and intellectual interactions with marine plants, algae, animals, ecosystems, and seascapes:** marine biota/ecosystem provision of opportunities for recreation and leisure as well as intellectual, emotional, and artistic development that can depend on a particular state of marine/coastal ecosystems (or where this can enhance it).	Physical and experiential interactions (recreation)	Experiential use of marine biota	✓	✓
		Intellectual and representational interactions	Scientific & Educational[24]	✓	✓
				✓	✓
			Heritage, cultural	✓	✓
			Entertainment	✓	✓
			Aesthetic	✓	✓

[24] According to EEA (2015), Scientific and Educational were two separate classes. However, the overarching characteristics of the classes makes them being integrated as one class.

Spiritual, symbolic and other interactions with marine plants, algae, animals, ecosystems and seascapes.	Spiritual and/or emblematic interactions.	Symbolic	✓	✓
		Sacred and/or religious	✓	✓
	Other cultural interactions	Existence	✓	✓
		Bequest	✓	✓