PBL Netherlands Environmental Assessment Agency

The **future** of the **North Sea**

The North Sea in 2030 and 2050: a scenario study

Policy study

The future of the North Sea

The North Sea in 2030 and 2050: a scenario study

Jan Matthijsen, Ed Dammers and Hans Elzenga

The Future of the North Sea. The North Sea in 2030 and 2050: a scenario study.

The Hague, 2018
PBL publication number: 3193

This report is the official translation of PBL's Dutch Policy Study: 'De toekomst van de Noordzee. De Noordzee in 2030 en 2050: een scenariostudie'

Corresponding author
jan.matthijsen@pbl.nl

Authors
Jan Matthijsen, Ed Dammers and Hans Elzenga

Project team
Ed Dammers, Hans Eerens, Hans Elzenga, Anton van Hoorn, Jasper Hugtenburg, Joppe Veul and Jan Matthijsen (project leader)

Guidance group of the Dutch Ministry of Economic Affairs and Climate, Ministry of Infrastructure and Water Management, Ministry of the Interior and Kingdom Relations, Ministry of Agriculture, Nature and Food Quality, Ministry of Education, Culture and Science and the Ministry of Defence.
Merkus, Van der Veeren, Schermer Voest, Rekers, De Leede, Weenink, Kock, Vis, Reijbroek, Brieskorn, Vermeulen, Keijser, Pas, Klomp and Du Saar

Acknowledgements
We thank the participants in the workshops of 13 June and 5 September 2017. We also thank Jurgen Batsleer, Wouter van Broekhoven (Visned), Eric Kreft, Barthold Schroot (EBN), Jaap Breunese (TNO), Katell Hamon (WER), Oscar Bos, Pauline Kamermans, Gerjan Piet, Nathalie Steins (WMR), Henk Weerts (RCE), Thomas Donders, Thomas Aksan (Tennet), Jaap de Rooij, Maarten van der Paard (KPN), Ernst van Zuijlen (TKI Energie Wind-op-zee), Frank van Rijn, Pieter Boot and Ton Dassen (PBL), as well as the participants in the workshop on ecology of 14 September 2017.

Graphics
PBL Beeldredactie

Maps
H+N+S Landscape Architects

Production coordination
English translation and English-language editing
PBL Publishers

PBL Netherlands Environmental Assessment Agency is the national institute for strategic policy analysis in the fields of the environment, nature and spatial planning. We contribute to improving the quality of political and administrative decision-making by conducting outlook studies, analyses and evaluations in which an integrated approach is considered paramount. Policy relevance is the prime concern in all of our studies. We conduct solicited and unsolicited research that is both independent and scientifically sound.

Contents

MAIN FINDINGS

MAIN FINDINGS

The North Sea in 2030 and 2050: a scenario study

Introduction

The North Sea is high on the Dutch political agenda, and various national policies are being developed, both for the short and the long term. These include the 2030 North Sea Strategy, 2030 Offshore Wind Energy Road Map (*Routekaart Windenergie op zee 2030*), North Sea Nature Policy Analysis (*Beleidsanalyse Noordzee-natuur*), National Integrated Environmental Policy Strategy (*Nationale Omgevingsvisie*), the national elaboration of the European Marine Strategy Framework Directive, the European Framework for Maritime Spatial Planning and the Political Declaration on Energy Cooperation between the North Seas Countries (North Seas Energy Cooperation). There are so many different policies that it is hard to come to a clear overview, which is why the Dutch Ministries of Economic Affairs and Climate Policy (EZK), Infrastructure and Water Management (IenW), Agriculture, Nature and Food Quality (LNV) and the Interior and Kingdom Relations (BZK) have asked PBL to carry out this scenario study for the North Sea for 2030 and 2050. The study aims to answer the following question:

What are the spatial and ecological consequences of plausible developments in the North Sea and, in particular, on the Dutch continental shelf, and what are the policy implications?

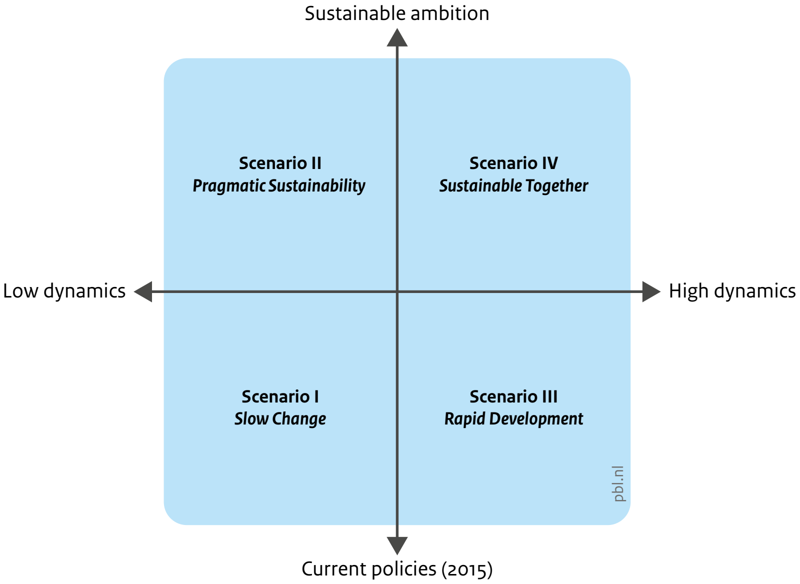
The North Sea scenarios developed for this study are based on the two scenarios in the Welfare, Prosperity and Quality of the Living Environment (WLO) Outlook, 'The Netherlands in 2030 and 2050' (*Nederland in 2030 en 2050*) (CPB and PBL, 2015a). These scenarios build on policy as it stood in 2015, and are characterised by low, or high, dynamism in the economy, technology, the climate and other areas. Both scenarios assume that current government policy continues unchanged and do not take into account the far-reaching ambitions included in the Paris Climate Agreement at the end of 2015. However, the scenarios do take into account the commitments made by individual countries regarding greenhouse gas emission reductions. Even so, the sum of these commitments is insufficient to achieve the Paris objective to 'keep a global temperature rise well below two degrees Celsius' (also see CPB and PBL, 2015b).

Two additional 'sustainable' scenarios have been developed for this North Sea scenario study. These assume that extra policy is developed that contributes to the ambitions of the Paris Climate Agreement and the UN sustainable development goal with implications for the North Sea. These scenarios also enable consideration of how to shape the 'energy transition', 'resilient ecosystems' and 'sustainable food supply' themes from the 2030 North Sea Strategy and the National Integrated Environmental Policy Strategy (which has a time horizon of 2050). Combining the WLO scenarios and the sustainable scenarios produces the following four scenarios (Figure 1): *Slow Change, Pragmatic Sustainability, Rapid Development and Sustainable Together.*

This scenario study focuses primarily on the main policy themes in the 2030 North Sea Strategy: towards an energy transition, towards resilient ecosystems and towards a sustainable food supply. Although in less detail, it also addresses the other themes in the North Sea Strategy, such as defence and cultural heritage (see Figure 2). The study focuses on the question how multiple use of space – which means combining various user functions in a certain area – can be implemented to make the most efficient and sustainable use of the limited space available on the Dutch continental shelf.

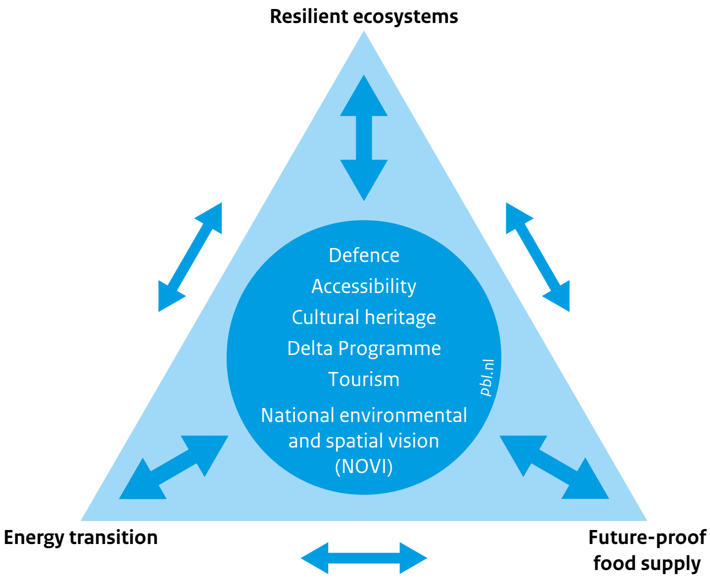
The developments in the three policy themes named above that are assumed in the scenarios may have a very large economic impact in terms of value added and employment opportunities. Of the three themes, the transition to a sustainable energy supply is expected to have by far the largest economic impact. The current economic value of the Dutch fisheries and aquaculture sectors is relatively small and will increase or decrease according to the developments assumed in the scenarios. Regarding ecosystems, the general benefit of nature and

Figure 1
Positioning of the North Sea scenarios



Source: PBL

Figure 2
Policy themes North Sea strategy 2030



Source: www.noordzeeloket.nl

nature conservation for society tends to be described in the form of ecosystem services, and is difficult to capture in economic terms. A quantitative analysis of the economic impacts of developments in these themes is beyond the scope of this study, and a follow-up study is therefore required to obtain more information about such impacts.

Here, in the findings section of this study, we present the main conclusions for the central themes in the 2030

Table 1
Energy transition overview, per scenario, for 2030 and 2050

	Scenario I Slow Change	Scenario II Pragmatic Sustainability	Scenario III Rapid Development	Scenario IV Sustainable Together
Greenhouse gas reduction (%, compared with 1990)[1]				
2030	30%	45%	40%	50%
2050	45%	80%	65%	100%
Offshore wind power (GW) [2]				
2030	4.5	7.5	11.5	15
2050	12	22	32	60
Carbon capture and storage (CCS) (Mt CO_2/yr)[3]				
2030	-	-	15	20
2050	-	30	25	45
Final energy consumption savings (%, compared with 2015)[4]				
2030	4%	9%	0%	13%
2050	10%	20%	0%	30%

North Sea Strategy (the energy transition, resilient ecosystems and a sustainable food supply). We also list some of the 'knowledge gaps' for each theme that became apparent during the study – these are areas in which considerable uncertainties still exist. In the last section of the findings, we discuss the spatial pressures on the North Sea identified in the scenarios and arising from the energy transition and the aim to achieve resilient ecosystems and a sustainable food supply.

In the full results, we describe the current situation in the North Sea. We summarise the four North Sea scenarios as a storyline for each scenario and maps of the Dutch continental shelf and the North Sea as a whole for 2050. These maps also show spatial developments in the exclusive economic zones of the other North Sea countries. We would like to emphasise that locations, purpose and size of the future wind parks, nature reserves and other future developments are envisaged by the authors purely for this publication. Therefore, any changes outside the Dutch continental shelf solely reflect our interpretation of the international context, which is described in the various scenarios in relation to the developments on the Dutch continental shelf.

The scenario outcomes are discussed in relation to the themes in the 2030 North Sea Strategy, as summarised in these findings. All other data, hypotheses and information on which the assumed developments in the North Sea sectors are based are described in a background document published to accompany this report (in Dutch). This background document also includes a chapter that qualitatively outlines the possible economic consequences of developments in the North Sea for the Netherlands.

Energy transition

As far as the Netherlands and other neighbouring countries are concerned, the North Sea can play a large role in the transition towards a sustainable energy supply. For example, offshore wind turbines can help reduce greenhouse gas emissions. The reduction achieved varies in the scenarios (Table 1), but only in scenario IV (*Sustainable Together*) does the Netherlands follow a pathway in which the goals of the Paris Climate Agreement are achieved. In this scenario, net greenhouse gas emissions are reduced to zero in 2050 – a reduction of 100% compared with the base year 1990. In scenario II (*Pragmatic Sustainability*), the Netherlands achieves a reduction of 80% in 2050. This is therefore at the lower end of the 80% to 95% reduction agreed on by European governments in 2009 as the European contribution to the global 'two-degree climate target'. In scenarios I (*Slow Change*) and III (*Rapid Development*), emissions in the Netherlands are reduced by 45% and 65% respectively. Comparable targets in the rest of the world will result in average global warming, under these scenarios, of considerably more than 2 °C: 2.5–3 °C for scenario III (*Rapid Development*) and 3.5–4 °C for scenario I (*Slow Change*).

The important role of the North Sea in the energy transition is expressed in these scenarios primarily as installed wind power (Table 1). Between now and 2050, thousands of wind turbines will be built on the Dutch continental shelf. Although other forms of renewable energy – solar, wave and tidal – may also play a role at some point in the future, their contribution is not quantified in this study. Furthermore, depleted natural gas fields are used in three of the four scenarios to store

CO_2 released during industrial activities and energy generation (carbon capture and storage, or CCS). In all of the scenarios, oil and natural gas activities on the Dutch continental shelf stop between 2030 and 2050. However, the point at which this takes place depends on developments in CO_2 and fossil fuel prices in the scenarios: the lower the fossil fuel price and the higher the price of CO_2, the earlier oil and natural gas production will stop.

In scenario IV (*Sustainable Together*) – the scenario with the highest growth in wind energy – 17% to 26% of the Dutch continental shelf is used for wind farms in 2050. In the scenario with the lowest growth in wind energy (scenario I, *Slow Change*), this is between 3% and 5% of the Dutch continental shelf. Compare this with the situation in 2017, when about 0.25% was used for wind farms. As mentioned above, all oil and natural gas production will have stopped in 2050 in every scenario. With the exception of scenario I (*Slow Change*), platforms are reused for CCS in all the scenarios. Even so, there is a significant reduction (over 80%) in the number of platforms on the Dutch continental shelf. The amount of wind energy and CCS required to achieve 'Paris' depends on national energy consumption, energy imports and exports and other energy transition measures taken both on land and in other countries. The 60 gigawatts (GW) of offshore wind energy in 2050 in scenario IV (*Sustainable Together*) may therefore not be essential to achieve 'Paris'. Depending on several factors, in particular the increase in the number of wind farms and CCS in the North Sea, the Netherlands could become a renewable electricity exporting country, or even store CO_2 for other countries.

Opportunities, bottlenecks and solution strategies

Designated wind energy areas sufficient up to 2030
In every scenario, the currently designated areas for wind energy provide sufficient room for growth in offshore wind energy up to 2030. In scenario I (*Slow Change*), there is enough room up to 2050. In the other three scenarios, the assumed growth in offshore wind energy means that new areas will need to be designated between 2030 and 2050, although the exact moment when this is required varies. It may also be necessary to designate other areas for wind energy prior to 2030, should the pressure on nature or fishing activities become unsustainable in currently designated areas.

Given the rapid increase in wind power after 2030, a combination with nature and/or fishing would be the obvious choice…
In scenario IV (*Sustainable Together*) in particular, the spatial claim made by offshore wind energy is so high in 2050 that the current distinction between wind farms on the one hand and nature and fishing on the other is difficult to maintain. In fact, we would need to accept that further expansion in nature reserves and fishing grounds has to stop, or even be reversed. Combining wind farms with nature reserves or fishing grounds may help solve the spatial pressure resulting from the growth in offshore wind farms. However, the number of wind farms also increases rapidly in scenarios II (*Pragmatic Sustainability*) and III (*Rapid Development*), therefore necessitating various forms of multiple use of space in the North Sea.

We therefore assume that measures can be taken to protect nature, but it is unclear whether this will be possible. We cannot fully analyse the effects of an increase in wind power by a factor of 30 (scenario III *Rapid* Development) or even 60 (scenario IV *Sustainable Together*) in 2050 based on current knowledge on the negative effects of wind farms. These negative effects may also reinforce increases in other environmental pressure such as climate change. The Dutch Ecology and Cumulation Framework (KEC) has produced initial findings on the possible ecological effects of offshore wind energy in combination with other pressures on ecosystems in the North Sea. A five-year Dutch research programme also started in 2016 (the Dutch Governmental Offshore Wind Ecological Programme, or WOZEP) to study gaps in our knowledge concerning the ecological impact of offshore wind farms. Although the programme will produce a large amount of new data over the next five years, it cannot be expected to answer questions that we are not yet even aware of. Continual monitoring, based for example on WOZEP and KEC results, should be able to provide more information on the long-term effects of offshore wind turbines. Such monitoring would benefit from cooperation with other North Sea countries.

It is not possible in this study to define the conditions under which wind farms can be combined with nature reserves or fishing activities. After all, this depends on political decisions made regarding the three policy objectives of the 2030 North Sea Strategy.

… and timely measures need to be taken for the transport of electricity to and on land
If the installed wind power is to increase to about 1 GW per year – the target named in the Dutch 2017 Coalition Agreement for the period 2024–2030 – or more, we may be presented with a bottleneck before 2030 if all this energy needs to be transported to the Netherlands in the form of electricity.

The first issue is the lack of space along the Dutch coast to land many more power cables. One solution may be to use larger capacity cables, but new landing locations may still need to be found. The second issue is that strong growth in a variable offshore electricity supply may cause problems in the onshore electricity network as early as

2024–2030, for example if the power supply exceeds network capacity (congestion). This could result in power failure. A solution could be to ensure more flexible demand for power in the short term, along with the ability to temporarily reduce the offshore power supply as required. In the longer term, the existing national grid and interconnections with foreign networks need to be improved and expanded, for example using sub-surface DC power cables and/or overhead high-voltage lines. This will be particularly important if the ambitious targets for wind energy in scenarios III (*Rapid Development*) and IV (*Sustainable Together*) are met. However, the completion time of about ten years for such infrastructure projects means that decisions need to be made soon.

Conversion of electricity into hydrogen a possible solution to transport problems

The rapid growth in offshore wind energy after 2030 in scenarios III (*Rapid Development*) and IV (*Sustainable Together*) may require more significant changes to the energy system than adjustments to the onshore electricity network. For example, the problems associated with landing more electricity from wind farms may be solved using electrolysis to convert wind power into hydrogen (power-to-gas). Hydrogen is a concentrated form of energy and relatively easy to transport and store for long periods of time. In theory, therefore, the technology has many advantages when it comes to managing the growing variable power supply from offshore wind farms, and the energy transition in general.

The widespread implementation of power-to-gas in the energy system and its use as a production method for industrial applications is still in its infancy. Tennet and Gasunie are two companies developing pilot projects for the construction of an ‘energy hub island’ in the North Sea with a power-to-gas installation. Such energy hub islands are included in scenarios III (*Rapid Development*) and IV (*Sustainable Together*). In the short term, however, power-to-gas will not solve congestion issues in the onshore electricity network resulting from the offshore energy supply. The large-scale development of power-to-gas represents a fundamental choice: there are advantages to converting a variable electricity supply into hydrogen, but there is still too little demand and infrastructure in place to use hydrogen as an energy source or raw material.

International cooperation important when planning large-scale energy infrastructure

The North Sea countries are facing a considerable infrastructural challenge. While new infrastructure is required if they are to achieve their offshore wind energy ambitions, they also need to remove or reuse existing oil and natural gas infrastructure. In 2016, the North Sea countries formed the North Seas Energy Cooperation to deal with this. Spatial planning in the North Sea is also regulated at the European level through the EU Framework for Maritime Spatial Planning and the North Seas Countries’ Offshore Grid Initiative.

An efficient, environmentally friendly energy infrastructure in the North Sea can only be achieved if countries coordinate their spatial plans for achieving national energy transition goals at an early stage in the development process. This mainly concerns large-scale infrastructure such as wind farm sites, energy hub islands, interconnections with mains power cables and natural gas and oil pipelines and, possibly, new pipelines for transporting hydrogen to land or storing CO_2 beneath the North Sea. Coordinating the energy infrastructure in the North Sea with other North Sea countries will help the Netherlands develop the best plan possible for its own infrastructure. It may also help reduce the costs involved in the construction of wind farms and their connection to the electricity network.

Legislation must be coordinated and adapted to allow CCS in depleted natural gas fields

All offshore oil and natural gas production stops by 2050 in the scenarios, in line with current views on the exploitation of small natural gas fields. However, the rate at which exploitation is reduced is different under each scenario, and does not automatically match the demand for depleted natural gas fields created by CCS. A period of no more than roughly ten years between the decommissioning of a natural gas platform and bringing it into operation for CCS can reduce costs, a timeframe that is in line with the introduction of CCS and phasing out of natural gas platforms in scenarios III (*Rapid Development*) and IV (*Sustainable Together*). However, CCS is not introduced until the end of the 2030–2050 period in scenario II (*Pragmatic Sustainability*). As a result, some platforms will no longer be suitable for reuse and not enough suitable platforms may be available. This can be prevented by encouraging cooperation between the offshore companies, coordinated by the Dutch Government. Current legislation, which states that oil and natural gas platforms should be dismantled and removed once exploitation has ended, also needs to be changed.

Growth in wind power may necessitate measures for vessels that operate outside shipping routes

The increasing amount of space taken up by wind farms, in particular in the busiest area of the North Sea, may mean that there is not enough space for vessels that are not confined to shipping routes, such as fishing and recreational boats. Large vessels that are confined to shipping routes use the main shipping lanes, which will continue to provide sufficient space for these vessels. An increase will also be seen in vessel movements in and around the wind farms, for maintenance and supply purposes. As a result, these two types of vessels will increasingly cross one another's paths. Extra maritime traffic regulation (Vessel Traffic Service) can help ensure the safety of this extra traffic. However, less and less space will be left for smaller vessels outside the main shipping lanes, especially if they have to share this space with aquaculture or cast net fishing activities (using gill nets or entangling nets). One solution could be to create extra corridors between the wind farms or to allow vessels to pass through the wind farms. It may also be possible to create spatial synergy with aviation, by combining corridors that are free of wind turbines with helicopter routes.

Knowledge gaps
The scenarios highlight a number of gaps in our knowledge, which can be used by knowledge institutes working on energy transition policy to identify areas of study in their research programmes:

- Although natural gas is important in the current energy supply and as an industrial resource, its role will be much reduced as we go through the transition to a sustainable energy supply. Are hydrogen or other gases from offshore wind energy a realistic alternative? For example, what are the expected cost developments of hydrogen production and its use for industry or energy generation?
- Timing is very important when it comes to managing and coordinating future changes in oil and natural gas production, offshore wind energy, CCS and conversion into and the sub-surface storage of hydrogen. What options are available for achieving the most optimum result, and what are the obstacles?
- Although we know quite a lot about CCS technology and costs, we can expect questions to arise when we actually start using CCS in the Netherlands. For example, there are various governance questions concerning responsibilities for the capture, supply, transport and storage of CO_2 in practise.
- We still do not know what the long-term effects of a large number of wind farms will be on nature, as seen in scenarios III (*Rapid Development*) and IV (*Sustainable Together*). A continual monitoring programme could provide some answers and would be more successful if conducted by a consortium of North Sea countries.

Resilient ecosystems

A resilient ecosystem is an ecosystem that can withstand some stress and that has a useful function (i.e. it provides ecosystem services). Not only is this a national policy objective, but it is also important if we are to achieve one of the United Nations' sustainable development goals: conserve and sustainably use the oceans, seas and marine resources.

Ecosystems have improved in recent years: some fish populations are recovering, commercial fish stocks are improving, harbour porpoise and grey seal numbers are increasing and vulnerable seabed ecosystems are being better protected. Such improvements are largely the result of limiting or banning fishing practices that disturb the seabed in nature reserves. The eutrophication (an excess of nutrients) of seawater and the presence of hazardous substances in water have also been reduced to such an extent that any harm they cause to organisms can be considered negligible. Furthermore, fishing, which is currently the activity with the largest impact on nature in the North Sea, is conducted using more environmentally friendly fishing techniques.

However, despite such improvements, we cannot yet describe ecosystems in the North Sea as 'resilient'. Fish populations remain unstable – with large, old fish rare in many populations, for example. Current and future Natura 2000 sites provide some protection from fishing practices that disturb the seabed. However, a good environmental status – in other words a North Sea that is biologically diverse, clean, healthy and productive and used sustainably – has not yet been achieved in every respect.

Important policy challenges for the coming years include developing a nature reserve network, recovery of the seabed ecosystem, developing the food web (multiple food chains with common links), improving the status of seabirds, reducing the effects of acidification in the North Sea, reducing the ecological impact of fishing and countering the negative impacts of large-scale offshore wind energy development on birds and marine mammals.

Opportunities, bottlenecks and solution strategies

Create ecological networks on various scales
The future ecological status varies considerably in the scenarios, and therefore also the extent to which resilient ecosystems are achieved. Nature improves in every scenario, although to varying degrees. The progress made depends largely on the ambitions of the government bodies and sectors involved. In scenarios I (*Slow Change*) and III (*Rapid Development*), current policies continue and the total area of nature remains the same (20% of the Dutch continental shelf). The 'sustainable' scenarios also take the UN sustainable development goals into account: in scenario II (*Pragmatic Sustainability*), a larger network of nature reserves is created that covers

35% of the Dutch continental shelf; and in scenario IV (*Sustainable Together*), an international network of nature reserves and unprotected nature areas that together cover 50% of the Dutch continental shelf is created. This is connected to nature areas in neighbouring countries, which have equally ambitious aims.

General protection helps create resilient ecosystems
If we want to create resilient ecosystems, we need to protect nature areas as a whole and only allow activities in these areas that do not harm nature. This means, for example, no fishing that disturbs the seabed and limited fishing using passive fishing methods such as cast net fishing. This level of protection is considerably more ambitious than the 30% to 35% of nature reserves currently (or soon to be) closed to seabed fishing.

When designating nature reserves, we should take into account the fact that some species will probably migrate northwards due to the increase in water temperature. It is also important to align national ambitions with those of neighbouring countries, both in terms of designating nature areas and the conservation measures introduced. This creates synergy between national ambitions. It is also important not just to create conditions for recovery, but to also actively encourage recovery, for example by creating oyster beds or artificial reefs, or by reusing oil and natural gas platforms and wind turbine foundations as a hard substrate[5]. This is expected to benefit biodiversity, which is why it is important to change the obligation to remove decommissioned platforms and detail the conditions under which a platform may be left on the seabed.

Biodiversity flourishes in larger, better protected nature areas and in better water quality
Fish stocks increase in all four scenarios due to further improvements in water quality, and even more so in scenarios II (*Pragmatic Sustainability*) and IV (*Sustainable Together*) due to the further increase in the number of nature reserves. The increase in fish stocks and water quality in all four scenarios means that the number of marine mammals also increases in the scenarios. Fishing activities also become more sustainable in every scenario, although at varying rates. For example, new fishing techniques are developed that make more selective fishing possible. This reduces the negative impact of fishing on biodiversity and the number of marine mammals caught in fishing nets. The increase in fish stocks means that the number of seabirds also increases in the scenarios, and that only those seabirds that benefit from fishing activities drop in number, due to the landing obligation for bycatch.

Good environmental status can be achieved by 2030 under current policy
A ‘good environmental status’, which means that the sea is biologically diverse, clean, healthy and productive and used sustainably, can be achieved by 2030. Eutrophication is already being reduced under current policy, while stricter environmental standards and new technologies introduced in all four scenarios ensure that eutrophication is reduced even further while the environmental status continues to improve. Rising CO_2 concentrations do mean that acidification and seawater temperature will increase further, but to differing extents under the various scenarios. In scenarios I (*Slow Change*) and III (*Rapid Development*), with an average global temperature rise of 2°C in 2050, shellfish are particularly at risk due to the acidification of seawater; in scenarios II (*Pragmatic Sustainability*) and IV (*Sustainable Together*), with a temperature rise of 1°C in 2050, the effect will be much less.

Minimise impact of wind turbines on nature
Offshore wind power may increase significantly, from about 1 GW in 2017 to 32 GW in 2050 in scenario III (*Rapid Development*), and even 60 GW in scenario IV (*Sustainable Together*). In these scenarios, wind farms are also built in nature reserves. However, the wind turbine foundations form a hard substrate, which benefits biodiversity. This effect can be stimulated by designing and constructing the piles and foundations of wind turbines in such a way that they are both functional and beneficial to biodiversity as much as possible.

The construction and later dismantling of wind turbines can cause underwater noise disturbance. This can be reduced by using innovative construction and demolition techniques and by using floating wind turbines in water depths of 50 metres or more. The implementation of noise standards in the EU and the United Kingdom would also help reduce noise disturbance. Naturally, such standards need to be aligned.[6] The demolition of wind turbines also leads to the loss of hard substrate but, as mentioned above, this can be prevented by changing the obligation to remove decommissioned platforms and structures.

Damage to nature can also be prevented by carefully selecting wind turbine locations. Furthermore, seabird and bat mortality can be reduced by placing extra-large turbines far apart from one another, or by using turbines with two blades, or even one. It is also important to place wind turbines in areas in which the least collisions with seabirds and bats are to be expected. These are locations further out to sea, and therefore more expensive. Locations can also be selected to enable the creation of large, interconnected nature areas.

Knowledge gaps

The scenarios highlight a number of gaps in our knowledge, which can be used by knowledge institutes working on nature policy to identify areas of study in their research programmes:

- We still do not know enough about the effect of the further acidification of the North Sea, for example on shellfish and other organisms.
- The warming of seawater will probably result in changing migratory patterns of fish and other species; what will the effect of this be on biodiversity in, and ideal locations for, nature areas?
- Human activities in the North Sea, such as shipping, wind farms and sand extraction, are increasing. What are the cumulative effects of this in the long term, for example on marine mammals? This could be addressed in cooperation with the Dutch Ecology and Cumulation Framework.
- Wind turbines are responsible for seabird and bat mortality. What kind of figures are we looking at, and what is the effect of the turbine location, blade size and rotor technology? Additional research can help validate existing calculations.

Sustainable food supply

A sustainable food supply means a food supply that is economically, socially and ecologically sustainable. In other words, commercial fishing companies make a reasonable income, fish from the North Sea is available to every EU citizen, and fishing activities do not harm nature and the environment, either in the short or the long term.

Fishing vessels have become more efficient in recent years, while the number of fishing companies and vessels has decreased. These trends are expected to continue in the years to come, mainly due to mergers between fishing companies. However, the rate at which this happens varies in the scenarios. For example, the number of fishing companies and vessels decreases rapidly in scenario I (*Slow Change*), due to a drop in demand for protein-rich food, but primarily due to the Brexit. The decrease is less pronounced in scenario III (*Rapid Development*), due to an increasing demand for high-quality, local fish, and a soft Brexit.

A reduction in the number of fishing companies and vessels does not however imply a reduction in production and therefore in the food supply. After all, vessels are becoming increasingly efficient, and new EU fishing policy (that focuses on sustainable yields) and new techniques will help fish stocks recover, which may make it possible to increase catches in the future. Mergers between fishing companies may also benefit the sustainability of fishing activities, as larger companies often take a more long-term approach to operations and are more able to invest in new fishing techniques.

Aquaculture may provide an alternative to fishing. At present, the aquaculture sector in the Netherlands is small in size and, although diverse, focuses mainly on mussel and oyster production. Whether the sector will take off in the coming years, and whether it will also move to fish farming, depends to a large extent on population growth in the Netherlands and the rest of Europe (more mouths to feed), growth in prosperity (more money to spend on food) and changing preferences (shift in demand to protein-rich seafood). Although, at the international level, aquaculture may displace fishing to some extent, this is not the case on the Dutch continental shelf in any of the scenarios. The reason for this is that this area of the North Sea is too warm for salmon farming, and too cold for bass. Shellfish, microalgae and macroalgae (seaweed) farming probably have more potential than sustainable fish farming at sea. Offshore fish farms are only really an option in closed-containment systems, in which different cultures together form a production cycle.

Opportunities, bottlenecks and solution strategies

Wind energy, nature conservation and a hard Brexit will restrict space for fishing

The scenarios show that there will be less space available for fishing activities in the North Sea in the coming years, and possibly considerably less. The main contributing factors are the Brexit and offshore wind energy ambitions. A hard Brexit, as assumed in scenario I (*Slow Change*), can mean that British fishing grounds are closed to Dutch fishing vessels. Nature conservation and aquaculture, in particular shellfish, sea vegetable and algae farming, may also play a role.

This therefore requires a change in mindset in the fisheries sector as, while fishing has traditionally been possible almost anywhere, the sector increasingly needs to take other users into account. A hard Brexit will have a particularly large impact on the demersal fishing industry (fishing close to the seabed, e.g. of sole and plaice) if Dutch vessels no longer have access to British fishing grounds. As scenarios I (*Slow Change*) and II (*Pragmatic Sustainability*) show, overcapacity may again develop, necessitating further cutbacks in the sector.

Assign areas that give priority to nature, as well as areas that give priority to fishing

It is theoretically possible to fish in nature areas with harming the biodiversity, but this requires small fishing quota and the strict control of these quota and the fishing techniques used. It also requires fishing to be made more sustainable, which means bycatch needs to be reduced. It also helps if a clear distinction is made between nature reserves in which no or only selective fishing is permitted (passive fishing methods, no seabed fishing) and fishing grounds in which fishing takes preference over nature conservation. For example, 'fish fields' could be created for seabed fishing, which results in more fast-growing species, and may also benefit commercial fish stocks.

Fishing in wind farms possible by setting conditions for both sectors
Wind farms can be designed in such a way that it is possible to fish between the wind turbines ('fishing-inclusive' wind farms). Of course, the distance between the turbines needs to be large enough to be able to use various types of trawl nets, and cables need to be buried beneath the seabed (possibly in combination with overhead cables). In turn, fishing vessels may not use aggressive fishing methods that disturb the seabed such as traditional trawling, as this could expose or even damage buried cables.

Fishing sector benefits from clarity concerning long-term wind energy and nature objectives
It is important that the fishing sector is made aware of long-term ambitions concerning wind farms and nature reserves as early as possible. It is then in a position to anticipate any changes, for example by investing in different vessels or fishing methods, or by focusing on new activities such as services for wind farms or aquaculture.

Aquaculture easier to combine with nature areas and wind farms
The development of new nature areas and wind farms has less of an impact on aquaculture. This is because sustainable shellfish, microalgae and seaweed farming is relatively easy to implement, and can even help improve the local water quality. Aquaculture farming can also take place inside wind farms, although the equipment used will need to be designed to withstand storms, otherwise it could break loose and damage the wind turbines.

Climate change may mean that the fisheries sector needs to focus on different fish species
The predicted climate change is going to have an impact both on the fishing industry and aquaculture. The fisheries sector needs to take into account the fact that fish will migrate due to climate change. Species such as cod will migrate to areas north of the Dutch continental shelf, and species such as red mullet will migrate from areas further south to the Dutch continental shelf. The Dutch fisheries sector may therefore need to focus on other species of fish. The same will apply to aquaculture if it starts to focus more on fish farming.

Knowledge gaps
The scenarios highlight a number of gaps in our knowledge, which can be used by knowledge institutes working on food supply policy to identify areas of study in their research programmes:
- What will be the impact of innovative fishing methods (in particular 'precision' fishing) on yield, bycatch, fish stocks, fuel costs and other factors?
- Which conditions do the fisheries and wind energy sectors need to meet for fishing in wind farms to be both feasible and financially attractive?
- Which new aquaculture technologies could be applied in the short and medium term, and which increase the feasibility of aquaculture in wind farms?
- What technical possibilities and threats are offered by closed-containment systems in which fish farming is combined with mussel and seaweed farming, and what is the economic feasibility?

Increase in spatial pressure in the North Sea

The scenarios show that spatial pressure on the North Sea could increase significantly in the coming years. This is caused both by the energy transition and the aim to achieve resilient ecosystems and a sustainable food supply.

The installed wind power in 2050 varies in the scenarios from 12 GW in scenario I (*Slow Change*) to 60 GW in scenario IV (*Sustainable Together*). This will require an area of 3% to 26% of the Dutch continental shelf. However, areas currently designated for wind energy will probably only be sufficient in scenario I.

Nature conservation objectives may vary from maintaining current nature reserves (20% of the Dutch continental shelf) to the creation of a larger national network or even an international network of nature reserves (35%–50% of the Dutch continental shelf).

The North Sea will also be used more intensively for existing functions such as shipping, sand extraction and defence, as well as new functions such as aquaculture. In almost every scenario, there will be less space for the fisheries sector due to wind energy and nature conservation ambitions, but also due to a hard Brexit.

Combination of functions – multiple use of space – is needed
It is going to be difficult to increase the size of offshore wind energy areas and nature reserves without sharing the space with other functions. Space can be used by two functions, such as wind energy and nature, but a

combination of three functions, such as wind energy, nature, and aquaculture or fishing, is also possible. If the expansion of wind energy takes place at the cost of other sectors, the decision needs to be made whether, and how, these sectors are to be compensated.

Multiple use of space can create synergy but also conflict
Combining functions can create synergy, such as improved water quality due to mussel farming in nature reserves, but also conflicts, such as fishing practices that disturb the seabed in areas with fragile seabed habitats. In many cases, the multiple use of space means that conditions need to be set for the use of that space. In areas with several spatial claims, it is important to clearly describe which functions are permitted and the corresponding conditions for each function in comprehensive visions.

Value maps can help identify areas of synergy or conflict
Value maps can help identify opportunities for synergy and limitations to the multiple use of space at sea. A value map shows which areas are most valuable for a particular function and, by laying the maps on top of one another, where these areas overlap. It is then possible to determine where synergy is found between functions, and where conflicts may arise. In this process, particular attention should be paid to the relationship between the energy transition, resilient ecosystems and a sustainable food supply. When developing these maps, it is important to establish common frames of reference and rules of play, and to focus not just on the Paris Climate Agreement, but also on achieving a good environmental status and on the UN marine sustainable development goal. When this has been done, it is possible to determine which conditions need to be created to enable synergy and prevent conflict. It is also recommended to establish which function has the highest priority at a given location. Finally, it may be worth identifying who is to bear the extra cost of making the multiple use of space possible.

Stakeholder involvement and coordination with neighbouring countries essential
The results of the value map analysis may be used to develop visions and policy strategies for the North Sea. A comprehensive vision can be developed for the North Sea as a whole or for the Dutch continental shelf, for example by outlining the offshore spatial framework in the National Integrated Environmental Policy Strategy. However, a more detailed vision is required for the separate areas of the Dutch continental shelf, based on local conditions and this offshore spatial framework. Stakeholder involvement and coordination with neighbouring countries is essential for forming this vision.

Finally: it may sometimes be better to allow a certain function exclusive rights to an area
Although we need to make multiple use of space, exceptions are possible. Should a certain area prove to have an exceptionally high value for a certain function, this function should probably be given exclusive rights to the area. An example could be a nature area of high ecological value.

Knowledge gaps
Multiple use of space is less common at sea than on land. There are therefore a number of knowledge gaps when it comes to the multiple use of space at sea:
- How can the development and implementation of detailed visions contribute to innovative and effective forms of the multiple use of space?
- What opportunities do decommissioned oil and natural gas platforms and wind turbine foundations provide for nature (hard substrate) and aquaculture (anchoring points for equipment)?
- What are the possible synergies between wind farms and marine nature in the various phases of a wind farm (construction, operation and demolition)?
- What are the technical, economic and other conditions that make fishing and aquaculture possible in wind farms?

The future of the North Sea and the 2017 coalition agreement

This study into the future of the North Sea makes use of four scenarios. Many of the themes in these scenarios are also named in the 2017 Dutch Government's Coalition Agreement. What is the relationship between them?

1. *Wind energy*: The Dutch Government's Coalition Agreement aims for an additional 11.5 GW of offshore wind energy in 2030. This corresponds to the growth in wind power in 2030 in scenario III (*Rapid Development*).
2. *Underground storage of* CO_2 *in the North Sea*: The Coalition Agreement gives a figure for the underground storage of CO_2 of 18 Mt in 2030. CCS takes place in the North Sea in 2030 in two of the four scenarios: 15 Mt CO_2 in scenario III (*Rapid Development*) and 20 Mt in scenario IV (*Sustainable Together*).
3. *Designation of new nature areas (including in the North Sea)*: The Dutch Government indicates in its Coalition Agreement that it will not designate any new nature areas in addition to those agreed under EU policy. It is not possible to compare this policy proposal directly with the North Sea scenarios, as current European plans for the expansion of nature areas in the North Sea have not yet been finalised. The number of nature reserves increases in scenarios II (*Pragmatic Sustainability*) and IV (*Sustainable Together*), while the present status is maintained in scenarios I (*Slow Change*) and III (*Rapid Development*).
4. *Fishing grounds in the North Sea*: The Coalition Agreement states that the government will work in Europe to ensure that no more fishing grounds are closed than required under European law. The Netherlands will also request that decisions made concerning the locations of offshore wind turbines take the interests of the fisheries sector into account and that multiple use is permitted wherever possible. This is addressed in various ways in each of the scenarios.
5. *Fishing methods*: According to the Coalition Agreement, the Netherlands will focus on 1) preventing an EU ban on electric pulse fishing, and 2) relaxing the landing obligation once alternatives become available that achieve the same purpose. This specific policy aim is not named as such in the scenarios. On 16 January 2018, the European Parliament voted as a majority to ban electric pulse fishing under EU fishing regulations. In the Netherlands, Dutch fishing companies carry out electric pulse fishing experimentally on a relatively large scale. At the time of writing this report, it is not known what the exact impact of this recent ban will be on the use of this fishing method by Dutch fishing vessels in European waters.
6. *The fisheries sector and Brexit*: The Coalition Agreement states that the Netherlands will lobby for the interests of the Dutch fisheries sector in the Brexit negotiations. The government is therefore aiming for the international relationship with the United Kingdom described in scenarios III (*Rapid Development*) and IV (*Sustainable Together*).
7. *Greenhouse gas reduction*: In its Coalition Agreement, the Dutch Government states that it aims to reduce greenhouse gas emissions by 49% by 2030, while pressing in the EU for this to be extended to 55% by 2030. The 49% target corresponds more or less with the interim target of 50% in 2030 in scenario IV (*Sustainable Together*).

Notes

1 In the base year of the Kyoto protocol, 1990, greenhouse gas emission in the Netherlands totalled 223 Mt CO_2 equivalents.

2 Wind turbines with a total power of about 350 megawatts were installed in the Dutch sector of the North Sea in 2015. This increased to about 1 gigawatt in 2017. These turbines are capable of generating about 4 terawatt hours of electricity per year. A wind power of 60 gigawatts can generate about 250 terawatt hours. Electricity consumption totalled about 120 terawatt hours in 2015 in the Netherlands.

3 If CCS is included in the scenarios, it is responsible for 17% to 20% of the greenhouse gas reduction named in the scenario for 2030 and 2050.

4 The gross final energy consumption was 2 076 petajoules in 2015 (Nationale Energieverkenning, 2016).

5 Hard surface on which organisms can grow.

6 It is not clear, following Brexit, whether the UK will implement the same standards as the EU.

FULL RESULTS

ONE

Introduction

1.1 Rationale and urgency

The North Sea is one of the busiest seas in the world, with many different users. National and international developments relating to the energy transition, nature conservation, the food supply and other themes mean that pressure on space and the ecology in the North Sea will continue to increase in the coming decades. But by how much? And what can the Netherlands do about it?

The plans of countries bordering the North Sea for offshore wind energy can considerably impact spatial developments in the North Sea. In the Energy Agreement for Sustainable Growth (SER, 2013), plans are made for 4.45 GW of installed wind power in 2023 in the Dutch sector of the North Sea (the Dutch continental shelf).[1] Areas have been designated for this in the National Water Plan 2016–2021 (IenM and EZ, 2015a). The Dutch Energy Agenda 2016 and the 2017 Dutch Coalition Agreement talk of an extra 7 GW between 2024 and 2030, while ambitions of 20, 40 or even 80 GW have been identified for 2050, in various outlook studies (Ros and Daniëls, 2017). In comparison, about 1 GW of wind power was installed on the Dutch continental shelf in 2017.

Such ambitions can enable the Netherlands to take considerable steps along the transition pathway towards a sustainable energy supply, and even towards a position as a regional renewable energy supplier. The Netherlands currently extracts mainly fossil energy in the form of natural gas and some oil from the North Sea. Reserves on the Dutch continental shelf are however finite, and are expected to be depleted by 2050. When this happens, the pipeline and platform infrastructure will also need to be dismantled. This will need to be carefully planned and timed, as it could also be used for offshore wind energy and CCS in depleted natural gas fields.

The large-scale introduction of wind energy in the North Sea will have a considerable impact on the existing spatial structure and spatial pressures in the North Sea, while it may also affect the North Sea's ecology.

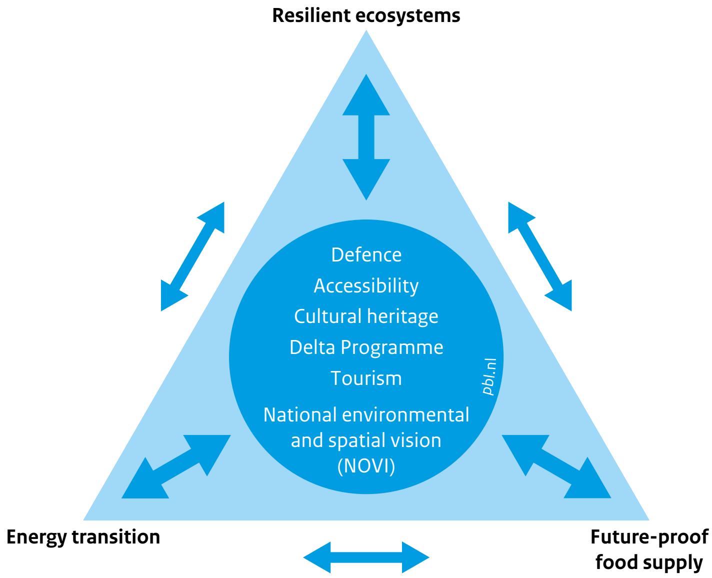
Under the European Marine Strategy Framework Directive (EU, 2008), the Netherlands aims to achieve a good environmental status (GES) in its seas. Even though the framework directive entered into force in 2008, achieving this GES in the North Sea in time ('by 2020') will not be easy. Of course, the Netherlands also depends on actions taken by other countries to achieve a GES in the North Sea. The possible rapid increase in human activities on the North Sea and the increasing influence of global climate change will also increase pressure on nature and the environment.

It is also clear that the current system of obtaining food from the North Sea will come under increasing pressure due to restrictions introduced to protect nature and the environment and due to the spatial claims of other sectors. In the short term, there is also the risk that Brexit will result in lower fishing quotas in the UK sector of the North Sea. The question for the long term is how the sector can continue to innovate to ensure a future food supply from the North Sea, for example by using sustainable and environmentally friendly fishing methods.

Such fundamental changes mean that policy choices need to be made now, while the uncertainties involved mean that a relatively large amount of flexibility is required. It is therefore important, while the Dutch Government is working on the 2030 North Sea Strategy, to consider long-term developments in the North Sea, and in particular on the Dutch continental shelf. What do we expect to be the main spatial and ecological bottlenecks, and what can or must the government and its partners do to solve these?

At the end of 2016, the Dutch Ministries of Economic Affairs and Climate (EZK), Infrastructure and Water

Figure 1.1
Policy themes North Sea strategy 2030



Source: www.noordzeeloket.nl

Management (IenW), Agriculture, Nature and Food Quality (LNV) and the Interior and Kingdom Relations (BZK) asked PBL to develop long-term scenarios to provide an idea of possible developments in spatial and environmental pressure in the North Sea. These were to be based on the scenarios in the WLO study, titled Welfare, Prosperity and the Human Environment (CPB and PBL, 2015a; 2015b).

1.2 Aim

In consultation with the ministries, PBL translated this request into a scenario study for the North Sea for 2030 and 2050, based on the question: 'What are the spatial and ecological consequences of plausible developments in the North Sea and, in particular, on the Dutch continental shelf, and what are the policy implications?'

This scenario study focuses primarily on the main policy themes in the 2030 North Sea Strategy: towards an energy transition, towards resilient ecosystems and towards a sustainable food supply (Figure 1.1). We also consider other sectors, users and themes in the North Sea. The scenario study focuses on national policy in the international context.

The scenarios can also help in the development of long-term visions for the various sectors, such as energy, fisheries, aquaculture and nature. What does the future hold for these sectors, and what are the long-term opportunities and threats, based on plausible developments in all the other sectors?

1.3 Methodology

We chose to investigate the future of the North Sea in 2030 and 2050 using scenarios, as the long-term nature of the study makes other methods less suitable. These North Sea scenarios do not represent policy plans or blueprints for the future but describe coherent possible and desirable future states of the North Sea and the developments and policies required to achieve these.

The North Sea scenarios are developed by applying two development pathways to two important scenario dimensions:

1. the economy and society: low or high dynamism;
2. policy ambition: current policies or sustainable ambitions.

Combining these two dimensions and two development pathways results in four scenarios. In terms of social and economic developments, the scenarios are in agreement with the 'The Netherlands in 2030 and 2050' WLO scenario study (CPB and PBL, 2015a). In the two current policies scenarios, developments in the North Sea assume the continuation of policy up to the end of 2017, and therefore do not include the ambitions of the 2017

Coalition Agreement. As far as achieving the climate targets is concerned, there is no difference between the scenarios and the 'high' and 'low' WLO scenarios. The two sustainable ambition scenarios assume that additional policy efforts are made to ensure that the contribution made by the Netherlands meets the ambitions of the Paris Climate Agreement and the UN sustainable development goal for the North Sea.[2] These scenarios therefore provide more opportunities for exploring the 'energy transition', 'resilient ecosystems' and 'sustainable food supply' themes from the 2030 North Sea Strategy and the National Integrated Environmental Policy Strategy (which has a time horizon of 2050).

In this study, each scenario consists of three components: the baseline situation, the scenario storyline and the conclusions. The baseline situation provides a brief analysis of current activities in the North Sea, current national and European policies, and developments that are expected to influence these. The scenarios explore possible future developments in activities in the North Sea, and the influence of policy and social and economic developments on these developments and in an international context. The conclusions include points for consideration and recommendations for policymakers and other stakeholders with an interest in the North Sea.

The scenarios provide comprehensive, coherent storylines regarding possible developments in the North Sea, which they place in a global and European context. The result is an overview of the most important developments and uncertainties, while providing the opportunity to consider developments in a particular sector in relation to overall developments.

Three workshops were organised to kick off the scenario development process: one to produce prototypes of the scenarios, one to develop these prototypes and one to extract the conclusions from the scenarios. A wide range of North Sea stakeholders took part in the workshops, including representatives from the ministries, provinces, business sector and knowledge institutes, and from various sectors, including energy, nature, fisheries, sand extraction and recreation (see background document (in Dutch)). The workshop outcomes were developed into four storylines for the future (see Chapter 3). Maps were produced to show the future state of the North Sea in 2050 under each of the scenarios. These maps were produced both for the North Sea as a whole and for the Dutch sector of the North Sea.

The scenario outcomes were produced using sector analysis. Model calculations were also made for the energy transition theme, based on the E-design model, which balances energy demand and supply with technologies that achieve a set greenhouse gas reduction target (see CPB and PBL, 2015b; Matthijsen et al., 2016). The background document provides an elaborated description of the energy demand under both current policies and the sustainable ambition scenarios is described in the background document.

Extra efforts will probably be required after 2030 to further reduce greenhouse gas emissions, while energy demand generally is expected to continue to increase as a result of macroeconomic developments. Note that the national energy mix[3] described in the scenarios should be regarded as primarily illustrative, even though it is based on current knowledge and realistic assumptions about developments in energy in the North Sea. It is of course possible to meet a certain energy demand and greenhouse gas reduction target using a variety of energy mixes.

The scenario study touches on various ongoing policy developments concerning the future of the North Sea (see Table 1.1). In this study, we describe possible developments in the North Sea, with a particular emphasis on energy, nature and food. Development in shipping and other North Sea sectors are addressed in the background report. This study therefore provides a comprehensive overview of relevant policy developments.

The scenario study can be used in a variety of ways. For example, the scenarios can be used to assess proposed policy as it may be considered desirable to develop policy that is both robust and flexible. Robust elements can be incorporated into every future explored in the scenarios (e.g. a minimum of 12 GW of offshore wind energy by 2050). Flexible policy elements may be implemented depending on developments and/or policy ambitions (e.g. 60 GW for a sustainable ambition and high social and economic dynamism). The scenarios can also help align future developments in the various sectors in the North Sea, based on the fact that they present coherent storylines of the future of the North Sea. Finally, the scenarios can be used as inspiration, for example to include aquaculture in wind farms or develop a policy process that goes further than the Dutch consensus approach to reach an agreement.

1.4 Structure of this report

The underlying data, hypotheses and information on which the developments in the North Sea sectors are based are described in a background document to this report. Reference is made to this background document at various points in this report.

ONE

Table 1.1

Current national policy developments relevant to the North Sea

2030 North Sea Strategy	A long-term Dutch strategy for the North Sea up to 2030 based on the national North Sea 2050 Spatial Agenda (IenW and EZK, not yet published).
2030 Offshore Wind Energy Road Map (*Routekaart Windenergie op zee 2030*)	Ensures continuity in Dutch Government ambitions for offshore wind energy up to 2030, after the current Offshore Wind Energy Road Map to 2023 has ended (EZK and IenW, 2018).
EU Marine Strategy Framework Directive	Obliges the Netherlands to develop and implement a marine strategy to maintain or achieve a GES and to ensure the sustainable use of the North Sea (EU, 2008). First cycle Marine Strategy (IenM and EZ, 2012).
National Integrated Environmental Policy Strategy	Contains strategic Dutch Government policy decisions regarding spatial planning in the physical environment, including the North Sea (BZK, not yet published). Based on the Environment and Planning Act.
EU directive for Maritime Spatial Planning	Ensures that the Member States develop and implement maritime spatial planning in order to contribute to the objectives of the framework directive (EU, 2014a).
North Sea Nature policy analysis	Part of the 2030 North Sea Strategy.
North Seas Energy Cooperation	Framework for international cooperation. Facilitates the use of efficient forms of renewable energy on the North Sea, in particular wind, and interconnections with the energy infrastructure of other countries (Political Declaration, 2016).

Chapter 2 starts with a description of the current environmental status of the North Sea, and of the North Sea as a source of food. This is followed by a brief overview of the activities that take place on the Dutch continental shelf, and the policy frameworks put in place by the Dutch Government to ensure the efficient and sustainable use of the space on the Dutch continental shelf. An overview is also given of the current policies in place relating to the multiple use of space, or the possibility or impossibility of combining several user functions in a particular area. The chapter ends with a brief description of the international context of offshore wind energy.

Chapter 3 deals with the four North Sea scenarios, which provide coherent visions of the North Sea. In these scenarios, we describe possible future developments at the national and international level and national and international policies that impact the North Sea. We also describe possible developments in the energy transition, sustainable food supply and resilient ecosystems themes, and briefly address development in other sectors.

In the fourth, and last, chapter, we discuss the scenario outcomes based on the themes in the 2030 North Sea Strategy: the energy transition, resilient ecosystems and a sustainable food supply. For each theme, we discuss futures according to the scenarios and name the bottlenecks and possible synergies. We then address the various pathways that can be taken to achieve the policy objective and possible solutions to the bottlenecks. We also name the main knowledge gaps as they emerge for each theme in this study. ‘Multiple use of space’ is also addressed as an overarching theme in Chapter 4.

Notes

1 The Dutch continental shelf, or the Dutch Exclusive Economic Zone (EEZ).

2 Sustainable development goal 14: conserve and sustainably use the oceans, seas and marine resources.

3 All the different technologies used to generate energy in the Netherlands.

TWO

The North Sea now

2.1 Introduction

The North Sea is one of the most intensively used seas in the world. Especially in the Dutch sector, where numerous shipping routes pass along the Dutch coast and to and from Rotterdam, Antwerp, Zeebrugge, Amsterdam and Eemshaven/Delfzijl. Oil and natural gas is produced in the North Sea, and wind energy is generated. Cables and pipelines connect oil and natural gas platforms and wind farms to land, and telecommunications cables form part of the global communications network. The North Sea is also an important source of sand for coastal protection and fill sand for infrastructure and buildings. Fishing also takes place in many areas in the North Sea, and military exercises are conducted using ships and other material. All of this is putting increasing pressure on the marine ecosystem (NIOZ et al., 2015).

In this chapter, we briefly describe the current environmental status of the North Sea and of the North Sea as a source of food. We then provide an overview of the activities and the space required for these activities on the Dutch continental shelf. We also summarise the policy frameworks put in place by national government to ensure the efficient and sustainable use of the space on the Dutch continental shelf, and of the current policies in place relating to the multiple use of space, or, in other words, the possibility or impossibility of combining several user functions in a particular area.
Most of this information has been obtained from the Policy Document on the North Sea 2016–2021 (IenM and EZ, 2015b) and noordzeeloket.nl (a government website).

2.2 The current environmental status of the North Sea

One of the main strategic aims of the 2030 North Sea Strategy and the National Integrated Environmental Policy Strategy is to achieve 'resilient ecosystems'. This will need to be weighed against the other two strategic aims, which are to achieve 'an energy transition' and 'a sustainable food supply'.

The status of nature in the North Sea has improved in recent years: some fish populations are recovering, commercial fish stocks are improving, harbour porpoise and grey seal numbers are increasing and vulnerable seabed ecosystems are being better protected (NIOZ et al., 2015). Roughly one third of the Dutch continental shelf is currently designated as nature: almost 20% as Natura 2000 sites and almost 15% as other areas of ecological interest. Of course, there is also nature outside these areas.

The environmental status of the North Sea has also improved: concentrations of eutrophying and hazardous substances in seawater have been reduced to levels at which they no longer harm organisms, and less litter is found on beaches. Furthermore, the fisheries sector using more environmentally friendly fishing methods and fishing practices that disturb the seabed are limited or banned in areas with vulnerable seabed ecosystems. The status has improved in particular at Natura 2000 sites, as the species found at these sites are protected. The introduction of new non-native species and therefore the increase in exotic species has also been reduced.

Despite such results, ecosystems are still not at a point where they can be called resilient. Large fish have either become rare or have disappeared altogether, and the populations of some vulnerable species such as sharks and rays have declined considerably. In addition, not every nature area has been designated as such and enjoys protection, and management plans have still not been drawn up for every area. Fishing practices that disturb the seabed are also still permitted in some nature areas, and litter is still found in the sea (plastic soup).

Furthermore, the environmental status is not satisfactory and does not meet EU agreements concerning a good environmental status of the sea (IenM and EZ, 2014a). A good environmental status (GES) applies to an ecosystem that functions optimally, is resilient and therefore can be used sustainably. Although we are closer to achieving a good environmental status, but the environment is slow to recover. The Marine Strategy Framework Directive obliges EU Member States to reach a GES by 2020, but this is unlikely to be achieved by the Netherlands, despite the policies in place. This means that one of the UN sustainable development goals – the sustainable use of the sea – will also not be achieved in the short term.

The main challenges for the coming years are therefore to develop a connected network of nature reserves, to encourage recovery of the seabed ecosystem and the development of the food web, to improve the status of seabirds, to combat the effects of acidification of the North Sea, to increase the sustainability of the fisheries sector and to analyse and limit the impact of offshore wind energy development on seabirds and marine mammals.

This is complicated by the fact that we do not know what exactly we are working towards in terms of a nature reserve network and the good environmental status, nor the contribution to be made by the Netherlands. This is due in part to the complex and dynamic nature of the North Sea ecosystem, the long-term or even permanent presence of hazardous substances and exotic species, and limits to our knowledge. It is therefore also difficult to determine the extent to which policy efforts can achieve recovery of the marine environment, and how long such recovery will take (IenM and EZ, 2015a).

2.3 The North Sea as food source

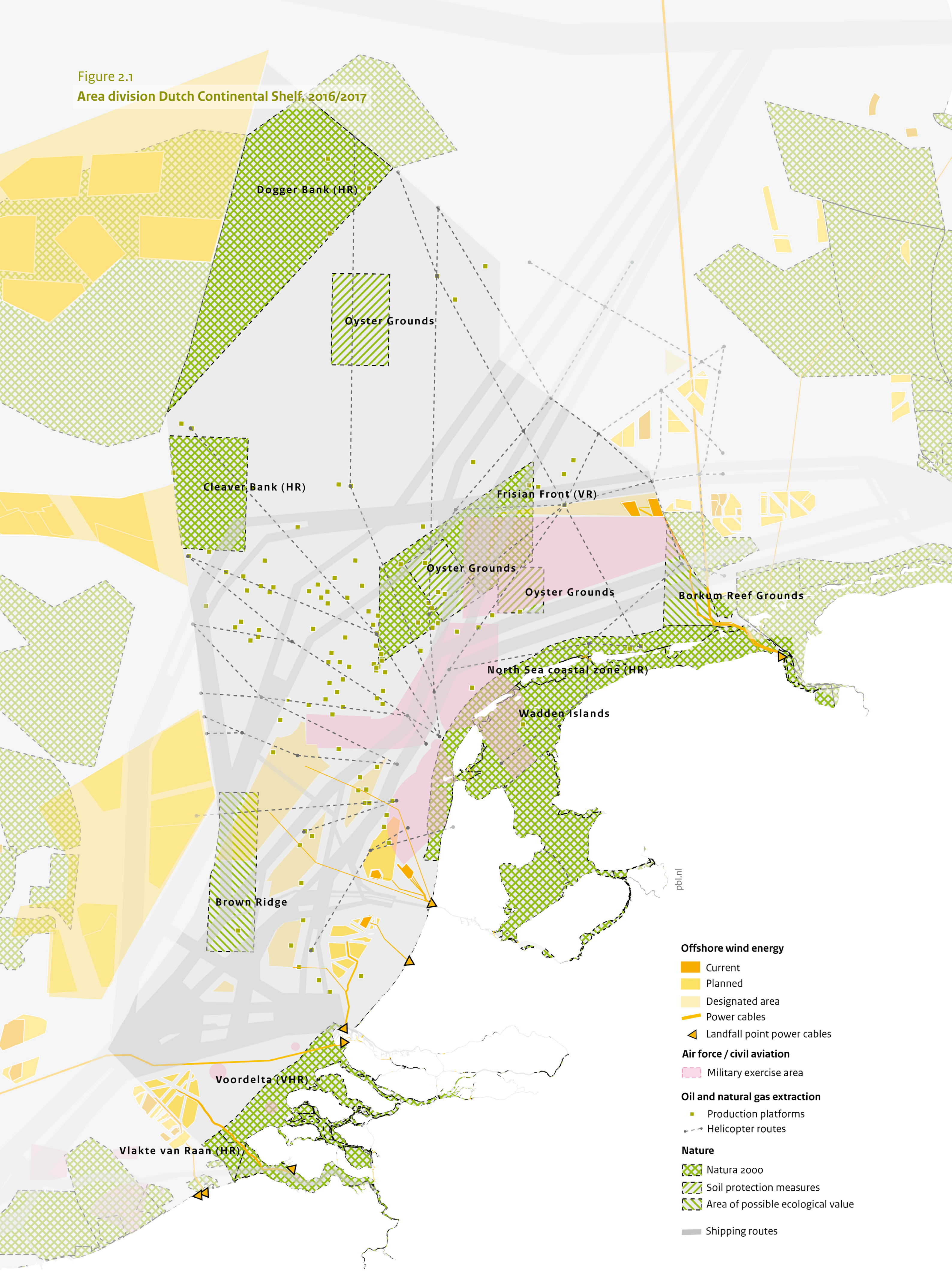
One of the strategic aims of the 2030 North Sea Strategy and the National Integrated Environmental Policy Strategy is to achieve ‘a sustainable food supply’. This will need to be weighed against the other two strategic aims, which are to achieve ‘an energy transition’ and ‘resilient ecosystems’.

There are currently over 650 vessels in the Dutch fishing fleet, of which almost 600 are active (LEI, 2017). Although there has been a large decrease in the number of deep sea fishing vessels, the number of other fishing boats has remained roughly the same. Following years of decline, the number of large cutters is starting to increase again, mainly due to good results in recent years and larger catches allowed within the fishing quotas. This trend is likely to continue in the short term.

Most fishing companies in the Netherlands are family businesses, many of which have been passed down from generation to generation. In the 1960s, companies started to intensify their operations (NIOZ et al., 2015). There has been a decrease in the number of crew members and vessels, while vessel efficiency has increased as a result of mechanisation and automation. There has also been a trend in recent years of larger companies buying vessels from smaller companies. All of these developments have led to high pressure on the fisheries sector and a significant increase in fish mortality due to fishing practices. Some fish populations have therefore been considerably reduced, so that fishing vessels have to travel further, using a lot of fuel to catch fewer fish.

A review of the Common Fisheries Policy aims to address such problems. The government hopes to regulate fishing so that populations can recover to a level that provides maximum productivity for the fisheries sector. At the same time, a ban has been introduced on the discard of healthy and edible fish at sea, which makes it easier to manage the actual fishing effort. Policy has increasingly come to focus on the protection and recovery of the marine ecosystem in recent years. It is therefore no longer just about the sustainable management of commercial fish stocks, but of all marine ecosystems (LEI, 2014). Policy also focuses on species that may not be of direct interest to the fisheries sector, such as birds and benthic organisms.

Figure 2.1
Area division Dutch Continental Shelf, 2016/2017



Source: H+N+S Landscape Architects

Table 2.1

Extent and area taken up by activities on the Dutch continental shelf

Activity	Extent of activity	Area	
		km²	percentage of Dutch continental shelf (59,000 km²)
Natura 2000 site	4 sites along the coast (North Sea coastal zone, Voordelta, Vlakte van de Raan and the Delta waters) + 4 areas in the Exclusive Economic Zone (Dogger Bank, Cleaver Bank and Frisian Front).	11 374	20
Wind energy	Currently 4 operational wind farms in the Dutch sector of the North Sea with a collective power of 957 MW: Egmond aan Zee (108 MW), Prinses Amalia (120 MW), Luchterduinen (129 MW) and Gemini Offshore (600 MW). Future wind energy sites have also been designated.	134 (current wind farms) 2,939 (designated sites)	0.2 (current) 5 (designated)
Surface mineral extraction	25 million m³/year, half of which is replenishment sand used for coastal defences and the other half fill sand for construction and infrastructure. Occasional large-scale sand extraction is also carried out for projects such as Weak Links (Zwakke Schakels) and the construction of Maasvlakte 2.	Average of 15 km²/year	0.03
Oil and natural gas production	161 platforms.	126 (based on a 500 m safety zone around each platform)	0.2
Cables and pipelines	There are 4,500 km of pipelines and 3,300 km of cables on the seabed.	7,800 (based on a 500 m safety zone along each side of the cable or pipeline)	13
Shipping routes		3,600	6
Military exercise areas	Areas to the west of Kop van Noord-Holland are designated as military ranges. Areas to the north-west and north of the Wadden Islands are designated as low-level flight training areas.	4,200	7
Fishing	The Dutch fishing fleet (roughly 600 vessels) can be divided into coastal and North Sea fishing vessels, deep sea fishing vessels (pelagic freezer trawlers), shellfish fishing vessels and cast net fishing vessels. Species of commercial interest in the North Sea include sole, plaice, langoustine, shrimps, mussels and oysters.	EEZ and territorial waters minus closed areas (wind farms and parts of Natura 2000 sites)	n/a
Helicopter main routes	Various flight paths are reserved over the North Sea for helicopters to ensure they have access at all times to platforms. This is in addition to the obstacle-free zone of five nautical miles around these platforms, and paths reserved for search and rescue operations.		

Source: IenM and EZ (2015b)

Technological developments are also taking place in the demersal, or seabed, fishing industry. Traditional trawling, which severely disturbs the seabed and uses a lot of energy, is used less and less, not just because of increasing fuel prices, but also due to stricter environmental legislation. Traditional trawling is increasingly being replaced with new trawling methods such as pulse trawling and the sumwing.

Many fish populations have started to recover since the year 2000. Most commercial species, such as plaice and herring, are doing better than they were, and some stocks are again within safe biological limits. A number of stocks (herring, plaice, haddock) are either at or below the 'maximum sustainable yield' level. It is increasingly possible to fish some species sustainably (plaice, sole, herring, whiting), while some stocks (cod, shark, ray) are still at risk.

Although the fisheries sector is doing well at the moment, several developments continue to put pressure on the sector. For example, the increase in the amount of space required for wind energy and nature limits the space available for fishing activities. Furthermore, Brexit negotiations between the United Kingdom and the EU could result in considerable restrictions on demersal fishing in the North Sea.

The aquaculture sector in the Netherlands is relatively small in size and highly diverse (LEI, 2016). Part of the sector is only active on the shore, in particular fish farming, and shellfish and seaweed farming currently take place mainly in the waters of the delta (Grevelingen, Oosterschelde). We are also seeing some initiatives for the farming of sea vegetables. European and Dutch policy both encourage the further development of the aquaculture sector, and various pilot projects are ongoing.

The role of sustainability certification in the fisheries and aquaculture sectors is increasing in the commercial retail and food service sector, not just in the Netherlands but throughout northern and western Europe (EZ, 2014). There are also certification schemes for organic production. Demand is also increasing for locally grown or caught products, and restaurants and caterers increasingly use this as a unique selling point.

2.4 Current activities on the Dutch continental shelf: extent and area

The Dutch continental shelf provides space for a large number of activities, as well as several Natura 2000 sites. Traditional activities include oil, natural gas, sand, gravel and shell extraction, shipping, fishing and aquaculture (fish, shellfish and seaweed farming), military exercises, recreation, oil and natural gas transport through pipelines, and electricity transport and communication through cables. Wind energy has recently been added to this, and the Dutch Government plans to store CO_2 in depleted oil and natural gas fields.

Figure 2.1 shows which areas on the Dutch continental shelf are designated for wind energy, shipping[1], oil and natural gas production, military exercise and nature. Nature areas include Natura 2000 sites under the Birds Directive, the Habitats Directive, and the Birds and Habitats Directive. Areas are also designated outside the Natura 2000 sites in which seabed protection measures apply, as well as other sites that may be of ecological value. Fishing activities are not shown on the map as these can, in theory, take place anywhere on the Dutch continental shelf, except in areas in which it is expressly forbidden (e.g. in wind farms). Fishing practices that disturb the seabed are also banned in some parts of Natura 2000 sites. This is discussed further in Section 2.6 on the multiple use of space. Table 2.1 shows the extent of each activity and the area it currently takes up.

2.5 Policy frameworks for future use of the Dutch continental shelf

The anticipated increase in the use of the Dutch sector of the North Sea means that we need to make good use of the limited space available. Policy has been drawn up to ensure that the various activities are coordinated, and to enable a healthy ecosystem to develop. In the Policy Document on the North Sea 2016–2021, the Dutch Government gives priority to activities that are of national interest to the Netherlands, within the relevant European frameworks (Water Framework Directive, Marine Strategy Framework Directive, Birds and Habitats Directives and the Malta Convention).

Table 2.2 shows, for each activity:
- whether it is of national interest;
- whether it is covered by an international agreement (and, if so, which one);
- government policy objectives relating to the activity.

2.6 Opportunities for the multiple use of space

No activities are permitted in areas designated by the government for activities of national interest (see Figure 2.1) that may hinder this primary activity. However, increasing spatial pressure on the Dutch continental shelf means that the government aims to ensure multiple use of space wherever possible. If activities of national interest overlap spatially, the aim is therefore to strive for a combined, efficient use of space, as long as the primary user does not experience any unreasonable adverse effects or impediments as a result (IenM and EZ, 2014b). In the 2050 spatial agenda (IenM and EZ, 2014a), areas are only reserved (temporarily or permanently) for a single activity if this is required due to the fragility of the marine environmental or for local safety reasons.

Designated areas for each activity are briefly discussed in Sections 2.6.1 to 2.6.6, along with how these activities may be combined under current policy.

Table 2.2

Activities on the Dutch continental shelf: national interest, international agreements and national policy objectives

Activity	National interest?	International agreements	National policy objectives
Marine ecosystem	No	Water Framework Directive, Marine Strategy Framework Directive, Birds and Habitats Directives	The marine strategy should take an ecosystem-oriented approach to the management of human activities and allow the sustainable use of marine goods and services for current and future generations.
Renewable energy	Yes	No	Sufficient space for wind energy and other forms of renewable energy, combined wherever possible. A wind power capacity of about 4.45 gigawatts is projected up to 2023.
Surface mineral extraction	Yes	No	The sand extraction strategy aims for the responsible and cost-effective management of available sand reserves in the priority zone (between the continuous NAP -20m isobath and the 12-mile boundary).
Oil and natural gas production	Yes	No	As much natural gas and petroleum as possible is to be extracted from Dutch reserves in the North Sea.
CO_2 storage	Yes	No	Sufficient space for the storage of CO_2 in depleted oil and natural gas fields or in underground aquifers.
Cables and pipelines	Yes (transport of fuels and CO_2; does not apply to telecommunication cables)	No	Space for wind energy, oil and natural gas production and the storage of CO_2, including the required cables and pipelines.
Shipping	Yes	Routes established by the International Maritime Organization (IMO)	Maintain a system of traffic separation schemes, clearways and anchoring areas capable of accommodating vessels safely and swiftly and ensuring access to sea ports.
Defence	Yes	No	Sufficient exercise areas in the North Sea.
Fishing and aquaculture	No	Fishing quota set in the Common Fisheries Policy	Foster responsible fishing and aquaculture practices and the balanced use of fish stocks, strive towards a state of equilibrium between fishing and nature and a different division of responsibilities between government and industry.
Underwater cultural heritage	No	Malta Convention	The conservation of sites of archaeological value (submerged settlements, shipwrecks and other archaeological values). If this is not possible, for example because other interests take priority, then the scientific value should be secured.
Tourism and recreation	No	No	No permanent structures are permitted in the 12-mile zone. Nevertheless, 2 additional wind energy areas have been designated between 10 and 12 miles from the Dutch coast.
Aviation	Yes	ICAO and EASA	The safe use of airspace above the North Sea for search and rescue operations and access to offshore platforms.

Source: IenM and EZ (2015b)

2.6.1 Shipping

Areas

Current shipping routes, anchoring areas and separation zones are shown in Figure 2.1. The system of shipping routes off the Dutch coast was adapted in August 2013[2], with the aim to ensure maritime traffic safety, the continued accessibility of ports and increasing space for offshore wind energy. The Netherlands thoroughly prepared and submitted these changes to the International Maritime Organization (IMO).

Opportunities for multiple use of space

- In traffic separation schemes, deep-water routes, anchorages, precautionary areas and clearways, shipping takes priority over other activities.
- For safety reasons, mining installations and other permanent structures are not permitted in shipping

routes or within a 500-metre zone alongside these shipping routes [3].
- Fishing, surface mineral extraction and recreational activities are permitted in shipping routes[2]. However, fishing vessels must always cross shipping routes perpendicular to the route.

2.6.2 Oil and natural gas production and CO_2 storage

Areas
The locations of oil and natural gas platforms are shown in Figure 2.1. Depleted oil and natural gas fields may be used for the future storage of CO_2.

Opportunities for multiple use of space
- Neither vessels nor any other activities (including fishing) are permitted within a 500-metre zone around mining or CO_2 storage installations.
- An obstacle-free zone of five nautical miles is required around platforms with a helipad. Exclusions may be made in specific situations, which means that wind turbines may also be permitted in this zone.
- The locations of and conditions for proposed wind energy sites will be determined in such a way that they have a minimal impact on future mining interests (prospects).
- Oil and natural gas production is, in theory, permitted at Natura 2000 sites.

2.6.3 Wind energy

Areas
Up to 2017, the Dutch Government had designated the following areas for offshore wind farms: Borssele, IJmuiden Ver, Hollandse Kust and the area to the north of the Wadden Islands. The government does not currently permit the construction of wind farms outside these designated areas. All of these areas lie outside the 12-mile zone, with the exception of two strips between 10 and 12 nautical miles that have been added to Hollandse Kust north and Hollandse Kust south. Based on the power density of the installed wind farms (6 MW/km^2), the designated areas, with a total surface area of 2 900 km^2, are capable of providing 17–18 GW of wind energy. This represents 5% of the total area of the Dutch continental shelf.

Opportunities for multiple use of space
- The generation of renewable energy takes priority over other activities in the areas designated for wind energy.
- Shipping is not permitted in wind farms or within a 500-metre safety zone around a wind farm.
- Vessels up to 24 metres in length will be able to pass through wind farms in daylight hours. Fishing vessels to which this applies may only pass through the safety zone around a wind farm if all fishing gear that could disturb the seabed is visible above the water line. All seabed activities (anchoring, towing fishing gear) are forbidden inside the safety zone (IenM, 2015).
- When allocating wind energy sites, the 'Distance between shipping routes and wind farms' development criterion apply.[4] The requisite safe distances for shipping are:
  - for vessels more than 400 metres in length: 1.87 NM on the starboard side and 1.57 NM on the port side;
  - for vessels more than 300 metres in length: 1.54 NM on the starboard side and 1.24 NM on the port side.
- Regarding the distance between cables and offshore wind farms, a maintenance zone of 500 metres is required for electricity cables and pipelines and 750 metres for telecommunications cables (this is reduced to 500 metres inside wind farms).
- Multiple use will be possible for recreational and other activities that do not disturb the seabed, as well as for aquaculture and other forms of sustainable energy generation.

2.6.4 Sand and shell extraction

Areas
Good sand extraction sites close to the coast are important for ensuring that coastal defences in the Netherlands remain affordable. Sand extraction, therefore, takes priority in the zone between the continuous NAP -20 m isobath and the boundary of the 12-mile zone. The average depth of a sand extraction pit must be greater than two metres. Such measures will ensure that the Netherlands has sufficient reserves in its designated sand extraction areas for the rest of the 21st century.

Shell extraction is permitted in areas between the NAP–5m isobath and 50 kilometres from the coast. As in the North Sea and the Voordelta, shells are also extracted in the outer deltas and tidal inlets of the Wadden Sea.

Opportunities for multiple use of space
- The extraction of sand and other surface minerals is banned or severely limited in the vicinity of cables and pipelines.
- New cables and pipelines should use preferred routes when transecting a sand extraction zone.
- In the case of possible spatially conflicting interests in the 12-mile zone (e.g. cable laying or wind farm construction), the party concerned must compensate the sand extraction company for the additional costs involved in extracting sand elsewhere.
- Shipping and fishing are possible in sand extraction areas.

2.6.5 Natura 2000

Areas

The Birds and Habitats Directives, Marine Strategy Framework Directive and OSPAR Convention stipulate that marine areas of particular ecological value must be protected. With this in mind, various Natura 2000 sites have been designated as nature along the Dutch coast: the North Sea Coastal Zone, Voordelta, Vlakte van de Raan and the Delta waters and, further out to sea on the Dutch continental shelf, Dogger Bank, Cleaver Bank and Frisian Front (Brown Ridge has not yet been designated a Natura 2000 site).

Opportunities for multiple use of space

- Natura 2000 sites have been avoided when designating wind energy areas (see Figure 2.1), to avoid any undesirable effects.
- Some shipping routes run straight through Natura 2000 sites.
- On average, 30% to 35% of Natura 2000 sites are closed to fishing activities that disturb the seabed.
- There is no physical overlap between sand extraction areas and Natura 2000 sites. Natura 2000 sites are found either in the zone between the coast and the NAP -20m isobath, or outside the 12-mile boundary, whereas sand extraction takes place in the zone between the NAP -2m isobath and the 12-mile boundary. However, sediment and silt released during the extraction of silt-rich sand can impact benthic communities in Natura 2000 sites located close to sand extraction areas. According to the Vlakte van de Raan draft management plan, sand extraction from sites deeper than two metres in the seabed is only permitted if it takes place at least 2 000 metres from the Natura 2000 site. The draft management plan for the North Sea Coastal Zone only explicitly states that no sand extraction for coastal replenishment may take place in the area and does not give a minimum distance.

2.6.6 Defence

Areas

Military exercise areas are designated in the Second National Structure Plan for Military Areas and in the National Water Plan 2009–2015. More specifically, these documents describe the military ranges and low-level flight training areas on and above the North Sea and the Wadden Sea. Areas to the west of Kop van Noord-Holland are designated as military ranges. Areas to the north-west and north of the Wadden Islands are designated as low-level flight training areas.

Opportunities for multiple use of space

- As long as no military exercises are being carried out, military exercise areas may also be used for other activities such as shipping, fishing and sand extraction.
- Multiple use involving permanent structures is prohibited for safety reasons.
- Oil and natural gas production using mobile installations is possible in certain periods.

2.6.7 Multiple use of space – conclusion

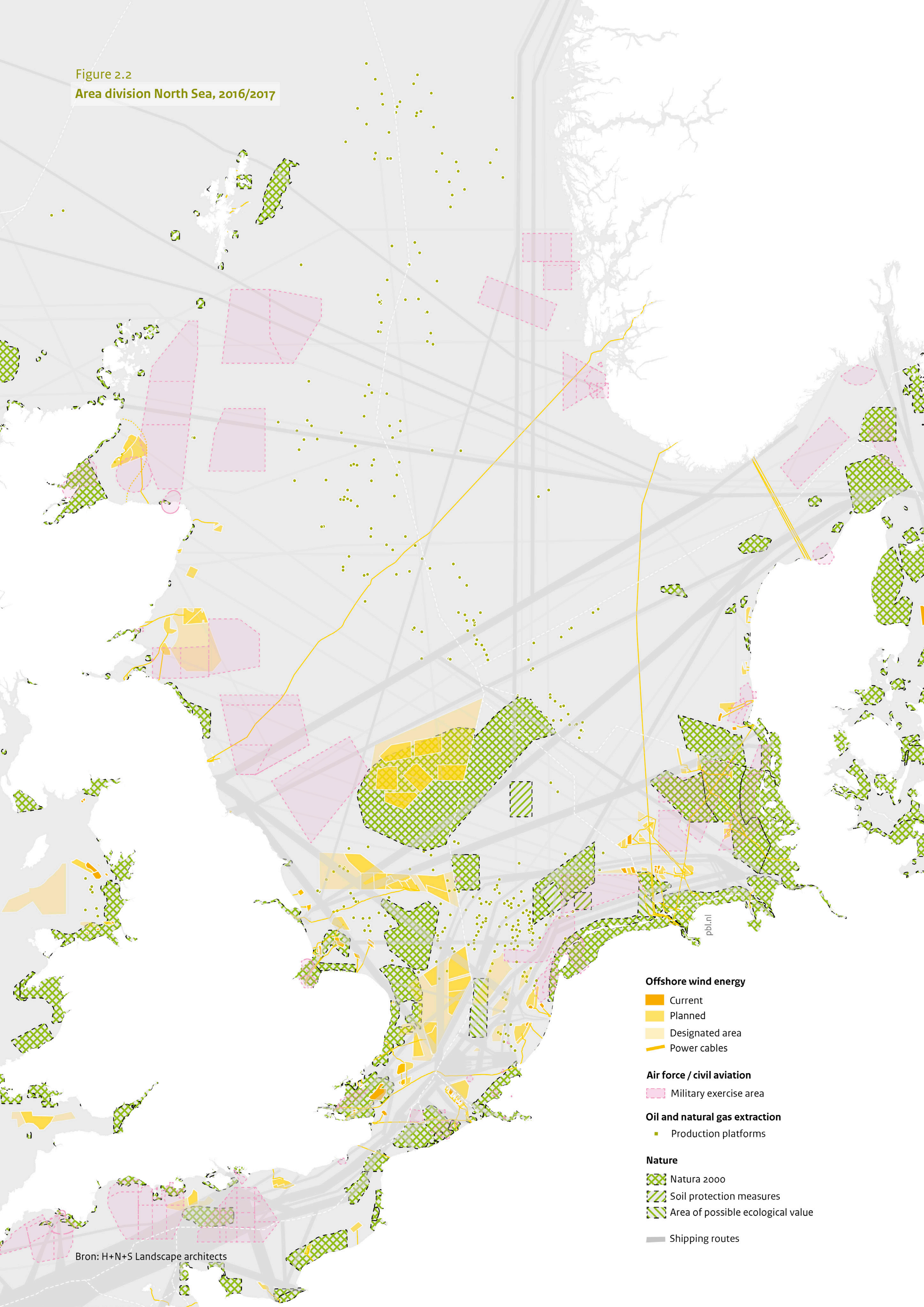
Measures in place to regulate the multiple use of space are currently sufficient to prevent any conflict. However, if – as is assumed in a number of scenarios in this study – wind power increases on the Dutch continental shelf from the current level of 1 GW to possibly 60 GW, bottlenecks will develop. This will be exacerbated if the number of Natura 2000 sites also increases. After all, the multiple use of space is not always possible under current legislation. For example, fishing methods that disturb the seabed are not permitted in wind farms and parts of Natura 2000 sites, which means there will be less sea to fish in. Neither is there enough space for wind energy and Natura 2000 sites to be kept separate, as is currently the case.

Choices therefore need to be made in the scenarios that represent high growth in wind power and/or the number of nature areas (scenarios II, III and IV); choices that deviate from the current spatial frameworks. For example, fishing is permitted in wind farms in scenarios II and III, and wind farms are permitted in Natura 2000 sites in scenarios III and IV. On the other hand, fishing is not permitted in Natura 2000 sites in the 'sustainable' scenarios II and IV, for ecological reasons. These choices are explained further in the relevant sections in Chapter 3.

2.7 Offshore wind energy: the international context

When designating areas for wind energy, we need to consider not only the interaction with other activities on the Dutch continental shelf, but also the interaction with activities in the Exclusive Economic Zones (EEZs) of the other North Sea countries[6]. It is important that the North Sea countries coordinate their plans. For example, a large wind farm on the border between the EEZs of two North Sea countries can affect the wind regime in a wind farm or the ecological pressure on a Natura 2000 site just across the border. The planning of infrastructure for the transport of electricity from wind farms also benefits from coordination between countries regarding wind farm locations.

Figure 2.2
Area division North Sea, 2016/2017



Bron: H+N+S Landscape architects

2.7.1 Planned wind power in neighbouring countries

The installed wind power on the whole of the North Sea was 9.1 GW in 2016. The United Kingdom and Germany are planning particularly large investments in offshore wind energy in the coming years. Over 19 GW of wind power was licensed on the North Sea in 2016 (WindEurope, 2017).

Figure 2.2 gives an overview of the areas designated by the North Sea countries for wind energy, Natura 2000 sites and defence activities. As we can see, activities in certain areas of the EEZs of the United Kingdom, Belgium, Germany and the Netherlands can negatively impact one another. Problems arise because the wind intensity downwind of a wind farm is lower and therefore capable of producing less power. The construction of a wind farm or wind turbines can also have a negative impact on nature. The most obvious problems are:

- The United Kingdom has planned several large wind farms on the Dogger Bank, while the Netherlands has designated the area just across the border as a Natura 2000 site.
- The United Kingdom has designated a large area for wind energy to the west of the Dutch IJmuiden Ver wind energy area. If this is developed, it could affect wind conditions in IJmuiden Ver.
- Germany is planning a wind energy area next to the Dutch wind energy area to the north of the Wadden Islands. This may also affect the wind intensity.
- Similarly, an area designated by Belgium as a wind energy area will affect the wind intensity in the Borssele wind farm on the Dutch side of the border, which is currently being developed to the north-east of the Belgian wind farm.

2.7.2 International wind energy cooperation

On 6 June 2016, the North Sea countries signed a political declaration and action plan for the period 2016–2019[7] to reinforce international energy cooperation. This builds on the European Framework for Maritime Spatial Planning, which requires countries in a marine region such as the North Sea to cooperate and coordinate their plans. The cooperation will focus primarily on the following areas[2]:

- Spatial planning that aims to optimise the use of the limited space in the North Sea, by sharing data, finding common approaches to minimise environmental impacts and coordinating permitting procedures.
- Developing and regulating an electricity grid that is able to accommodate large-scale offshore wind energy and connecting markets so that electricity is available when and where it is needed. Earlier studies by the European Commission have shown that savings of up to 5.1 billion euros are possible if network development is coordinated, as this requires fewer and shorter cables (Ecofys et al., 2014).
- Participating countries sharing information on their individual offshore infrastructure needs, to help plan investments and align subsidy schemes.
- Identifying best practices and ways of harmonising technical regulations and standards.

Notes

1 The minor changes made to the shipping routes on 1 June 2017 are not included on the map.
2 A few more changes were made in 2017. These are not shown in Figure 2.1.
3 See for example https://www.noordzeeloket.nl/functies-en-gebruik/scheepvaart/.
4 This criterion has been applied to the Hollandse Kust and north of the Wadden Islands wind energy areas.
5 The United Kingdom, Belgium, Germany, Denmark and Norway. According to the Political Declaration on Energy Cooperation between the North Seas countries, France, the Republic of Ireland, Luxembourg and Sweden are also North Sea countries.
6 The United Kingdom, Belgium, Germany, Denmark and Norway. According to the Political Declaration on Energy Cooperation between the North Seas countries, France, the Republic of Ireland, Luxembourg and Sweden are also North Sea countries.
7 Political Declaration on Energy Cooperation between the North Seas Countries.
8 Http://europa.eu/rapid/press-release_IP-16-2029_en.htm.

THREE

The future North Sea – integrated scenarios

3.1 Introduction

In this chapter, we discuss the four North Sea scenarios. We provide an overall picture of how the North Sea may develop, how this can be achieved, and the consequences that this has for some of the themes in national North Sea policy.

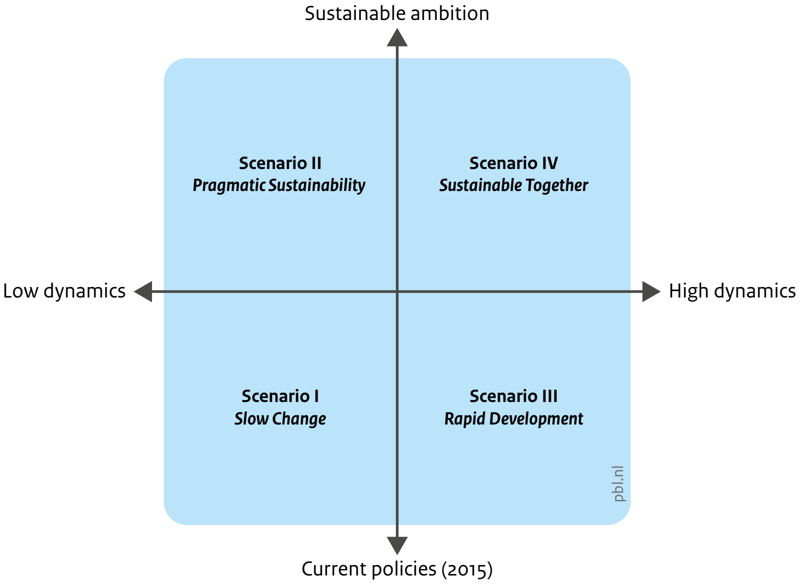
These four scenarios may serve as inspiration for people involved in developing national policy, or for sectors active in the North Sea. For example, they can show how it is possible to combine wind farms with nature or fishing activities. The scenarios can also be used to integrate policy for the various sectors, as well as activities (e.g. the integration of wind turbines with nature and aquaculture). In addition, the scenarios help assess the feasibility of proposed government policy or sectoral ambitions, such as ambitions for wind energy under high or low social, economic and technological dynamics.

The scenarios provide a coherent description of possible national and international developments and changes in national and international policy that will impact the North Sea. International developments could include changes in the global economy, global shipping activities and technological innovations. Policy refers, for example, to global climate agreements and European and national policy that focus on the North Sea. The scenarios also provide a general idea of the directions that the energy transition, sustainable food supply and resilient ecosystems themes could take, and briefly address developments in other sectors. The maps give a comprehensive overview of the situation on the Dutch continental shelf and in the North Sea as a whole according to the scenarios for 2050. These maps also show spatial developments in the exclusive economic zones of the other North Sea countries. We would like to emphasise that locations, purpose and size of the future wind parks, nature reserves and other future developments are envisaged by the authors purely for this publication. Therefore, any changes outside the Dutch continental shelf solely reflect our interpretation of the international context, which is described in the various scenarios in relation to the developments on the Dutch continental shelf. The outcome of the current Brexit negotiations can be an important factor for some future North Sea developments. Therefore, it is included as one of the scenario variables. The Brexit varies between a hard Brexit, in scenario I *Slow Change*, and one with very limited consequences, in scenario IV *Together Sustainable*. The extent of the Brexit, per scenario, is visualised on the map: spatial developments within the EEZ of the United Kingdom have been made less or more visible expressing either a hard or soft Brexit. Oil and natural gas activities are not included. This is because the scenarios assume that all oil and natural gas activities will have stopped in the North Sea by 2050 (compare with Geuns et al., 2017). To give some idea of the developments in oil and natural gas in each scenario, the maps therefore show the situation for 2030. The maps also provide a quantitative representation of the scenarios, although there may be some minor differences between the figures shown in the maps and the figures given in this study. The maps are therefore primarily intended to provide an inspiring illustration of the scenario storylines.

Scenarios I (*Slow Change*) and III (*Rapid Development*) are based on the two scenarios in the WLO outlook study, *The Netherlands in 2030 and 2050* (CPB and PBL, 2015a). Both scenarios focus on international developments and their impact on the economy and the living environment in the Netherlands. They assume either high or low dynamics in economic, technological, climate and other developments. Both scenarios assume that government policy as implemented in recent years will continue unchanged, revealing the policy challenges.

The Paris Climate Agreements demand ambitious renewable energy and greenhouse gas emission reduction policies, which is why we have also included two scenarios that assume sustainable ambitions:

Figure 3.1
Positioning of the North Sea scenarios



Source: PBL

Pragmatic Sustainability (scenario II) and *Sustainable Together* (scenario IV). As described in Section 1.3, the United Nations sustainable development goal is also achieved in these sustainable scenarios (conserve and sustainably use the oceans, seas and marine resources). This therefore makes it possible to consider how to develop the energy transition, resilient ecosystems and sustainable food supply themes from the 2030 North Sea Strategy and the National Integrated Environmental Policy Strategy. The sustainability ambitions in the scenarios are therefore sometimes more ambitious than the ambitions in the Dutch Coalition Agreement.
A comparison of the scenarios is made in Figure 3.1, while a general description of the scenarios is given in Table 3.1. The scenarios are described in more detail in the next sections.

3.1 Slow Change

Globalisation stagnates due to an increase in international conflicts and increasing nationalism. Priority is increasingly given to vested interests, reducing the focus on innovation and slowing technological development. The global objectives in the Paris Climate Agreement are only partially implemented. Dutch and European policy increasingly focuses on economic growth and jobs. The sectors that are active in the North Sea do not do much to improve the sustainability of their operations and there is very little development in offshore wind energy.

In *Slow Change*, globalisation stagnates due to an increase in international conflicts and increasing nationalism (CEFAS, 2017). The influence of the United States and Europe on the world economy decreases, while the influence of countries such as China and India does not increase much either. As priority is increasingly given to vested interests, there is little focus on innovation, which reduces global economic growth and shipping activities. These developments also mean that measures to achieve the global climate agreement are not fully implemented. As a result, the global temperature increases by 2 °C by 2050 and 4 °C by 2100. The North Pole remains ice-free for longer periods of the year, opening up a northerly shipping route between north-western Europe and Northeast Asia (CPB, 2015; Danish Government, 2012). Energy prices increase because of international conflicts, but the failure to achieve the climate objectives means that the CO_2 price in the EU remains limited to 20 euros per tonne in 2030 and 40 euros per tonne in 2050.

The economy grows by 1% a year in the EU and the Netherlands (CPB and PBL, 2015a). This limited economic growth and the limited increase in life expectancy means that the Dutch population remains stable up to 2030, after which it decreases to 16 million in 2050. The population decline and moderate growth in prosperity in Europe and the Netherlands result in a slight decrease in demand for protein-rich seafood. Sustainability is still important, but economic growth and jobs are considered more important.

Table 3.1
General description of the four scenarios

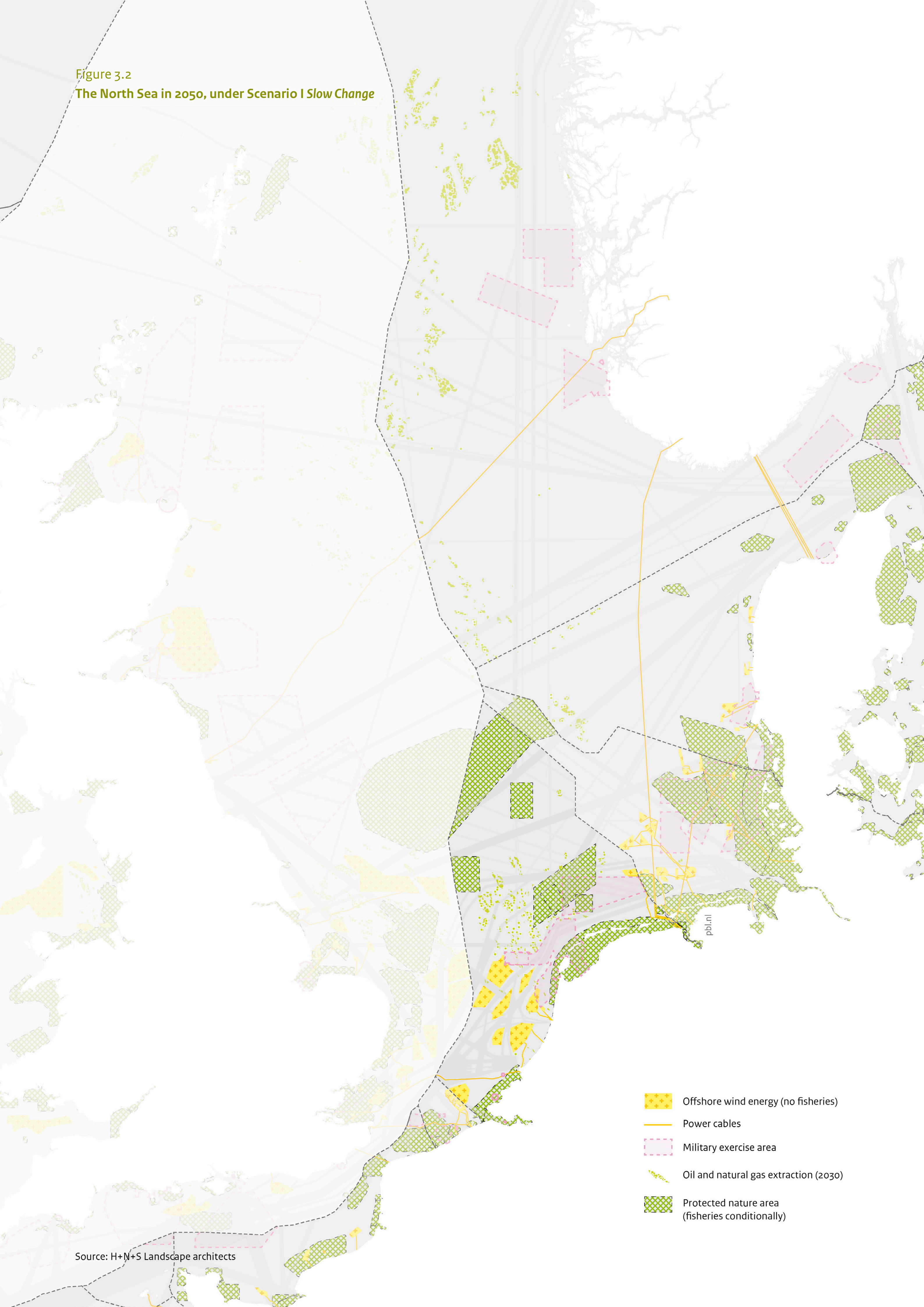
	Slow Change	Pragmatic Sustainability	Rapid Development	Together Sustainable
National and international developments	Stagnating globalisation and partial implementation of climate agreements	Trade blocs dominate and climate agreements implemented	Continued globalisation and partial implementation of climate agreements	Continued globalisation and climate agreements implemented
National and international policy	Focus on growth and jobs, hard Brexit and greenhouse gas reduction target of 45% compared with 1990	Focus on green growth, softer Brexit and greenhouse gas reduction target of 80% compared with 1990	Focus on material wealth, trade agreement with UK and greenhouse gas reduction target of 65% compared with 1990	Focus on circular economy, trade agreement with UK and greenhouse gas reduction target of 100% compared with 1990
Energy transition	12 GW offshore wind power, oil and natural gas reserves depleted, no CCS	22 GW offshore wind power, oil and natural gas reserves depleted, 30 Mt CCS	32 GW offshore wind power, some oil and natural gas reserves left unexploited, 25 Mt CCS	60 GW offshore wind power, oil and natural gas reserves quickly uneconomic, 50 Mt CCS
Resilient ecosystems	Same nature areas as in 2015, biodiversity also improves outside nature areas, good environmental status achieved in around 2030	Netherlands Nature Network completed, biodiversity improves compared with 2015, very good environmental status achieved in around 2040	Same nature reserves as in 2015, biodiversity also improves outside nature reserves, good environmental status achieved before 2030	International nature network realised, biodiversity improves the most in this scenario, very good environmental status achieved in around 2030
Sustainable food supply	Some innovation in fisheries sector, sustainable in the long term; limited developments in aquaculture	Some innovation in fisheries sector, becomes sustainable in the short term; strong developments in aquaculture, especially plant-based	Strong innovations in fisheries sector, sustainable in medium term; strong developments in aquaculture, especially animal-based	Strong innovations in fisheries sector, sustainable in the very short term; very strong developments in aquaculture
Shipping	Shipping activities move northwards	No change in shipping activities	Shipping activities move northwards	Shipping activities move to Scandinavia and the Baltic
Cables and pipelines	Oil and natural gas infrastructure remains in place after 2030; few electricity cables and connection points; twice as many telecommunications cables as in 2015	Oil and natural gas infrastructure removed following depletion of fields, taking into account future needs of CCS; many electricity cables and connection points; 2.5 times as many telecommunications cables as in 2015	Oil and natural gas infrastructure removed and partially replaced with CCS infrastructure; many electricity cables and connection points, 1 'energy hub island'; 3.5 times as many telecommunications cables as in 2015	CCS infrastructure and possibly pipelines for hydrogen from steam; many electricity cables and connection points, 3 'energy hub islands'; 4 times as many telecommunications cables as in 2015
Sand extraction	60 million m^3	30 million m^3	75 million m^3	40 million m^3
Recreation	Strong decrease	Decrease	Increase	Increase
Defence	More intense use of exercise areas	More intense use of exercise areas	Less intense use; more movements to and from bases	Less intense use; more movements to and from bases

Because of the energy savings and energy efficiency improvements made, the final energy consumption by 2050 – despite the economic growth – will be 10% lower than in 2015. The high fossil fuel price stimulates oil and natural gas production, so that reserves will be depleted sooner. At the same time, and despite the high fossil fuel price, the low CO_2 price discourages the development of wind energy and other forms of renewable energy at sea.

The decline in agriculture and industry, the slight increase in mobility and energy consumption and the environmental measures in place ensure that the input of phosphate, nitrogen and sulphur emissions from rivers and the air is reduced. Seawater temperatures increase due to climate change, sea level will rise by 35 centimetres by 2050, and acidification of the sea continues.

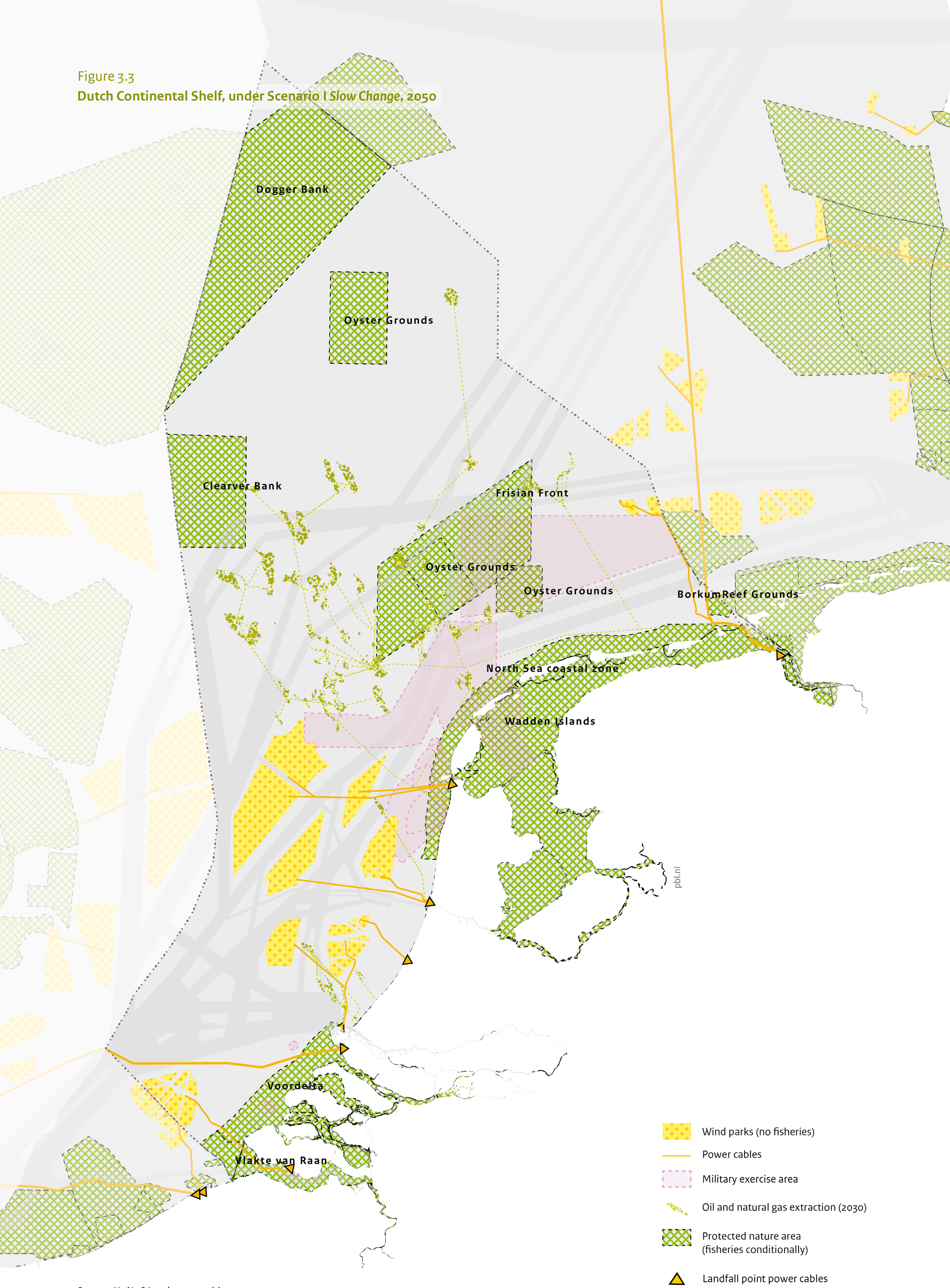
Figure 3.2

The North Sea in 2050, under Scenario I *Slow Change*



Source: H+N+S Landscape architects

Figure 3.3
Dutch Continental Shelf, under Scenario I *Slow Change*, 2050



Source: H+N+S Landscape architects

The focus in European and national policy increasingly turns to economic recovery and job creation rather than sustainability, and the sustainability ambitions do not go as far as those of the current cabinet. There is also an increase in military interventions to secure important trade routes (IPV, 2010). The Brexit leads to the imposition of trade tariffs between the EU and the United Kingdom and to the closing of fishing grounds. Although the Paris Climate Agreement officially remains in force, the effort and cost involved means that they are not implemented in full. The IMO also fails to achieve ambitious objectives in the agreement to reduce the environmental impact of the shipping sector.

The EU and the Netherlands do no more than other trade blocs and Member States, and no more than at present (compare this with the scenarios described by Cooper et al. (2008), for example). Current European and national policies remain in place and the focus on sustainability in the fisheries sector and waste reduction will weaken. Areas in the North Sea designated for nature are the same as in 2030 and 2050, therefore no new nature areas will be created.

North Sea policy can be characterised as area development. Policymakers and stakeholders from various sectors coordinate their ambitions and come to an agreement for a particular area, such as Dogger Bank. The dominance of vested interests means that implementation of the Dutch consensus approach to reach agreement on the marine area involves high transaction costs, while little progress is made. International cooperation remains fragmented and the North Sea countries largely organise themselves.

The transition to a sustainable energy supply is not achieved by 2050 in *Slow Change*. The number of offshore wind turbines increases up to 2030, after which it levels off. Total wind power is 4.5 GW in 2030 and 12 GW in 2050. This is produced by existing wind farms, wind farms currently under development and wind farms in currently designated areas to the west of North Holland and South Holland (see Figure 3.3). Greenhouse gas emissions are reduced by 30% in 2030, which is considerably less than the EU reduction target of 40% for 2030 (EU, 2014b) and the 49% national target for 2030 in the 2017 Coalition Agreement. Greenhouse gas emissions are reduced by 45% in 2050 compared with 1990.

The high oil and natural gas prices and the low CO_2 price mean that all the oil and natural gas reserves in the North Sea are exploited. The Netherlands also remains strongly dependent on oil imports. Natural gas reserves are further depleted and reduced production from the Groningen gas field means that the Netherlands is completely dependent on natural gas imports by 2050. The CO_2 price remains too low up to 2050 for the development of CCS. The number of empty natural gas fields at sea that could be used for CCS increases, but the platforms have to be dismantled once the natural gas fields have been depleted. This takes place long before CCS can be implemented.

Nature becomes more resilient in this scenario, but not much more than in 2015. The nature reserves are the same in 2050 as in 2015, and include the Delta Waters, Dogger Bank and Cleaver Bank. Together, these cover 20% of the Dutch continental shelf. Species diversity improves more in the reserves than elsewhere as only passive fishing methods are permitted in the reserves. The increased sustainability of the food supply and other sectors means that biodiversity also improves outside the nature reserves, for example in areas of particular ecological value such as Brown Ridge and the Central Oyster Grounds. These areas cover 15% of the Dutch continental shelf. However, the nature areas are not connected to one another and the level of protection does not increase (PBL, 2012). The rise in sea level also means that larger areas of the Wadden Sea are submerged all year round, which has a negative effect on migratory birds. The further acidification of the sea water also affects shellfish.

Although the food supply is more sustainable, no significant steps are taken to achieve this. Only in around 2030 does fishing take place within the limits of the maximum sustainable yield. The hard Brexit means that seabed (demersal) fishing moves to the Dutch, German and Danish part of the North Sea, increasing the pressure on fish stocks in these areas and creating overcapacity. Renewal of the fleet and innovation in fishing methods are also slow to take place, due to the slow rate of technological development. Shellfish farming remains limited in size due to the lack of demand for protein-rich seafood (CEFAS, 2017), as do seaweed, algae and sea vegetable farming. Cost considerations mean that aquaculture only takes place in the waters of the delta and a few locations in shallow waters along the coast.

The slow growth in global shipping activities means that growth in the volume of sea transport in the North Sea also remains limited, at 10% compared with 2015 in 2030 and 20% compared with 2015 in 2050. The opening up of northerly shipping routes results in a slight shift in shipping movements northwards. The environmental standards introduced in the 2010s and modest developments in shipping technology result in a slight decrease in net emissions of nitrogen oxides, sulphur oxides and CO_2. The development of ports in the Netherlands and other countries in north-western Europe is also modest in this scenario. Maasvlakte 2 is able to meet demand until 2050 and, although the larger ports such as Rotterdam and Antwerp are able to maintain their positions, the smaller ports are not (Van Dorsser, 2012).

The rapid rise in sea level necessitates a considerable increase in sand extraction activities for coastal defence. The amount of sand extracted increases from 25 million m^3 in 2015 to 60 million m^3 in 2050. Sand reserves in the sand extraction priority zone are sufficient to meet this demand. There is a considerable decrease in the number of recreational vessels in the coming decades in this scenario, and a corresponding decrease in the number of ports and facilities (Waterrecreatie Advies, 2016). Increasing international tensions mean that existing military exercise areas to the west of Kop van Noord-Holland (military ranges) and the north and north-west of the Wadden Islands (low-level flight training areas) are used more intensely. This put limits on their use for other activities such as fishing and sand extraction and causes more disturbance to the nature in these areas. Archaeological values are also put under increased pressure, due to the construction of wind turbines and, more especially, the increase in sand extraction activities.

3.3 Pragmatic Sustainability

Global economic growth slows due to faltering globalisation and slow technological progress which, in turn, are the result of limited competition. Under the Paris Climate Agreement, sustainable innovation initiatives are taken, so that the global temperature rise remains within limits. European and national policy focuses on a thriving economy, but not necessarily on high growth. Policy ambitions improve the sustainability of the sectors active in the North Sea and help achieve high levels of offshore wind energy and CCS.

In *Pragmatic Sustainability*, global economic growth is slowed by faltering globalisation and slow technological progress. The focus shifts to trade blocs that seek to protect their own economies (QinetiQ et al., 2013), although these trade blocs manage to come to ambitious bilateral agreements to limit climate change. The global temperature increases by 1 °C up to 2050 and by 2 °C up to 2100 (CPB and PBL, 2015b). This means that, up to 2050, the waters of the North Sea warm less quickly than in recent years, acidification slows and the North Sea's sea level increases by 15 centimetres. Fossil fuel prices increase due to international conflicts, and the climate agreements result in a high CO_2 price: 100–500 euros per tonne CO_2 in 2030 and 200–1000 euros per tonne in 2050 (CPB and PBL, 2015b; CPB and PBL, 2016).

The economy grows by 1% a year in the EU and the Netherlands (CPB and PBL, 2015a). Because of the limited economic growth and the limited increase in life expectancy, the Dutch population remains stable up to 2030, after which it decreases to 16 million in 2050. Environmental awareness grows considerably: economic growth and jobs are considered important but must be achieved through green growth. Population decline and modest growth in prosperity result in a drop in demand for seafood. However, the increased environmental awareness results in an increase in demand for plant-based seafood.

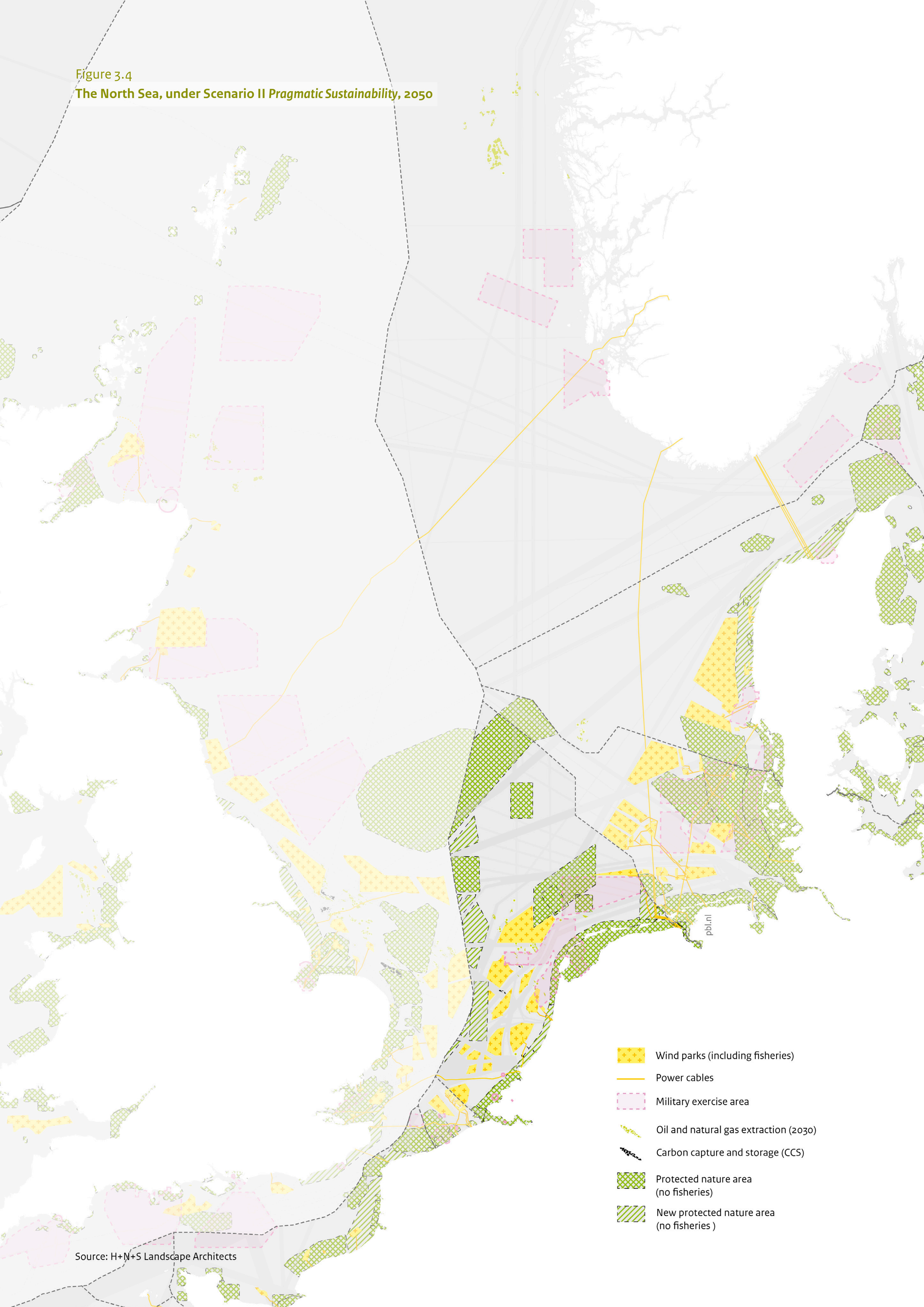
Economic growth causes a slight increase in energy demand, but significant savings and a focus on energy efficiency mean that the final energy consumption is 20% lower in 2050 than in 2015. Although the high energy and CO_2 prices stimulate the development of offshore wind energy and other forms of renewable offshore energy, slow technological developments and the low level of economic dynamism limit opportunities for large investments. The decline in agriculture and industry, the modest increase in mobility and stricter environmental standards ensure that phosphate, nitrogen and sulphur emissions to rivers and the air are reduced almost to zero.

European and Dutch policy focus on economic development, but not necessarily high growth (Cooper et al., 2008). In response to the increase in international conflicts, the EU creates its own defence force in which the armed forces of the Member States work closely together. Because of the Brexit, access to fishing grounds is limited. Measures related to the Paris Climate Agreement are implemented differently in different countries, and the effort required and costs involved mean that targets are slow to be achieved. Policy does however become stricter over the years.

European and national environmental policy are tightened considerably (PBL, 2013), with more ambitious objectives for a good environmental status, where the aim is not just to operate within ecological limits, but for ecosystems to flourish. IMO also tightens environmental standards for the shipping sector. The aim of climate and energy policy is to reduce emissions in 2050 to a level that makes the two-degree target possible. Policy aiming to increase the sustainability of the fisheries sector is also tightened. Nature policy focuses on creating a larger national nature network at sea.

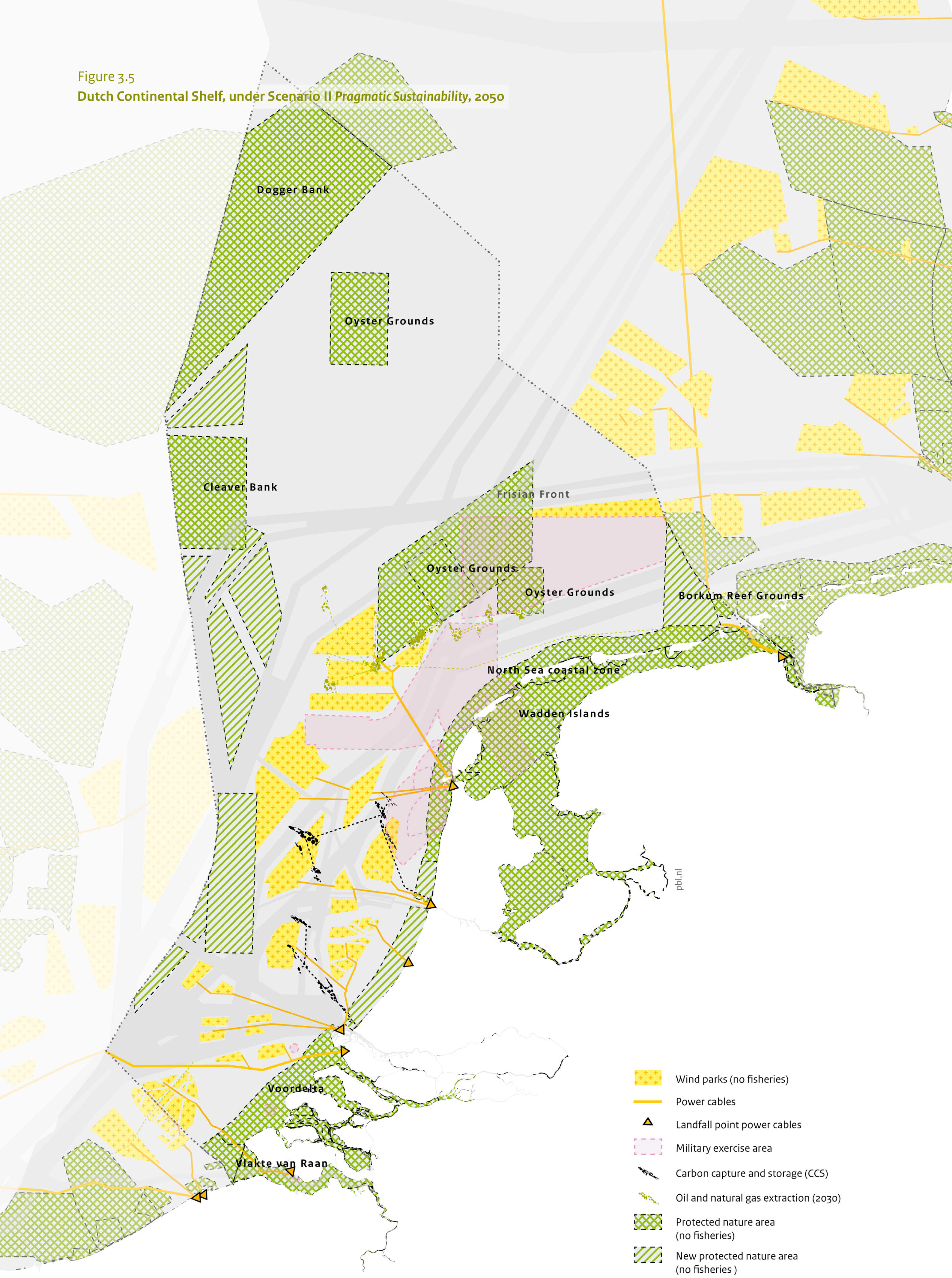
The national government implements policy for the North Sea because it is also responsible for achieving the objectives in the Paris Climate Agreement as well as a

Figure 3.4
The North Sea, under Scenario II *Pragmatic Sustainability*, 2050



Source: H+N+S Landscape Architects

Figure 3.5
Dutch Continental Shelf, under Scenario II *Pragmatic Sustainability*, 2050



Source: H+N+S Landscape architects

good environmental status. This is achieved by developing a shared vision as well as an integrated investment programme for the North Sea that also provides funding for nature conservation (PBL, 2012). The government continues to cooperate with companies and other non-governmental organisations in the various sectors to achieve this. This ensures that the necessary progress is made, despite the vested interests in place. International cooperation is therefore more coherent than at present.

In *Pragmatic Sustainability*, an energy transition is achieved despite low economic growth and a low level of technological development. The number of wind turbines initially increases in accordance with current policies under the *Slow Change* scenario, but the pace is later accelerated. As a result, the total power is 7.5 GW in 2030 and 22 GW in 2050. Changes are made to the areas currently designated for wind energy to the west of North Holland and South Holland, as cost considerations mean that more wind farms are constructed close to the coast, although still outside the 10 nautical mile zone (see Figure 3.5). The size of the wind turbines, and the fact that they are sometimes switched off, means that the impact on seabirds and bats remains modest. A greenhouse gas reduction of about 40% – the EU target – is achieved in 2030 compared with 1990, and an 80% reduction in 2050.

The high oil, natural gas and CO_2 prices mean that offshore oil and natural gas operations barely generate a profit and some known reserves remain unexploited, although existing oil and natural gas fields are depleted. Large-scale CCS in empty natural gas fields in the North Sea is implemented in 2050, totalling about 30 Mt.

Nature becomes more resilient in this scenario, largely due to the creation of a larger national network of marine nature areas that are closed to fishing and other activities. This network includes not just the current Natura 2000 sites such as the Delta Waters, Dogger Bank and Cleaver Bank, but also areas of particular ecological value such as Brown Ridge, the Central Oyster Grounds and the Borkum Reef Grounds. Most of the nature reserves are connected. The nature network covers an area that totals about 35% of the Dutch continental shelf. Because the seabed in these areas is no longer disturbed by fishing and other activities, new shellfish and seagrass beds are free to develop. Fish that had disappeared from these areas (skate, surgeon) return and many more fish return to the rivers to breed (eel, bass). This focus on marine species conservation means that several species achieve an ecological balance before 2050, such as the bluefin tuna and several shark species. The noise made by the large number of new wind turbines does however cause more disturbance to marine mammals such as porpoises and seals, as well as increased seabird and bat mortality.

The Brexit and the development of wind farms and nature reserves increase the economic pressure on the fisheries sector, although it does manage to improve the sustainability of its operations (Pinnegar et al., 2006). Because of the Brexit, Dutch fishing vessels are only permitted to fish on British fishing grounds under very strict conditions (limited quotas). As a result, demersal fishing shifts to the Dutch, German and Danish sectors of the North Sea, although not as much as in scenario I. Expansion of the wind farms does not impact fishing activities as much as would be expected, as no wind farms are sited on strategic fishing grounds, and demersal fishing is permitted inside the wind farms. Although nature reserves are closed to fishing vessels, the fish quotas do not change. Improvements in the sector before 2030 mean that iconic species (cod, ray) increase in numbers. Although shellfish farming remains more or less at current levels, the farming of seaweed and other sea vegetables increases (LEI, 2016). Cost considerations mean that aquaculture does not develop beyond the waters of the delta and shallow coastal waters. Marine aquaculture does however increase in size (CEFAS, 2017).

The limited growth in global shipping activities means that growth in the volume of sea transport in the North Sea also remains limited, at 10% compared with 2015 in 2030 and 20% compared with 2015 in 2050. With support from the EU and improved hinterland connections, short-sea shipping on the North Sea increases considerably. Stricter environmental standards, technological innovations and a switch to ships run on biofuels mean that nitrogen and sulphur oxide and CO_2 emissions are drastically reduced. The development of ports in the Netherlands and other countries in north-western Europe is modest in this scenario. As in scenario I, Maasvlakte 2 is able to meet demand until 2050 and, although the ports of Rotterdam, Amsterdam and Antwerp are able to maintain their positions, the smaller ports are not (Van Dorsser, 2012).

Sea level rise is limited, so that there is only a slight increase in the amount of sand required for coastal defence. The amount of sand extracted increases from 25 million m^3 in 2015 to 30 million m^3 in 2050, and no problems are expected concerning the availability of reserves in the priority zone. A decrease is seen in the number of recreational vessels, due to population decline and a preference for other forms of recreation (Waterrecreatie Advies, 2016). As a result, marinas are less frequented, facilities decline and eventually the marinas disappear. Increasing international tensions mean that existing military exercise areas to the west of

Kop van Noord-Holland (military ranges) and the north and north-west of the Wadden Islands (low-level flight training areas) are used more intensely. This places limits on their use for shipping, fishing and other activities, and causes more disturbance to the nature in these areas. Archaeological values are also put under slightly more pressure, due to the construction of wind turbines and the increase in sand extraction activities.

3.4 Rapid Development

Accelerated globalisation and technological development stimulate economic growth. Although the global objectives under the Paris Climate Agreement are initially pursued energetically, this later turns out to be insufficient to achieve the targets. Both European and national policy remain focused on sustainability, but material wealth becomes increasingly important. Sectors active in the North Sea do not increase the sustainability of their operations very much, but wind ambitions increase considerably as offshore wind energy becomes profitable. An 'energy hub island' is built on Doggers Bank.

In this scenario, continued globalisation and rapid technological development stimulate global economic growth (CEFAS, 2017). Globalisation is made possible by a decrease in international conflicts and by more ambitious international trade agreements. Energy prices are not negatively affected by geopolitical tensions, and the limited implemention of measures related to the Paris Climate Agreement prevents high CO_2 prices. The partial implementation of the measures under the Paris Climate Agreement means that global temperatures increase by 2 °C up to 2050 and by 3 °C up to 2100 (CPB and PBL, 2015b). Because of climate change, and because the North Pole remains ice-free for longer periods of the year, a northerly shipping route opens up between north-western Europe, western North America and Northeast Asia (QinetiQ et al., 2013). These developments spur further growth in international shipping activities.

The economy grows by 2% a year in the EU and the Netherlands up to 2050 (CPB and PBL, 2015a). The Dutch population grows to over 19 million in 2050, due to increasing migration and a higher life expectancy. A few major land reclamation projects are implemented, such as an extension to the Port of Rotterdam. The increase in the population and wealth lead to a significant growth in demand for protein from the sea. Not much change takes place in environmental awareness: sustainability continues to be important, but increasing prosperity is considered more important.

Energy savings and higher energy efficiency mean that the final energy consumption in 2050 is – despite the economic growth – roughly the same as in 2015. The energy demand and the initially low energy and CO_2 prices stimulate offshore oil and natural gas production. The CO_2 price increases to 80 euros per tonne CO_2 in 2030 and 160 euros per tonne CO_2 in 2050. These developments and the technological innovation taking place provide a stimulus for wind energy and other forms of renewable energy. Environmental standards and new environmental technologies result in a decline in input of phosphate, nitrogen and sulphur from rivers and the air. The water temperature in the North Sea increase because of climate change, acidification intensifies and the sea level rises by 35 centimetres.

EU and Dutch policy focus primarily on stimulating economic growth and material wealth (Cooper et al., 2008). The decrease in the number of international conflicts, the more equal status of countries in NATO and the inclusion of new countries mean that the United States decides to reduce its spending on defence.
The Brexit has little effect as the EU and United Kingdom draw up a free trade agreement. The effort and costs involved in meeting the targets under the Paris Climate Agreement mean that relevant measures are not implemented in full. Current IMO environmental standards continue to be applied to the shipping sector and the current focus on sustainability and waste reduction in the fishing sector weakens.

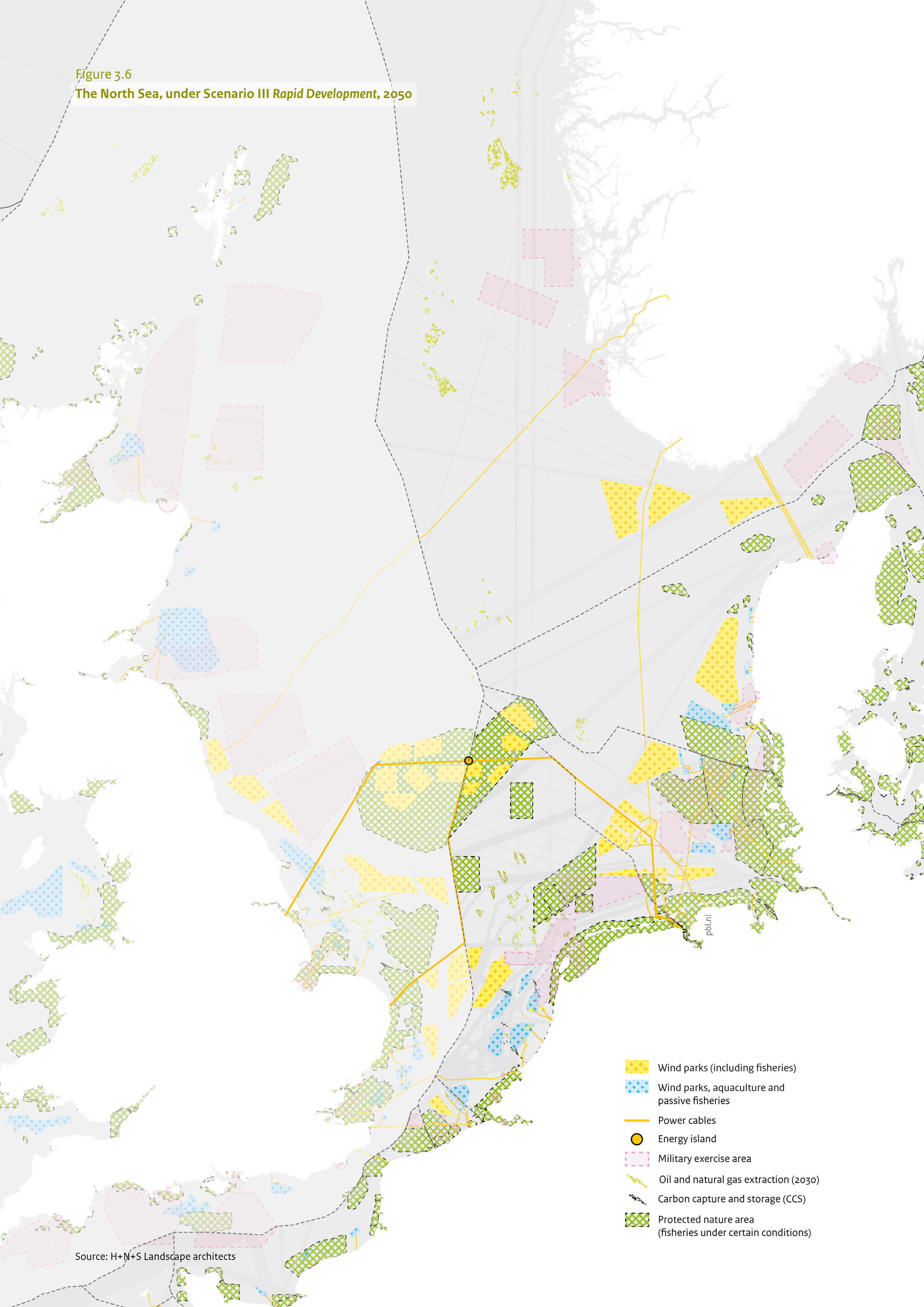
No major EU and Dutch policy developments take place after 2015, but current European and national policies continue to be implemented (CPB and PBL, 2015a). Pressured by Member States with less competitive fishing fleets, the Common Fisheries Policy bans pulse fishing. Areas in the North Sea currently designated for nature are also designated as such in 2030 and 2050; no new nature areas are created.

North Sea policy can be characterised as area development. Policymakers and stakeholders from various sectors coordinate their ambitions and reach agreement for certain areas. The focus on 'enlightened self-interest' and the willingness to work together mean that implementation of the Dutch consensus approach to reach agreement is successful, with few transaction costs. Cooperation and consultation also takes place with other North Sea countries. The EU supports this with the implementation of regional policy for the North Sea.

The energy transition continues in this scenario, although it is not completed. The increase in the number of wind farms accelerates, so that a total power of 11.5 GW is achieved in 2030, and 32 GW in 2050. In addition to the currently designated areas, additional areas are required in Dogger Bank and to the north-east of Frisian Front (see

Figure 3.6

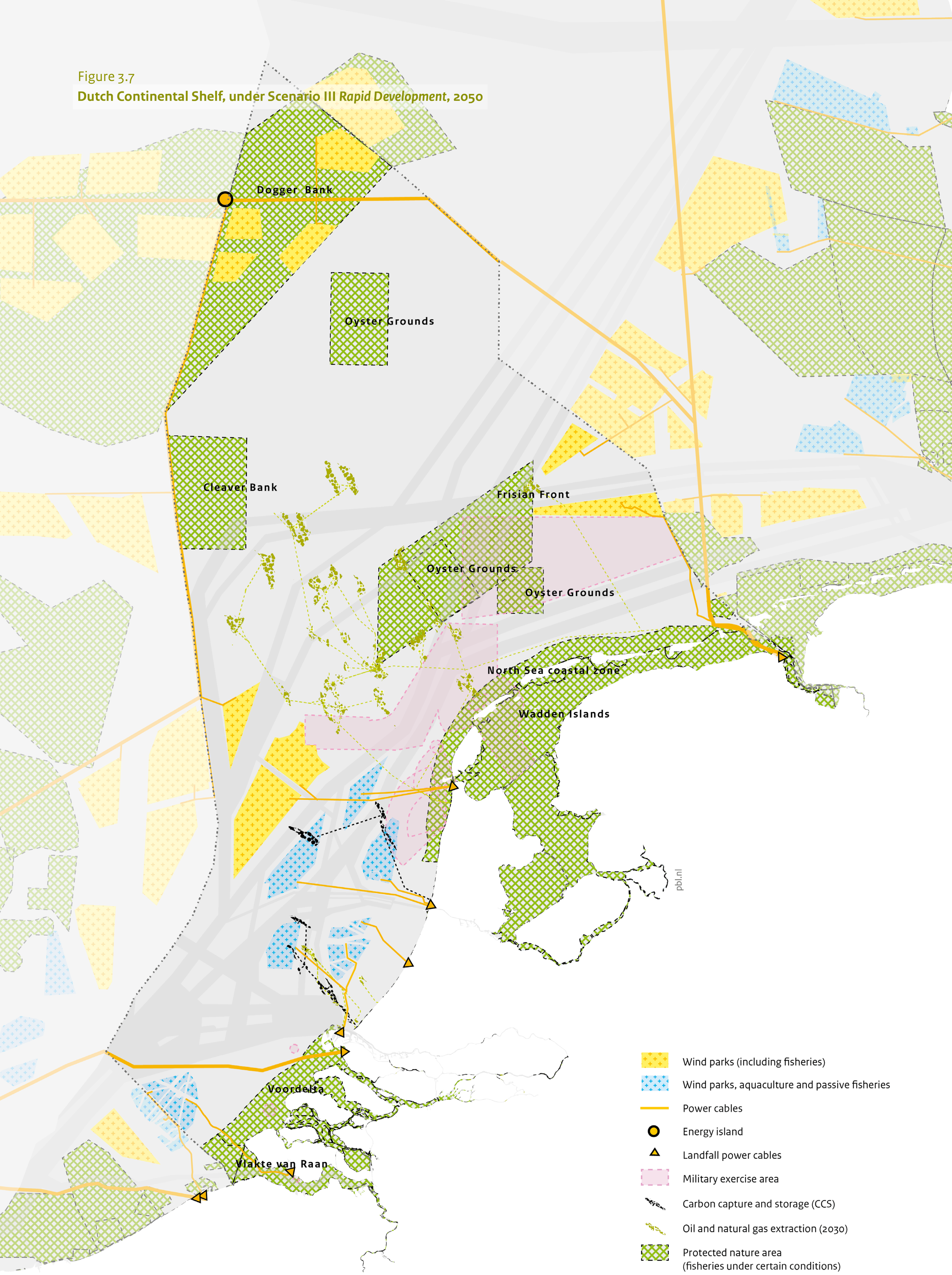
The North Sea, under Scenario III *Rapid Development*, 2050



Source: H+N+S Landscape architects

Figure 3.7

Dutch Continental Shelf, under Scenario III *Rapid Development*, 2050



Source: H+N+S Landscape architects

Figure 3.7). Concerning greenhouse gas emissions, the current EU target of a 40% reduction compared with 1990 levels is achieved in 2030, and a reduction of 65% is achieved in 2050. The low oil and natural gas prices and increasing CO_2 price make offshore oil and natural gas production less and less economically viable. The CO_2 price increases to 80 euros per tonne between 2015 and 2030, so that CCS becomes profitable. Technological development and the increasing number of depleted natural gas fields also play a role in this. CCS increases steadily, to about 25 Mt CO_2 per year in 2050. In around 2030, technology is introduced that makes it possible to store excess electricity from offshore wind energy using power-to-gas.

Nature becomes more resilient in the *Rapid Development* scenario, but not much more than at present. This is because the designated nature areas are the same in 2050 as at present, and the level of protection is not increased. These nature areas include Natura 2000 sites such as the Delta Waters and Dogger Bank, which together cover 20% of the Dutch continental shelf, as well as areas of particular ecological value, such as the Central Oyster Grounds and the Borkum Reef Grounds, which cover 15% of the Dutch continental shelf. Biodiversity improves, mainly because the sectors active in the North Sea use new and less environmentally damaging techniques. The rise in sea level means that larger areas of the Wadden Sea are submerged all year round, which has a negative impact on migratory birds. As the sea water warms, fish species such as plaice and cod migrate northwards and new species such as red mullet and bass migrate up from the south (LEI, 2014). The continued acidification of sea water has a particularly negative effect on shellfish.

The food supply becomes increasingly sustainable. A soft Brexit means that Dutch fishing vessels retain access to British fishing grounds. The design of wind farms to include fishing activities means that ambitions for wind energy do not have too much of an impact on the fisheries sector. Fishing is also permitted in nature reserves, as long as sustainable fishing techniques are used. The regular introduction of new fishing methods means that the sector becomes increasingly sustainable (STT, 2016). Not long after 2020, the fishing sector is operating within the limits of the maximum sustainable yield. Because of the rapid rise in demand for protein-rich seafood, and despite the acidification of seawater, shellfish farming grows considerably (Pinnegar et al., 2006). Offshore fish farming also grows strongly, but seaweed and algae farming less so. These activities initially take place in the Delta Waters and shallow coastal waters, but later require more space and move further offshore, to wind farms and nature areas to the west of the Zeeland, South Holland and North Holland coast. Larger scale operations are needed to enable competition with Asian countries (CEFAS, 2017).

The growth in global shipping activities means that the volume of sea transport in the North Sea grows by 15% compared with 2015 in 2030 and 40% compared with 2015 in 2050. As the pole ice melts, trade routes to the north of Russia and Canada become more navigable, resulting in more north-bound shipping movements in the North Sea. The continued implementation of current environmental standards and rapid technological developments result in a further decrease in net emissions of CO_2 and sulphur and nitrogen oxides from the shipping sector. The Port of Rotterdam expands further out to sea not long after 2030. The depth and breadth of the ports of Amsterdam, Rotterdam and Antwerp and the high level of automation mean that they retain their dominance over other ports in north-western Europe (Port of Rotterdam, 2011).

Rising sea levels mean that sand extraction for coastal defence increases considerably. Sand is also required for the expansion of the Port of Rotterdam. Sand extraction increases to 75 million m^3 in 2050, all of which can be extracted from the priority zone. The number of recreational vessels at sea increases, due to growth in the population and welfare and the number of pensioners. A corresponding increase is seen in the number of marinas, which offer a wider range of berths. The decrease in international tensions and a more internationally oriented navy means that exercise areas to the west of Kop van Noord-Holland and to the north-west and north of the Wadden Islands are used less intensively. Their shared use with shipping, fishing and other activities is therefore made easier, and they have less of an impact on nature. Archaeological values are put under pressure, due to the construction of wind turbines and, more especially, the significant increase in sand extraction activities. It is therefore important to secure the scientific value of these archaeological sites.

3.5 Sustainable Together

In this scenario, continued globalisation and rapid technological development stimulate global economic growth. Climate targets are consistently met, which limits global warming. European and Dutch policy focus on achieving a transition to a circular economy. Sectors active in the North Sea considerably improve the sustainability of their operations and many new wind farms are built, combined with other forms of renewable energy. A number of 'energy hub islands' are also built.

In this scenario, continued globalisation and rapid technological development stimulate global economic growth and shipping activities. The resulting increased competition between companies, and the growing environmental awareness produce numerous green innovations (CEFAS, 2017). Furthermore, globalisation and growing environmental awareness also result in ambitious global agreements to limit climate change. As a result, global warming is limited to about 1 °C in 2050 and 2 °C in 2100 (CPB and PBL, 2015b). Energy prices are not checked by geopolitical tensions but the climate targets and high CO_2 price are responsible for a large increase in fossil fuel prices. The CO_2 price is 100–500 euros per tonne CO_2 in 2030 and 200–1 000 euros in 2050 (CPB and PBL, 2015b; 2016).

The economy grows by 2% a year in the EU and the Netherlands up to 2050 (CPB and PBL, 2015a). The Dutch population grows to over 19 million in 2050, due to increasing migration and a higher life expectancy. Economic growth and jobs are considered important, but they are to be achieved primarily by increasing the sustainability of the economy. High global and European growth in the population and prosperity levels result in an increased demand for seafood, in particular sea vegetables.

Despite economic growth, the final energy consumption decreases by 30% in 2050 compared with 2015 (also see Matthijsen et al., 2018), mainly due to high energy savings and high levels of energy efficiency. Because of the low energy prices, not all the offshore oil and natural gas fields are exploited, and the high CO_2 price leads to an acceleration in the development of renewable energy forms. Stricter environmental regulations, a reduction in energy consumption and new environmental technologies mean that the input of nitrogen, phosphate and sulphur from rivers and the air is reduced almost to zero. The limited increase in global temperatures means that sea level rise in the North Sea totals 15 cm in 2050, and that the increase in seawater temperature and acidification also remain limited.

European and Dutch policy focus on achieving a transition to a circular economy (PBL, 2017). In response to decreasing international tensions and a less dominant role on the world stage, the European armed forces focus on peace missions and human rights. The Brexit has limited consequences as the EU and the United Kingdom draw up a free trade agreement which includes non-tradeables, such as environmental standards. Measures related to the Paris Climate Agreement are implemented within the set time limit, as rapid technological innovation and high economic growth ensure that the effort required and costs involved are achievable.

The EU and the Netherlands set an example when it comes to turning words into action. Policy is further refined, including the environmental standards set by IMO for the shipping industry. More ambitious objectives are developed for achieving a good environmental status, where the aim is not just to operate within ecological limits but for ecosystems to flourish (CEFAS, 2017). The current focus on sustainability and waste reduction in the fisheries sector also sharpens. New nature areas are created as part of an international network and designated as nature reserves.

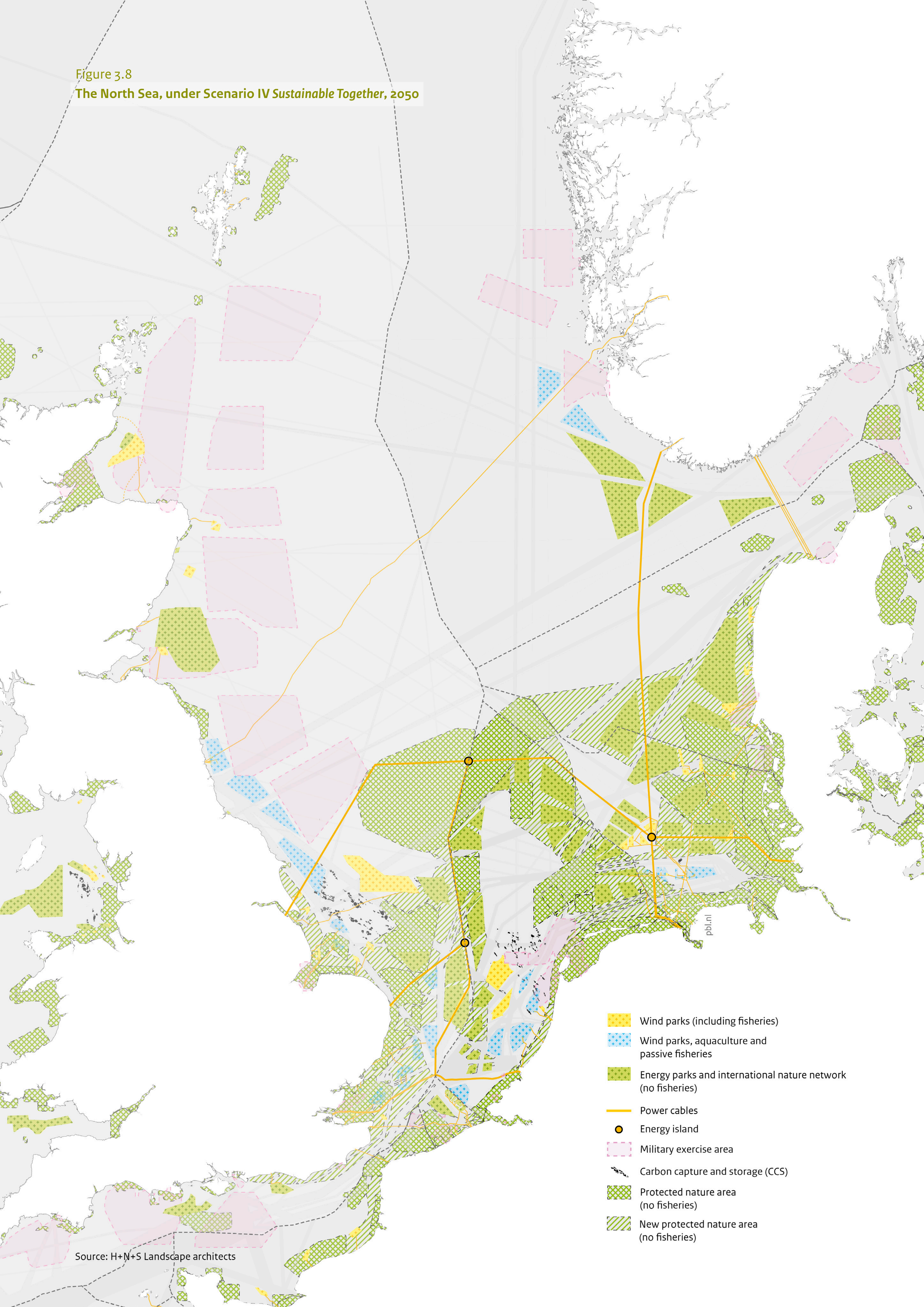
This all means that a transition needs to be made that actively involves governments, businesses, public organisations and knowledge institutes in the various sectors (PBL, 2012). This applies at the local level, the national level and the level of the North Sea region. Cooperation takes place through innovation networks in which frontrunners from various sub-sectors in the marine sector discuss the challenges, come up with innovative solutions and share their knowledge. The high ambitions of the EU and national governments and the high level of investment form a fertile breeding ground for innovation. Pricing of the external costs and a tightening of environmental standards also work as incentives.

The energy transition is more fully accomplished in the *Sustainable Together* scenario than in the other scenarios. Offshore wind power totals 15 GW in 2030, increasing to 60 GW in 2050. This extra wind energy comes, for example, from wind farms to the east of Dogger Bank, to the north and east of the Central Oyster Grounds and to the east of Frisian Front. The Netherlands becomes a net exporter of electricity, and some of the electricity it generates is used to produce green gas. Progress is also made in other forms of offshore renewable energy, such as tidal energy and wave energy. As a result, a greenhouse gas reduction of 100% is achieved compared with 1990. The low oil and natural gas prices and a high CO_2 price mean that offshore oil and natural gas production is no longer cost-effective and some reserves are left unexploited. Part of the infrastructure is adapted for CCS and the production of green gas from surplus electricity from wind farms. The Netherlands and its neighbouring countries play a pivotal role in large-scale CCS after 2030, with 45 Mt of CO_2 stored in 2050.

Nature is most resilient in this scenario, and biodiversity in the North Sea improves considerably. An ecological balance between ecosystems is achieved in large areas of the North Sea well before 2050. The main contributors to this are the creation of international nature networks and the exclusion of fishing activities in nature areas. For example, the coastal zone forms a single protected

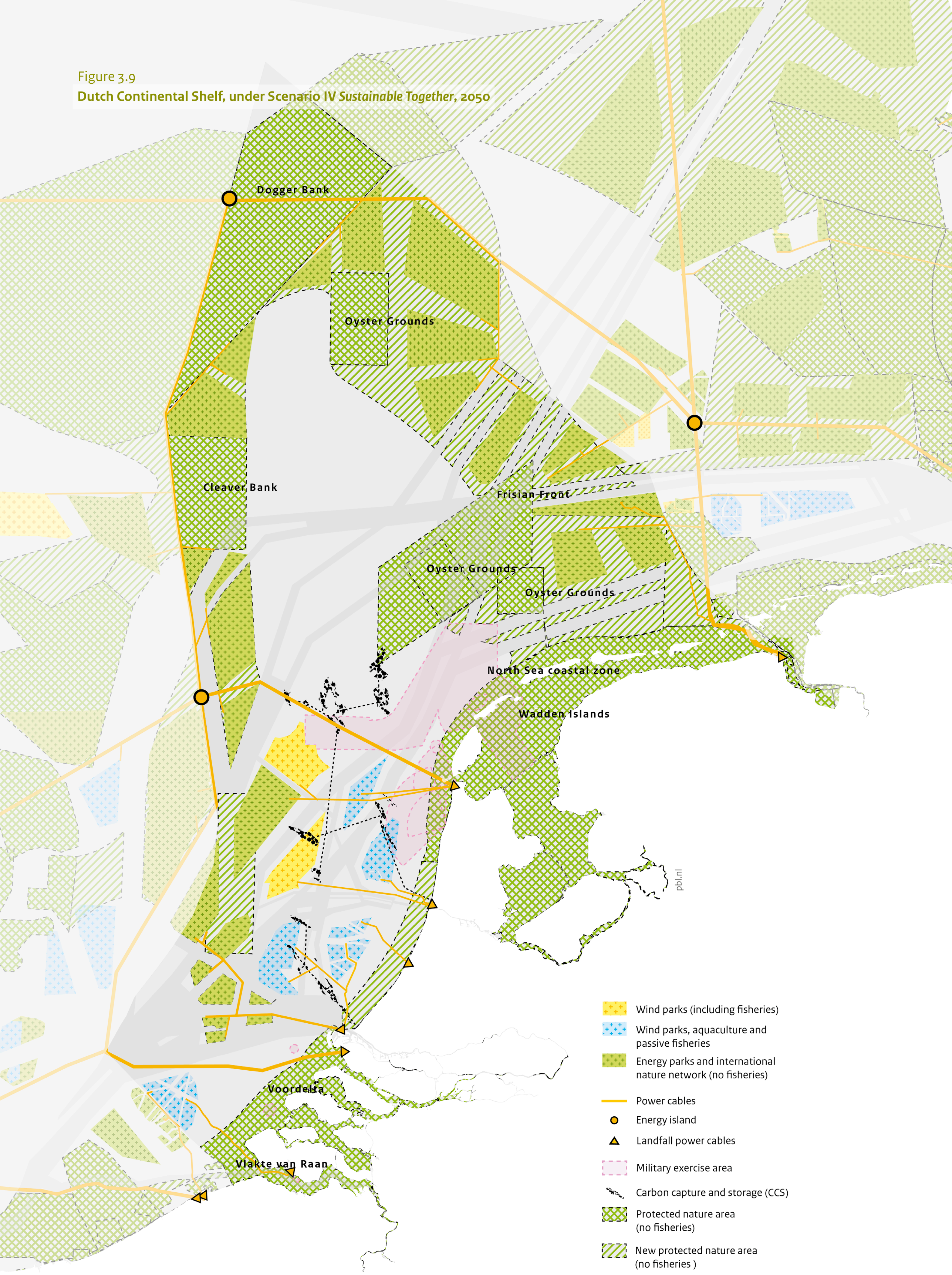
Figure 3.8

The North Sea, under Scenario IV *Sustainable Together*, 2050



Source: H+N+S Landscape architects

Figure 3.9
Dutch Continental Shelf, under Scenario IV *Sustainable Together*, 2050



Source: H+N+S Landscape architects

nature reserve and Brown Ridge, Cleaver Bank, Dogger Bank, the Central Oyster Grounds and the Borkum Reef Grounds are connected both to one another and marine nature areas in neighbouring countries (see Figure 3.8). Ecosystem recovery also plays a large role, which is achieved for example by creating large oyster beds and artificial reefs in the nature areas. The construction of large numbers of offshore wind farms further out to sea also benefits nature. However, these wind turbines do cause more disturbance to marine mammals, despite new construction techniques. Seabird and bat mortality also increases, even though most wind turbines are situated further offshore.

A sustainable food supply is achieved in this scenario, although this does require a transition from fishing to aquaculture. The construction of new wind farms and the development of new nature areas that exclude fishing activities increase the pressure on the fisheries sector. A soft Brexit means that UK fishing grounds remain open to EU fishing vessels. At the same time, increasing prosperity and population growth, as well as a greater focus on healthy food, result in a much higher demand for sustainable fish and shellfish (LEI, 2016). The shift in demand to plant-based food means that sustainable sea vegetable farming also expands considerably. Raw materials are also extracted on an increasingly large scale, such as bioplastics from seaweed and biofuels from algae. This takes place not just in the Delta Waters and shallow waters along the coast, but also in wind farms and nature areas to the west of the Zeeland and Dutch coast (IMARES and LEI, 2016). Such farming takes place on a larger scale than in scenario III. Fish farming takes place in offshore closed-containment systems (sea farms), in which various forms of cultivation together form a cycle (STT, 2016).

The strong growth in global shipping activities means that the volume of sea transport in the North Sea grows by 15% compared with 2015 in 2030 and 40% compared with 2015 in 2050. More and more vessels are built using new, reusable materials and with engines that run on biofuels or hydrogen (NISS, 2016). The growth in the shipping route towards Scandinavia and the Baltic results in more northbound shipping movements in the North Sea. Stricter environmental standards, a switch to new fuels and the introduction of new forms of propulsion result in a considerable decrease in net emissions of nitrogen and sulphur oxides and CO_2. Port capacity is used more efficiently, which means that expansion is not necessary. The depth and breadth of the ports of Amsterdam, Rotterdam and Antwerp and the high level of cooperation and automation mean that they are able to reinforce their global position (Port of Rotterdam, 2011).

The amount of sand extracted increases from 25 million m^3 in 2015 to 40 million m^3 in 2050. Most of this is used to build the 'energy hub islands' (see Figure 3.9). Sand reserves in the sand extraction priority zone are large enough to meet this demand. The number of recreational vessels at sea increases, as do the number of autonomous and electrically propelled vessels. International tensions decrease, which means that military exercise areas are used less intensively and can therefore more easily be used by other sectors. This also results in less disturbance to nature in these areas. Extra space is created for wind farms by moving the low-level flight training areas currently located to the north of the Wadden Islands to the Scottish section of the North Sea. The armed forces could receive compensation from wind farm operators for any extra costs this involves. Archaeological sites come under pressure, due to sand extraction activities and, more especially, the construction of large numbers of wind turbines and islands, making it important to secure the scientific value of such sites.

FOUR

The future North Sea – an elaboration per theme

4.1 Introduction

In this chapter, we describe the scenario outcomes based on the themes in the 2030 North Sea Strategy: the energy transition, resilient ecosystems and a sustainable food supply. The final section of this chapter addresses multiple use of space on the North Sea, which is an overarching theme in this study. For each theme, we discuss the future situations outlined in the scenarios and the development pathways. We also describe the opportunities, bottlenecks and solution strategies, as well as the relevant stakeholders. A focused knowledge agenda is required for the North Sea, to reduce uncertainties and enable innovation. Although countries are already working together on this, international cooperation needs to be further stimulated, and more focus is required. We therefore identify the main knowledge gaps for each theme. The underlying data, hypotheses and information, on which developments in the North Sea sectors are based, are described in a background document.

4.2 Energy transition

The North Sea may play a large role for the Netherlands and other neighbouring countries in the transition towards a sustainable energy supply. Offshore wind turbines in particular can help reduce greenhouse gas emissions (see box). Different emission reductions are achieved in different scenarios (Table 4.1). In this section, we discuss the possible future use of space on the Dutch continental shelf for wind farms, oil and natural gas production, CCS, and cables and pipelines. We also describe the opportunities, bottlenecks and solution strategies, as well as the relevant stakeholders.

Future situations and development pathways

Only in scenario IV does the Netherlands find itself on a pathway in which the Paris Climate Agreement's objectives are achieved, if all countries make a similar effort. In this scenario, greenhouse gas emissions are reduced by 100% in 2050 compared with the base year 1990. In scenario II, the Netherlands achieves a reduction of 80%, which is at the lower end of the 80% to 95% reduction agreed on by European governments in 2009 as the European contribution to the global 'two-degree climate target'. In scenarios I and III, emissions in the Netherlands are reduced by 45% and 65% respectively in 2050, in agreement with the CPB and PBL (2015b) WLO scenarios. Comparable efforts in the rest of the world will result in average global warming, under these scenarios, of considerably more than 2 °C: 2.5 °C to 3 °C in scenario III and 3.5 °C to 4 °C in scenario I.

In these scenarios, the important role of the North Sea in the energy transition is expressed primarily as installed wind power (Table 4.1). Between now and 2050, thousands of wind turbines will be built on the Dutch continental shelf. Although other forms of renewable energy – such as solar, wave and tidal energy – may also play a role at some point in the future, their contribution is not quantified in this study.

Depleted natural gas fields are also used in three of the four scenarios to store CO_2 released during industrial activities and energy generation (CCS). In every scenario, oil and natural gas production stops on the Dutch continental shelf between 2030 and 2050, as described by Geuns et al. (2017). Exactly when this happens depends on developments in CO_2 and fossil fuel prices in the scenarios: the lower the fossil fuel price and the higher the CO_2 price, the earlier oil and natural gas production will stop. A mix of energy technologies is therefore required to reduce greenhouse gas emissions.

The data in Table 4.1 are based on model calculations of the Dutch energy system (see CPB and PBL, 2015b) that balance energy supply and demand. These calculations are shown in more detail and discussed further in the background document.

Table 4.1
Summary of energy transition data, per scenario, for 2030 and 2050

	Scenario I *Slow Change*	Scenario II *Pragmatic Sustainability*	Scenario III *Rapid Development*	Scenario IV *Sustainable Together*
Greenhouse gas reduction (%, compared with 1990)				
2030	30%	45%	40%	50%
2050	45%	80%	65%	100%
Offshore wind power (GW)				
2030	4.5	7.5	11.5	15
2050	12	22	32	60
CCS (CO_2 Mt/yr)				
2030	-	-	15	20
2050	-	30	25	45
Final energy consumption savings (%, compared with 2015)				
2030	4%	9%	0%	13%
2050	10%	20%	0%	30%

Wind farms

The largest spatial developments in all physical compartments (air, soil and water) in the scenarios are related to the growth in offshore wind energy. The maps of the North Sea and the Dutch continental shelf (Chapter 3) show possible wind farm sites in 2050 according to the scenarios.

In 2015, wind farms covered about 0.1% of the Dutch continental shelf. Between 2015 and 2017, wind power on the Dutch continental shelf increased from about 350 MW to about 1 GW, and in 2017 covered about 0.3% of the Dutch continental shelf (CLO, 2017). By 2030, the total area covered by wind farms varies from 1% of the Dutch continental shelf in scenario I to 4% to 6% in scenario IV. By 2050, this increases to at least 3% of the Dutch continental shelf in scenario I to 17% to 26% in scenario IV (see Table 4.2). This is explained further in the text box 'Spatial coverage of wind farms and power density'.

Spatial coverage of wind farms and power density

The lowest spatial coverage values in Table 4.2 for each scenario correspond to a power density of 6 MW per km², as assumed in the Policy Document on the North Sea 2016–2021 (IenM and EZ, 2015b). The highest values correspond to a power density of 4 MW per km². A power density of 4–6 MW per km² corresponds to between 6 and 9 wind turbines that each produce 7 MW over an area of 10 km². In practice, there are wind farms with power densities higher than 6 MW per km² and wind farms with power densities lower than 4 MW per km². For example, both of the Dutch Gemini wind farms have a power density of almost 9 MW per km², while the British East Anglia One wind farm, which is currently under development, will have a power density of 3.5 MW per km².
We therefore adopt 6 MW per km² as an average value, and the lower 4 MW per km² as an indication that the spatial coverage can be much higher. A much higher power density, like that in the Gemini wind farms, takes up much less space. With a power density of 9 MW per km², 60 GW of wind turbines requires 11% of the Dutch continental shelf – much less than the 26% required for a power density of 4 MW per km². However, a higher power density can have negative effects. Depending on the location of the wind farm and the type of wind turbine used, bird mortality may be higher and the output lower, and multiple use more difficult to realise.
Power density is therefore an important factor in the design of a wind farm for determining the spatial coverage, the opportunities for multiple use and the environmental impact.

The currently designated wind energy areas cover about 5% of the Dutch continental shelf and provide space for an installed wind power of 12 to 18 GW. This means that, based on the developments in offshore wind energy in the scenarios (see Table 4.2), new areas will need to be designated between 2030 and 2050. When this is required exactly depends on the increase in wind energy power, which varies between the scenarios. Based on a capacity of 60 GW in 2050 (scenario IV), this will be in around 2030, as about 15 GW of wind turbines will then need to have been installed. No new areas are required for a capacity of 12 GW in 2050 (scenario I).

The last column in Table 4.2 shows which combinations of activities are assumed in each of the scenarios.

Table 4.2
Spatial coverage, location and multiple use of wind farms in 2030 and 205

	2030		2050		Multiple use
	Area of Dutch continental shelf	Location	Area of Dutch continental shelf	Location	
Scenario I Slow Change	1%–2%	Designated areas	3%–5%	Designated areas	Nature, passage for small vessels
Scenario II Pragmatic Sustainability	2%–3%	Designated areas	6%–9%	New locations no further than approx. 100 km from the coast	Nature, fishing, passage for small vessels
Scenario III Rapid Development	3%–5%	Designated areas	9%–14%	New locations on Dogger Bank	Nature, aquaculture, fishing, passage for small vessels
Scenario IV Sustainable Together	4%–6%	Designated areas plus possible new areas	17%–26%	Many new locations outside current nature areas	Wind farms part of international nature network, aquaculture, passive fishing methods, passage for small vessels

Oil and natural gas production and CCS

There were 11 oil platforms and 150 natural gas platforms on the Dutch continental shelf in 2015. Assuming a safety zone of 500 metres around each platform, this required an area of 126 km², or 0.2% of the Dutch continental shelf. This does not include the space required for oil and natural gas pipelines on the seabed (see cables and pipelines). Platforms with a helideck require an obstacle-free safety zone of 5 nautical miles; therefore, if all 161 platforms were to have a helideck, the space required would be up to 3% of the Dutch continental shelf. However, if platforms with a helideck are located in an area designated for wind power, it may still be possible to place wind turbines in these areas, but this will be determined on a case-by-case analysis of the situation (IenM and EZ, 2015b).

The number of platforms decreases in every scenario in the coming decades (Table 4.3), so that more space gradually becomes available (EBN and Gasunie, 2010). We also see more and more platforms without a helideck, which will further decrease the space required. The Dutch Mining Act states that platforms that are no longer in use must be demolished. However, it may make sense to leave them in place, so that they can be used for CCS. From an ecological perspective, there is also something to say for leaving a platform, or part of the platform, where it is. Existing platforms act as an artificial reef and can have a positive effect on local biodiversity. Even so, although demolishing a platform may disturb the ecosystem at the site level, nature will benefit more in the long run from the creation of large nature reserves rather than a few platforms with a high local ecological value dotted here and there.

In practise, multiple use of space will largely be confined to combinations of two sectors: energy and nature, nature and food supply (fishing and aquaculture) or energy and food supply. Sectors considered to be of national importance will be given priority.

All offshore oil and natural gas production stops by 2050 in the scenarios, in line with current views on the exploitation of small natural gas fields (Geuns et al., 2017). This also means that the number of platforms is reduced to zero if they are all dismantled, as legally required, after decommissioning. However, CCS is introduced in scenarios II, III and IV (also see the background document). The Dutch Government describes in the 2017 Coalition Agreement the ambition to store 18 Mt CO_2 per year, starting in 2030. No CCS currently takes place on the Dutch continental shelf, although limited CCS has been carried out for many decades in other areas of the North Sea. Since the 1990s, Norwegian- Government-owned oil and natural gas company Statoil has stored about 1 Mt CO_2 each year that is produced during the natural gas extraction process in the Norwegian Sleipner gas field.

Table 4.3
Number of installations for oil and natural gas production and/or CCS on the Dutch continental shelf

	2015	2030	2050
Scenario I *Slow Change*	161	67	0
Scenario II *Pragmatic Sustainability*	161	20	20
Scenario III *Rapid Development*	161	48	17
Scenario IV *Sustainable Together*	161	30	30

A CCS installation to store CO_2 under the North Sea may take up less space than a natural gas platform. Underground storage for 30 Mt CO_2 per year (as in scenario II) should be possible using about 20 wells (DHV and TNO, 2008).

The number of installations for oil and natural gas production and/or CCS on the Dutch continental shelf will therefore decrease (Table 4.3). As the 2050 scenario maps of the Dutch continental shelf show (Chapter 3), old natural gas fields can be used for CCS. However, the maps do not show which natural gas fields are most suitable and should be used first. Although it is possible to determine the technical feasibility, and in some cases this is already known, the timing of CCS is complex as it depends on other choices that have or still need to be made concerning the energy transition. Current and future research needs to focus on analysing the possibilities and the timing of CCS (EBN, 2016; Havenbedrijf Rotterdam, 2017).

The developments in Table 4.3 assume that oil and natural gas installations are dismantled immediately following decommissioning, unless there are plans to use them for CCS (EBN, 2016). As a result, a few dozen installations are left in place in scenarios II and IV in 2030 that should, strictly speaking, have been dismantled. In some cases, this means that the old natural gas platforms are left unused for a considerable length of time, even up to ten years or more, in particular in scenario II.

Cables and pipelines
A maintenance zone of 500 metres for pipelines and electricity cables and 750 metres for telecommunications cables is required alongside all cables and pipelines laid on the Dutch continental shelf. Taking this maintenance zone into account, the actual space needed[1] for the 7,800 kilometres of cables and pipelines was about 16% of the Dutch continental shelf in 2015; 8% for oil and natural gas pipelines, 7% for telecommunications cables and less than 1% for electricity cables. No sand extraction activities may be carried out in these areas, and the presence of cables and pipelines places restrictions on the siting of wind turbines and other installations on the seabed.

The increase in space for cables and pipelines shown in Figure 4.1 assumes that cables are bundled similarly to the way in which telecommunications and electricity cables are currently bundled. Based on this continuation of current bundling methods, cables will cover between one fifth (scenario I) and half of the seabed on the Dutch continental shelf (scenario IV) in 2050. The increase in space taken up by telecommunications cables is the largest and the most uncertain.

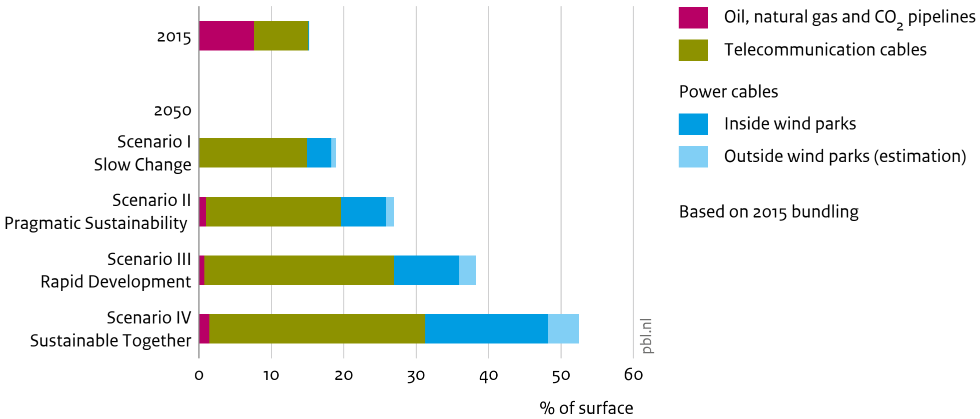
The amount of space required on the Dutch continental shelf for electricity cables in 2050 (Figure 4.1) is calculated based on current space requirements (about 330 km² per GW). Furthermore, the space required for electricity cables in wind farms depends on the size of the wind farm. Most of the space required for electricity cables will be in the wind farms (estimated to be 85% of the space requirement for all electricity cables in scenarios I and II and 80% in scenarios III and IV).

It is recommended to develop a more efficient infrastructure system to accommodate the large growth in wind energy and wind farms located further offshore (Ecofys et al., 2014) that is predicted in scenarios III and IV (see maps in Chapter 3). Two new infrastructural elements are added in these scenarios: one or more 'energy hub islands' and a network of high-capacity interconnection cables to which cables from a wind farm can be connected. This makes it unnecessary for cables from every wind farm to make landfall. If the infrastructure is not made more efficient, many more cables will be required outside the wind farms in scenarios III and IV, increasing the chance of bottlenecks.

The total amount of space required for pipelines decreases (Figure 4.1), as the decrease in the number of oil and natural gas pipelines is not compensated by the number of new CO_2 pipelines. If pipelines are not removed when they are no longer used, it is possible that the area covered by pipelines will remain at current levels, which is 8% of the Dutch continental shelf. Although power-to-gas is included in two scenarios for 2050 (scenarios III and IV), these scenarios do not include a dedicated infrastructure in the North Sea for this system.

Opportunities, bottlenecks and solution strategies
Several bottlenecks and possible synergies are identified in the scenarios for the energy transition theme.

Figuur 4.1
Extent and area of cables and pipelines on the seabed of the Dutch continental shelf



Source: PBL

Space for wind farms

In every scenario, the currently designated areas for wind energy provide sufficient room for growth in offshore wind energy up to 2030. However, space is already restricted as a result of oil and natural gas production and biodiversity protection (Birds and Habitats Directives). Failure to deal with these restrictions will mean that new areas may need to be designated for wind farms at an installed wind power of less than 12 GW. Wind farm locations may also conflict with fishing activities.

Bottlenecks on land

If the installed wind power is to increase by about 1 GW per year – the target named in the Dutch 2017 Coalition Agreement for the period 2024–2030 – or more, problems may arise before 2030 if all this energy needs to be transported to the Netherlands as electricity (Tennet KCD, 2017a). First of all, there is not enough space along the coast to land many more electricity cables, making it difficult to develop new landfall points. Secondly, strong growth in a variable offshore electricity supply may cause problems in the onshore electricity network as early as 2024–2030. For example, the power supply may exceed network capacity (congestion), which can result in power failures. One solution could be to ensure greater flexibility in demand for power in the short term, along with the ability to temporarily reduce the offshore power supply as required. In the longer term, however, the existing national grid should be improved and extended, and interconnections should be made with foreign networks, for example using sub-surface DC power cables and/or overhead high-voltage lines. This applies in particular if we are to achieve the wind ambitions in scenarios III and IV. Given the turnaround time of roughly ten years for such changes to the infrastructure, decisions will need to be taken soon.

Conversion of wind energy to hydrogen

To continue to accommodate a rapid growth in offshore wind energy after 2030, as predicted in scenarios III and IV, larger changes may be required in the energy system than minor adjustments to the onshore electricity network. For example, problems associated with landing more electricity from wind farms may be solved using electrolysis to convert wind power into hydrogen (power-to-gas). As a concentrated form of energy, hydrogen is relatively easy to transport and store for long periods of time. Hydrogen is produced in the scenarios either on 'energy hub islands' or on the shore. The scenarios assume that any hydrogen produced offshore is transported to land by ship. In theory, power-to-gas has many advantages when it comes to managing the growing variable power supply from offshore wind farms, and for the energy transition in general. The widespread implementation of power-to-gas in the energy system and its use as a production method for industrial raw materials is still in its infancy. The large-scale conversion of wind energy into hydrogen therefore represents a fundamental choice that requires a careful consideration of the opportunities and threats involved. Although still in the experimental phase, Tennet is currently developing plans together with Gasunie and other international partners for an 'energy hub island' in the North Sea that includes power-to-gas (Tennet KCD, 2017b). Such 'energy hub islands' are included in scenarios III and IV. In the short term, however, power-to-gas cannot solve congestion issues in the onshore electricity network resulting from the offshore energy supply.

Multiple use in wind farms

In scenario IV in particular, the spatial claim made by offshore wind energy is so high in 2050 that the current distinction made between wind farms on the one hand and nature and fishing on the other, will be difficult to maintain, unless it is accepted that nature reserves and fishing areas can no longer grow, or even need to decrease in size. Combining wind farms with nature reserves or fishing areas may help solve the pressure on space resulting from the large growth in offshore wind farms.

Effect of wind farms on nature

Various forms of multiple use of space are seen in the scenarios with high to very high growth in offshore wind energy (II, III and IV) (see Figure 4.2 in Section 4.5, Multiple use of space). The assumption is made that measures can be taken to protect nature, although it is uncertain whether this will be possible. Based on current knowledge on the negative effects of wind farms, it is not possible to fully analyse the effects of an increase in wind power by a factor of 30 (scenario III) or even up to 60 (scenario IV) by 2050. Moreover, negative effects may accumulate even more, since the scenarios assume that the other North Sea countries have wind power plans comparable to the Dutch efforts and ambitions.

Research into effects of offshore wind energy on ecology

The Dutch Ecology and Cumulation Framework (KEC; IenM and EZ, 2015b) has produced initial findings on the possible ecological effects of offshore wind energy when combined with other pressures on ecosystems in the North Sea. A five-year research programme also started in 2016 – the Offshore Wind Ecological Programme (WOZEP) – which aims to identify gaps in our knowledge relating to the ecological impact of offshore wind farms (WOZEP, 2016). Although the programme will produce a lot of new knowledge over the next five years, it cannot be expected to provide answers to questions that we are not yet aware of. The accumulation of future ecological pressures on the North Sea may also have as yet unknown negative effects on ecosystems (IMARES, 2017).

Monitoring

Continual monitoring, based for example on Wozep and KEC results, is expected to provide more information on the long-term effects of growth in offshore wind energy. It is not possible in this study to define the conditions under which wind farms can be combined with nature reserves or fishing activities. After all, this depends on political decisions made regarding the three policy objectives of the 2030 North Sea Strategy.

From natural gas to CCS

Offshore oil and natural gas production stops by 2050 in every scenario. However, the rate at which this happens is different under each scenario and does not necessarily match the demand for depleted natural gas fields created by CCS, under scenarios II, III and IV. In terms of cost effectiveness, there should be a period of no longer than roughly ten years between the decommissioning of a natural gas platform and its recommissioning for CCS (TNO and EBN, not yet published). However, CCS is not introduced until the end of the 2030–2050 period in scenario II, which means that some platforms will no longer be suitable for reuse. This can be prevented by encouraging cooperation between the offshore companies, to be coordinated by the Dutch Government. Current legislation, which states that oil and natural gas platforms should be dismantled and removed if no longer used for production, also needs to be changed.

Synergy between natural gas production, wind energy and CCS

It is possible to achieve synergy by coordinating the activities of offshore oil and natural gas production, wind energy and CCS companies. This will reduce both costs and CO_2 emissions. Given the high CO_2 prices in scenarios II and IV, lower CO_2 emissions will also result in lower costs. Progress can be made in the short term with the electrification of platforms and the reuse of infrastructure. The main actors as far as this is concerned are national government (through policy), oil and natural gas companies, *Energie Beheer Nederland* (EBN) and the relevant knowledge institutes.

Space for electricity cables

A lot of space is potentially required on the seabed for cables for offshore wind farms, mostly inside the wind farms themselves. This means that, even if the cables are buried, the use of these wind farms for fishing that disturbs the seabed or other activities could result in an increase in damage to these cables. One alternative is to construct overhead pylons for electricity cables, high enough to allow the free passage of small vessels.

Cooperation reduces costs

The Dutch Government has no direct influence on the prices of fuel, CO_2 and raw materials such as steel, but these prices have a considerable effect on investments in the energy transition. Working together with other North Sea countries involved in the development of offshore wind energy can help reduce the costs associated with constructing and connecting wind farms. For example, countries can work together to develop joint standards, share knowledge and coordinate spatial planning for wind farms and the corresponding infrastructure.

Traffic control

An increase in the amount of space taken up by wind farms, especially in the busiest area of the North Sea, may mean that there is not enough space for vessels that are not confined to shipping routes, such as fishing and recreational boats. Large vessels that are confined to shipping routes use the large shipping lanes, which will continue to provide sufficient space for these vessels. There will also be an increase in vessel movements in and around wind farms, for maintenance and supply purposes. The currently installed capacity of 1 GW requires 8 trips per wind farm per day, and there will therefore be more encounters between vessels confined to shipping lanes and vessels that are not. Extra maritime traffic control (Vessel Traffic Service) can help ensure the safety of this extra traffic. Less and less space will therefore be left for smaller vessels outside the main shipping routes, especially if they need to share this space with aquaculture or cast net fishing activities. One solution could be to install extra corridors between the wind farms, or to allow vessels to pass through the wind farms. It may also be possible to achieve spatial synergy with aviation, by combining these corridors with helicopter routes. The main actors as far as this is concerned are the North Sea countries, national government (policy), the EU, IMO, IALA, OSPAR (international policy) and the commercial and recreational shipping sectors.

International spatial planning for infrastructure

All the North Sea countries require new infrastructure to realise their ambitions for offshore wind energy, while they also need to dismantle or reuse existing oil and natural gas infrastructure. In 2016, the North Sea countries decided to coordinate their energy efforts by forming the North Seas Energy Cooperation. Furthermore, spatial planning in the North Sea is regulated at the European level in the EU Framework for Maritime Spatial Planning, the consultation structure and the North Seas Countries' Offshore Grid Initiative of the European network organisations (ENTSOE). If we are to develop an efficient, more environmentally friendly energy infrastructure in the North Sea, countries need to coordinate their spatial planning and their national energy transition goals at an early stage in the development process. This mainly concerns the large-scale infrastructure, such as wind farm sites, 'energy hub islands', interconnections with main power cables and natural gas and oil pipelines and, possibly, new pipelines for transporting hydrogen to land or storing CO_2 beneath the North Sea. Coordinating the North Sea energy infrastructure with other North Sea countries will help the Netherlands develop the best plan possible for its own infrastructure. It may also help reduce the costs involved in the construction of wind farms and their connection to the electricity network. The main actors as far as this is concerned are the North Sea countries, national government (through policy), the offshore oil and natural gas industry, Tennet, ENTSOE, EBN and Gasunie.

Knowledge platform

For countries to work together, a joint knowledge platform is required that can be used to access all kinds of relevant knowledge. In the Netherlands, the Dutch Government has set up the Noordzeeloket (www.noordzeeloket.nl), a knowledge platform that brings together relevant information about the North Sea. An international version of this for the whole of the North Sea region would support existing and future partnerships by providing partners with a shared knowledge base. Given the importance of a good international knowledge base to the Netherlands, the government could take the initiative in this. The need for such a knowledge platform is equally large in every scenario. The main actors as far as this is concerned are the North Sea countries, national government (through policy), knowledge institutes, the sectors and companies.

Growth in international telecommunications connections

If the need for new international telecommunication connections grows at the speed predicted in the scenarios, more efficient methods for laying cables in the North Sea will need to be found. The increase in the number of cables and the growing dependence on data flows (security), combined with the limited space available in the North Sea, require smart innovations in terms of management and maintenance if we are to develop a safe, reliable network that takes up less space. For example, we need to develop a method that bundles telecommunications cables much more efficiently, so that they take up less space while still allowing for repairs and maintenance activities. The main actors as far as this is concerned are the North Sea countries, national government (through policy), the telecommunications sector and companies.

Knowledge gaps

The scenarios highlight a number of gaps in our knowledge that can be used in the development of research programmes:

- Although natural gas plays a large role in the current energy supply and as an industrial resource, this role will be much reduced as we go through the transition to a sustainable energy supply. Do hydrogen or other gases from offshore wind energy present a realistic alternative? For example, what are the expected developments in the cost of hydrogen production and its use for industry or energy generation?

- Timing is very important when it comes to synergy between oil and natural gas exploitation, offshore wind energy, CCS and possible conversion into and the sub-surface storage of hydrogen. What options are available in terms of achieving the most optimum result, and what are the obstacles?
- Although we know quite a lot about CCS technology and costs, we can expect questions to arise when we actually start using CCS in the Netherlands. For example, there are various governance questions concerning the capture, supply, transport and storage of CO_2 in practise.
- We still do not know what the long-terms effects of a large number of wind farms, as seen in scenarios III and IV, will be on nature. A continuous monitoring programme could provide some answers and would be more successful if conducted by a consortium of North Sea countries.
- How much need is there for new international telecommunications connections in the North Sea? The uncertainty in the growth in the number of international telecommunications cables assumed in the scenarios is high. Reducing this uncertainty would help achieve better spatial planning for the cables and pipelines in the North Sea.

4.3 Resilient ecosystems

Future situations and development pathways

A resilient ecosystem is an ecosystem that can withstand some stress and that serves one or more purposes (EZ, 2014). Achieving resilient ecosystems is not just a national policy objective but is also important if we are to achieve a UN sustainable development goal to which both the EU and the Netherlands has committed itself. This is SDG 14: conserve and sustainably use the oceans, seas and marine resources.

The scenarios predict widely varying types of nature for the future, and therefore very different levels of ecosystem recovery. Improvements are however seen in every scenario, although the level of improvement is uncertain and depends in part on national government policy ambitions. In scenarios I and III, which assume continuation of current policies, the area of nature reserves remains the same – 20% of the Dutch continental shelf. However, the emphasis on vested interests and poor coordination in scenario I mean that these reserves do not form a single network. The focus on enlightened self-interest and an ability to think beyond the own sector mean that such a network is seen in scenario III. The area of nature reserves increases significantly in the sustainable ambition scenarios.

In scenario II, we see an extensive national network of nature reserves that covers 35% of the Dutch continental shelf. In scenario IV, we even see an international network of nature reserves, whereby the Dutch section covers 50% of the Dutch continental shelf.

It is important that nature reserves are protected as a whole, and that only activities that do not harm nature are permitted, which means, for example, no or limited commercial and recreational fishing. In designating nature reserves, we should also take into account the fact that some species will migrate northwards as the seawater temperature increases. It is also important not just to focus on national ambitions, but to align these with the ambitions of neighbouring countries. This applies not just to the designation of nature reserves but also the conservation measures introduced, and will greatly benefit nature.

An increase in the area of nature reserves in scenarios II and IV will benefit benthic biodiversity. However, not just the size of a nature area is important, but also the conservation and nature development measures taken. We therefore see that benthic species (which live in or one the seabed) recover the most in scenarios II and IV, in which no fishing that disturbs the seabed is permitted in nature reserves. The policy in these scenarios is much more ambitious that the 30% to 35% of existing Natura 2000 sites currently closed to demersal fishing. It is also important not just to create the necessary conditions for recovery, but to also take measures that encourage recovery, for example by creating oyster beds or artificial reefs and making use of decommissioned oil and natural gas platforms (Rozemeijer et al., 2017).

The increase in the number of nature reserves and further improvements in water quality mean that fish populations improve in all four scenarios. The increase in scenario I is modest, as the national nature network is not fully developed and no extra conservation measures are introduced. Such measures are however introduced in scenario III. In scenarios II and IV, vulnerable species that are currently in decline, such as sharks and rays, start to increase again in numbers. The largest increase in big fish is also seen in these two scenarios, as fishing is banned in a more extensive area. Migratory fish, such as eel and sturgeon, also do better in these two scenarios as more barriers are removed in the rivers, allowing them to migrate upstream.

The increase in fish stocks – the main source of food for marine mammals – and the improved water quality in all four of the scenarios mean that the number of marine mammals also continues to increase in the scenarios. The sustainability of fishing activities also continues to improve in every scenario, although this takes place at varying rates. This means that fewer marine mammals are caught in fishing nets. The increase in fish stocks – also the main source of food for seabirds – means that the number of seabirds also increases in the scenarios. Only those seabirds that benefit from fishing activities, such as the northern gannet, decrease in number, due to the landing obligation for bycatch.

Eutrophication of seawater decreases in all four of the scenarios. In scenarios I and III, current policies achieves a reduction in phosphate, nitrogen and sulphur input from rivers and the air. In scenarios II and IV, stricter environmental standards lead to a greater reduction. New environmental technologies introduced in scenario III, and in particular in scenario IV, also contribute. A further reduction in eutrophication can be achieved if the North Sea countries work together to achieve this (NIOZ et al., 2015).

Acidification of the sea continues in all the scenarios, although to varying degrees. Acidification depends on seawater temperature (warmer water absorbs more CO_2), which in turn depends on climate change. In scenarios II and IV, in which a global effort is made to achieve the objectives under the Paris Climate Agreement, climate change remains limited to 1 °C in 2050 and 2 °C in 2100, so that seawater warming and acidification continue at a slightly lower rate than at present. In scenarios I and III, the climate warms by up to 2 °C in 2050 and up to 3 °C or 4 °C in 2100 (CPB and PBL, 2015b). Shellfish are most at risk under such conditions, although there is still much to be learnt about the effects of acidification.

A good environmental status (the sea is biologically diverse, clean, healthy and productive and used sustainably) can be achieved in or around 2030 if current policies continue. It is achieved earlier in scenario III than in scenario I, as technological developments take place more quickly in this scenario. The introduction of stricter policies may even make a more ambitious good environmental status possible, where the aim is not just to operate within the ecological limits of existing ecosystems (with the risk that these limits are not strictly observed), but for ecosystems to flourish (e.g. by reducing eutrophication using aquaculture).

Opportunities, bottlenecks and solution strategies

The expected progress regarding resilient ecosystems depends on reducing a number of conflicts and achieving synergies. In all four scenarios, the negative impact of fishing on biodiversity decreases as the fishing sector becomes more sustainable. This decrease takes place fairly rapidly in scenarios II and IV due to stricter bycatch regulations, and in scenario III due to rapid technological developments. In scenarios I and III, fishing is still permitted in some parts of nature reserves, limiting improvements in biodiversity in these areas. In scenarios II and IV, fish numbers increase significantly in the nature reserves, leading to larger catches for the fishing sector immediately outside these areas.

If wind energy capacity increases to its highest level (32 to 60 GW by 2050), wind farms will also be built in new nature reserves. This offers opportunities, as the wind turbine foundations provide a hard substrate (a hard surface on which organisms can grow), which benefits biodiversity. This can be stimulated through the ecological design of the wind turbine tower and by using larger amounts of eco-friendly concrete for the foundations. An increase in the number of wind farms can also help connect nature areas, resulting in one large area. This does however require sites to be carefully selected. A large increase in the number of wind turbines will however also result in increased seabird and bat mortality, although this can be limited by building very large turbines. It is also important not to site wind turbines close to the coast, even if this is cheaper, and even if there is little support from society, and therefore less money for more expensive solutions such as building wind farms further offshore. This reduces the chance that the wind turbines are built in migration routes.

Furthermore, the construction and subsequent dismantling of wind turbines can cause underwater noise disturbance. In scenarios III and IV in particular, there may be so much noise that marine mammals experience disturbance in large areas of the Dutch continental shelf and start to avoid these areas. Possible solutions may be to use new foundation and demolition techniques, or to use floating wind turbines in water depths of 50 metres or more, although these options involve high costs for the wind sector. The introduction of consistent noise standards in the EU and the United Kingdom will help limit such disturbance.

An increase in the number of nature reserves in scenarios II and IV and stricter conservation measures will result in extra restrictions for the fishing sector. In these scenarios, both demersal fishing (which catches fish that live close to the seabed) and pelagic fishing (which catches fish in the upper layers of the sea) are not permitted in nature reserves, or are limited to protect vulnerable species. This applies both to commercial and recreational fishing.

Knowledge gaps

Knowledge gaps are identified in the scenarios that can be used in the development of research programmes. As much is still not known about the effects of noise disturbance on marine mammals, further research needs to be carried out. The same applies to seabird and bat mortality resulting from wind turbines, and the effect of the particular site, the blade size and rotor technology on this. Very little is also known about the effect of an increase in seawater temperature on the migration patterns of fish and other species, and therefore on biodiversity in the nature reserves. The same applies to the effect of further acidification of the North Sea on shellfish and other organisms. It is also recommended to conduct research into active recovery using hard substrate in nature reserves and wind farms. Finally, the cumulative effects of all the different human activities in the North Sea should be investigated, as a follow up to research conducted for the Ecology and Cumulation Framework (IenM and EZ, 2015b). This should include the effects on marine mammals and other organisms of an increase in shipping, the number of wind farms and military exercises.

4.4 Sustainable food supply

Future situations and development pathways

The trend seen in recent years and described in Section 2.3, in which the number of fishing vessels and crew members decreases and vessel efficiency increases, is expected to continue (CEFAS, 2017). The main reason for this is the predicted increase in the concentration of fishing companies, whereby small companies are taken over by larger companies. The rate at which this happens varies in the different scenarios. For example, the number of vessels and crew members decreases rapidly in scenario I due to a decrease in demand for protein-rich seafood, but mainly due to the Brexit. In scenario III, the decrease is less pronounced as there is an increase in demand for locally sourced, high-quality fish and other types of fish. This scenario also assumes a soft Brexit.

Mergers between fishing companies may also improve the sustainability of fishing activities, as larger companies often take a more long-term approach to operations and are more able to invest in new fishing techniques. The scenarios also include the possibility that major retail and food service companies will buy up vessels so that they have more control over the quality of the fish caught. This is important if they are to meet sustainability certification requirements.

However, a decrease in the number of vessels and crew members does not automatically imply a decrease in production. After all, new EU fishing policy —with a focus on maximum sustainable yield— and new techniques will help fish stocks recover, which may make it possible to increase catches in the future. In scenarios III and IV, with relatively quick technological development, techniques will soon be developed that will enable selective fishing (‘precision fishing’). Technological innovation will take place less quickly in scenarios I and II, so that selective fishing will take longer to develop.

At mentioned previously, aquaculture in the Netherlands is currently limited in size and diverse. Whether the sector will take off in the coming years depends mainly on population growth in the Netherlands and the rest of Europe (more mouths to feed), growth in prosperity (more money to spend on food) and changing preferences (shift in demand to or from protein-rich seafood). In scenarios I and II, aquaculture remains limited to the waters of the delta and possibly coastal waters. In scenario III, aquaculture is also located further out to sea, and in scenario IV in nature reserves and other nature areas and in wind farms. The scale of operations also increases considerably in these two scenarios.

Shellfish, microalgae and macroalgae (seaweed) farming depends very much on changes in demand for biofuels, bioplastics and other renewable resources. Aquaculture as a sector is developing rapidly and seems to have much potential, also as an alternative for fishing. It is therefore important to intensify research into new techniques and the funding of experiments that focus on new techniques to reduce the risks.

Although aquaculture could replace some fishing activities internationally, this will be limited on the Dutch continental shelf. This is because there is little fish farming in this area of the North Sea, as it is too warm to farm salmon, and too cold for bass. Fish farming with the aim to provide a sustainable food supply on the Dutch continental shelf is only possible in closed-containment systems, in which various forms of cultivation together form a cycle (STT, 2016). Species such as red mullet could be farmed on the Dutch continental shelf, but these are less in demand. Retail and food service companies therefore need to launch marketing campaigns to increase the popularity of such fish.

Opportunities, bottlenecks and solution strategies

There will be considerably less space available for fishing activities in the North Sea in the coming years. In scenarios I and II, this is mainly due to the hard Brexit, which will mainly affect demersal fishing. In scenarios II and IV, space will be limited due to the building of new wind farms and the designation of new nature reserves in which stricter conservation measures apply than at present. This therefore requires a change in mindset in the fisheries sector: while traditionally fishing was possible almost anywhere, the sector increasingly needs to take other users into account. Fishing companies could present themselves more as ‘blue’ organisations, offering their services for example for the maintenance of wind farms or aquaculture systems.

As mentioned above, a hard Brexit will have severe consequences for demersal fishing as Dutch vessels will no longer be allowed access to British fishing grounds. Of course, British fishing vessels will not be allowed to enter EU fishing grounds, but this will affect far fewer fishing companies. Far fewer Dutch vessels are involved in pelagic fishing operations in the British part of the North Sea, and we could even see overcapacity developing again, requiring further mergers in the sector. This will make it even more difficult to improve the sustainability of the fishing sector and will mean that fishing at the maximum sustainable yield takes place not in 2020 but in around 2030.

It is theoretically possible to fish in nature reserves with no detrimental effect on biodiversity, but this requires small quota and the strict control of these quota and the fishing techniques used. It also requires measures to increase the sustainability of the fishing sector to reduce bycatch. The fishing sector should continue to innovate and therefore increase the sustainability of its operations. Uncertainties about the impact of the Brexit are currently making the sector cautious, but this situation will not last for ever. Furthermore, if the sector is to innovate, less detailed rules are required under the Common Fisheries Policy, and more room for experimentation using new techniques. It would also help if there were a clear distinction made between nature reserves in which fishing is not allowed and fishing areas in which nature takes second place. For example, ‘fishing fields’ could be implemented where fishing that disturbs the seabed is allowed, also using traditional beam trawling with tickler chains. This form of fishing could result in more fast-growing species in these fields that are beneficial for commercial fish stocks.

Although the construction of wind farms that are also suitable fishing grounds (fishing-inclusive wind farms) is theoretically possible, this does require changes to be made. This applies both to the wind farms (larger distances between wind turbines, burying of cables or hanging cables on masts) and the fishing vessels (cast net fishing or other passive fishing methods). It is important that the fishing sector learns of the long-term ambitions concerning wind farms and nature reserves as early as possible, so that the sector can prepare for such changes, for example by investing in different types of vessels and fishing techniques.

The development of new nature reserves and wind farms has much less of an impact on aquaculture. This is because it is relatively easy to farm shellfish, microalgae and seaweed sustainably, and such farming can even help improve local water quality. Aquaculture can also take place inside wind farms as it involves few shipping movements. The aquaculture systems do however need to be constructed to withstand storms. Pilot projects and experiences in other North Sea countries can be used to determine the necessary conditions for aquaculture in nature areas and wind farms.
The predicted climate change is going to have an impact both on the fishing industry and aquaculture. The fisheries sector needs to take into account the fact that climate change will cause fish to migrate northwards. This means that fish such as the cod will migrate north of the Dutch continental shelf, while fish such as the red mullet will migrate to the Dutch continental shelf from the south. This may mean that the Dutch fisheries sector will need to focus its operations on different types of fish.

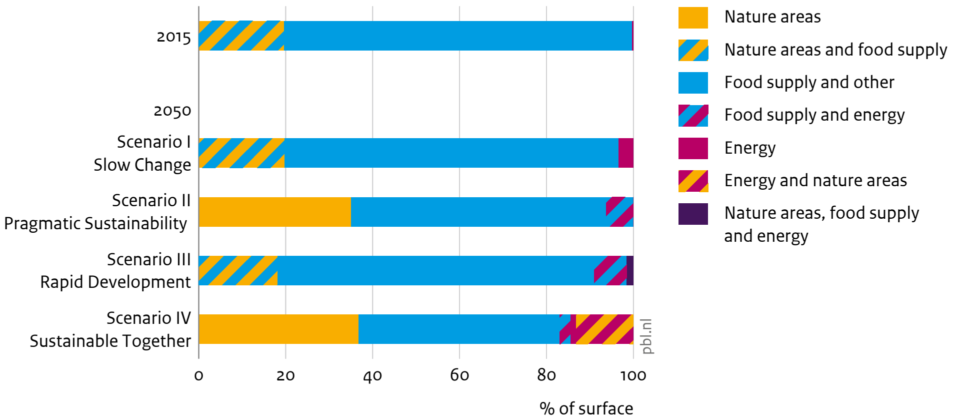
Knowledge gaps
Knowledge gaps are identified in the scenarios that can be used in the development of research programmes. For example, little is known about the effects of innovative fishing techniques such as precision fishing on yield, bycatch, fish stocks, fuel costs and other factors. Information is also required on the conditions under which fishing in wind farms is possible and financially attractive, both to the fisheries sector and the wind sector.

Regarding aquaculture, market research is required to analyse future demand for shellfish, farmed fish and sea vegetables, and ways of encouraging this demand. This will provide more information on potential growth opportunities in the sector. Research is also required into future demand for biofuels, bioplastics and other raw materials, and the extent to which this can be met by marine microalgae. Furthermore, research into new aquaculture techniques, including systems that can be built in wind farms, is also relevant. Finally, research into the technical opportunities and threats and the economic feasibility of closed-containment systems in which fish farming is combined with mussel and seaweed farming is also relevant.

4.5 Multiple use of space

Importance of multiple use of space
More and more use is being made of the North Sea, which is increasing the pressure on an already limited amount of space. The increasing spatial demand for energy and nature in the scenarios affects the amount of space available for other activities, including the food supply,

Figure 4.2
Extent and area of nature areas, food supply and energy on the Dutch continental shelf



Source: PBL

shipping and defence. Multiple use of space in the North Sea is based on planning in space and time, and involves combining functions such as wind farms, nature and culture. Although the government aims to combine such functions wherever possible, in some cases it may be necessary for functions to remain separate, or be separated (IenM and EZ, 2015). This may be the case, for example, if shipping safety or vulnerable ecosystems are found to be at risk.

In practice, functions may not yet be combined, even where it is possible (IenM and EZ, 2014). This is because the policy focus is on first developing one function (mainly offshore wind energy) before then going on to consider multiple use. In the case of multiple activities of national interest in a single area, the government aims to combine these as efficiently as possible.

The scenarios show that the spatial pressure on the North Sea will increase significantly, for example with wind ambitions of up to 12 GW in scenario I and even 60 GW in scenario IV. In this scenario, extra areas will need to be designated for wind energy. Nature ambitions can vary from maintaining currently designated nature areas in scenarios I and III (current policies) to creating a larger national or even international network of marine nature areas in scenarios II and IV (new policy). The North Sea will also be used more intensively for existing activities such as shipping, sand extraction and defence, and will be used by new activities such as aquaculture. The space available for fishing activities is reduced in almost all the scenarios. This may be due to a hard Brexit, as in scenarios I and II, but could also be due to wind energy and nature ambitions, as in scenarios II and IV. Figure 4.2 provides an overview of the area used for the strategic aims in the Dutch 2030 North Sea Strategy in 2015 and in the four scenarios.

Future use of space at sea

Figure 4.2 shows a schematic of the mulitiple uses of space for energy, nature and the food supply in 2015 and in the four scenarios in 2050. It therefore summarises the maps of the Dutch continental shelf.

- *Nature areas, food supply and other, energy.* Areas that do not have multiple uses are either designated for nature alone (orange) or for energy alone (red). Although sustainable aquaculture is permitted in marine nature areas in scenario IV, it is not possible to see this in the figure as it concerns a very small area. The area for food supply and other (blue) includes, in addition to fishing and aquaculture, all areas outside the nature reserves and designated energy areas. It therefore also includes areas that are clearly assigned for other functions, in particular shipping routes in the traffic separation scheme and military exercise areas (see Figure 2.1). These are included as food supply areas in this study as fishing is permitted almost everywhere in these areas, even though specific rules may sometimes apply (IMO, 2016). In fact, multiple use is made of all the space in this area of the Dutch continental shelf.
- *Nature areas and food supply (orange/blue).* Fishing and aquaculture activities are permitted in nature areas in 2015 and in scenarios I and III. This does not however apply to all forms of fishing. An amendment to the Fishing in Protected Areas agreement, which applies to the Dutch continental shelf, was signed in 2017 (Visserij in beschermde gebieden, EZ, 2017). This agreement will

enter into force once it has been ratified by the EU. The agreement bans fishing that disturbs the seabed in more than half of currently protected nature areas (about 12% of the Dutch continental shelf), to protect and allow benthic communities to recover. All fishing activities are banned in a small section of coastal nature areas, which represent 0.3% of the Dutch continental shelf (EZ, 2017). All forms of fishing are banned in nature areas in the sustainable scenarios II and IV.
- *Energy and nature areas* (red/orange). About 13% of the Dutch continental shelf is used for wind farms in nature reserves in scenario IV, the assumption being that this is possible without affecting the resilience of ecosystems in and around the North Sea.
- *Food supply and energy* (blue/red). Fishing or aquaculture that disturbs the seabed and cast net fishing (passive fishing methods) are allowed in wind farms in scenarios II, III and IV.
- *Nature areas, food supply and energy* (orange/blue/red). In scenario III, nature reserves such as Dogger Bank are combined with wind farms. Fishing activities are permitted in these wind farms.

Furthermore, small vessels may pass through wind farms in all the scenarios, as long as this is not prevented by aquaculture. The space used by various forms of energy is discussed in detail in Section 4.2. It will be difficult to expand wind operations on the Dutch continental shelf without combining them with other functions. It is possible to combine functions in two sectors, such as wind energy and nature, but also three, such as wind energy, nature and aquaculture.

The space used for oil and natural gas production on the Dutch continental shelf is reduced to zero in every scenario in 2050. However, when assessing sites for new wind farms we need to take into account not just existing platforms in some scenarios, but also 'contingent' resources and 'prospective' oil and natural gas resources and their corresponding platforms (safety zone ~ 1 km²) and possible helideck (safety zone ~ 11 km²). This could be the case in scenarios I and III, and probably concerns sites in existing designated wind energy areas (scenario I) and on Dogger Bank (scenario III). Some of this space will also be taken up by CCS platforms on old natural gas fields (in scenarios II, III and IV). The space used for cables will increase due to an increase in the number of wind farms and the telecommunications cables.

Nature reserves – Natura 2000 sites such as Dogger Bank, Cleaver Bank and Frisian Front – cover, at over 11 000 km², almost 20% of the Dutch continental shelf. There are also several areas of particular ecological value, such as the Central Oyster Grounds, Brown Ridge and the Borkum Reef Grounds. Together, these areas cover almost 35% of the Dutch continental shelf. Nature is of course also found outside these areas. Although the Birds and Habitats Directives place restrictions on multiple use in Natura 2000 sites, protection measures vary between North Sea countries. Areas that currently have high biodiversity levels and resilient ecosystems can also change as a result of climate change. It is important to take this into account when developing nature protection measures and when designating new nature areas.

The number of designated nature areas either remains the same in the scenarios (20% of the Dutch continental shelf) or increases considerably (to 35% of the Dutch continental shelf in scenario II and even 50% in scenario IV). In the scenarios with the highest increase in wind energy capacity (32 GW in scenario III and even 60 GW in scenario IV), wind farms are also built in nature reserves that are yet to be designated, but not in existing nature reserves. If no additional sustainable development policy is implemented there will still be space for fishing activities. Under policy with more sustainable ambitions, wind farms will be built as part of an international nature network. In both cases, extra measures are required to limit the impact on nature during the construction and demolition of wind turbines (acoustic disturbance to marine mammals) and operations (seabird and bat mortality).

The area of the North Sea and the Dutch continental shelf required for the food supply (fishing, aquaculture) varies considerably in the scenarios. The space available for fishing activities on the Dutch continental shelf will be increasingly limited by the increasing number of wind farms and nature reserves in which fishing activities are either restricted or banned. If Dutch sustainability policy is developed that bans fishing not just in wind farms but also in nature reserves, the area available for fishing activities on the Dutch continental shelf will be considerably smaller in 2050 than at present. Furthermore, scenario II also includes a hard Brexit, although less hard than in scenario I. This will mean that British fishing grounds are only accessible to Dutch vessels under strict conditions. The impact of new wind farms on demersal fishing can be limited by siting wind farms outside key fishing grounds wherever possible. Fishing-inclusive wind farms can also be designed to limit their impact on pelagic fishing.

Although the increased area for wind and nature results in less space for fishing, there is enough space for an expansion in aquaculture. Aquaculture is currently only found in the waters of the delta, but in the future could also take place in shallow coastal waters and further out to sea, and possibly in nature areas and wind farms.

Mussel and seaweed farming can even help improve local water quality. For ecological reasons, fish farming should take place in closed-containment systems (sea farms).

Shipping activities take up about 17% of the Dutch continental shelf. This includes the complete traffic separation scheme (waterways, anchorages, Rotterdam/IJmuiden ports), with just the waterways taking up 6%. Although the scenarios show an increase in sea transport, the increase in vessel size does not result in more vessel movements in every scenario. It is important that seagoing vessels are able to travel and manoeuvre in designated shipping lanes without being hindered by any other activities. Given the space available on the Dutch continental shelf and in the North Sea, no spatial bottlenecks are expected.

More shipping activities will also take place outside the traffic separation system, including ferry services, recreational activities and shipping activities for operations in the North Sea. This can be accommodated by creating corridors between the wind farms for larger vessels and by permitting shipping activities inside wind farms for smaller vessels. It may also be necessary to create fixed routes and corridors for sailing vessels. The placing of wind turbines near shipping lanes increases the risk of collision, and therefore implies a greater role for traffic control.

Under the scenarios, sand extraction increases in volume by up to a factor of three. The amount of space currently available is therefore more than sufficient. It however may not be enough for the sand that is required to create one or more artificial islands in the North Sea. Since these artificial islands are assumed to be international projects, the required sand may also orginate from places other than Dutch territory. Innovative techniques may need to be developed to extract such large amounts of sand both cheaply and at the correct locations. Despite sand extraction being an activity of national interest, a large increase in the number of cables on the seabed will increase the pressure to limit the number of locations on the Dutch continental shelf in which sand extraction takes priority.

An increase in the number of wind farms will also change the sailing experience for recreational vessels in the North Sea. In scenarios III and IV in particular, the number of places from which an unobstructed view of the horizon is possible will become scarce. However, it is many decades since the North Sea was free of obstacles such as oil and natural gas platforms, and most of these platforms will disappear in the future to be replaced by lots of wind turbines. This makes the energy transition visible.

Under current policies, the presence of cultural artefacts on the seabed (e.g. shipwrecks, archaeological finds) do not stand in the way of wind farms or cables and pipelines. Current policies focuses on allowing such archaeological artefacts to remain in their original location wherever possible. If this is not possible due to the construction of wind turbines or islands or due to sand extraction or other activities, then policy moves to securing the scientific value of the site through archaeological surveys. This is particularly important in scenarios III (sand extraction, new wind turbines) and IV (new wind turbines and islands).

Current military training areas remain in place in scenarios I, II and III; only in scenario IV does the military training area to the north of the Wadden Islands make way for wind farms. In this scenario, low-level flight training areas move to the Scottish section of the North Sea. This does of course entail extra costs for the air force. If this is not to affect the quality of the exercises carried out, compensation should be provided. In scenarios I and II, the more intensive use of the military training areas limits their use for shipping, fishing and leisure activities.

Working towards multiple use of space

As we have seen above, the scenarios show that the spatial pressure on the North Sea will increase in the years to come. However, they also show that multiple use of space can be achieved in many different ways, such as wind farms combined with nature, fishing and/or aquaculture. Multiple use of space means that the space we have is used more efficiently, but also that more space remains or is made available. For example, the reduction in the space available for fishing will be limited if opportunities are also created for fishing in wind farms. At the same time, wind farms offer opportunities for enabling the recovery of benthic species following fishing activities that disturb the seabed. A combination between wind farms and nature with existing marine fishing practices is not considered possible at the moment, but is possible if sustainable passive fishing methods are introduced.

Multiple use of space may also take place in time. One example of this is the use of depleted oil and natural gas fields for CCS. This does however require good timing. For example, it is important that CCS starts soon after oil and natural gas production finishes.

Combining functions can create synergy, such as improved water quality due to mussel farming in a nature area, but also conflicts, such as bottom trawling in areas with fragile seabed habitats. In many cases, the multiple use of space means that the right conditions need to be created for the use of that space. For example, the wind turbines in wind farms must be spaced far enough apart to prevent collisions between fishing vessels. It is also important that fishing vessels do not use traditional beam trawling, to prevent damage to exposed electricity cables. Both the opportunities for synergy between the various activities and the conflicts between activities can encourage innovation. Examples are the design of fishing-inclusive wind farms in scenario III and the introduction of more selective fishing methods (precision fishing) in scenario IV to limit bycatch and therefore the impact on nature.

It can be useful to produce a series of maps to obtain an idea of the opportunities and threats regarding the multiple use of space on the Dutch continental shelf. Each map can show which areas are most valuable for a particular function (value maps). By placing these maps on top of one another, we can then see where the areas of value overlap and, based on this, which locations offer opportunities for synergy between two, three or even more functions, and which result in conflict between functions. In doing so, particular attention should be paid to the relationship between the energy transition, resilient ecosystems and a sustainable food supply. It is important to develop common frames of reference and rules of play, and to focus not just on the Paris Climate Agreement, but also the UN sustainable development goal for the sea. When this is done, we can see which conditions need to be created to enable synergy and prevent conflict. It is also recommended to determine which function has the highest priority at which location. Finally, it is possible to determine whether the extra costs required to enable the particular combination are to be paid for by the primary users or by the co-users.

The results from this analysis can be used to develop policy visions and strategies for the North Sea.
A comprehensive vision can be developed for the North Sea as a whole, or for the Dutch continental shelf; for example, by outlining the offshore spatial framework in the National Integrated Environmental Policy Strategy. Although it is difficult right now to produce a policy strategy for the fishing sector, this is possible if we use the value maps. Specific strategies can be drawn up for each area, based on the local situation and the offshore spatial framework. These strategies should not be regarded as blueprints for the future but should be adapted to reflect changing conditions. In forming this policy strategy, stakeholder involvement and coordination with neighbouring countries is essential. Note that we are not saying that multiple use of space should be applied everywhere in the North Sea. Should a certain area prove to have an exceptionally high value for a certain function, then this function should have exclusive rights to the area. It is therefore also important to indicate zones in which multiple use of space is possible and zones in which it is not. Again, these zones can be adapted to reflect new developments and insights (adaptive zoning).

Knowledge gaps

Multiple use of space is less common at sea than on land. Working to achieve multiple use of space at sea therefore raises several questions, such as which new combinations of functions are possible, and which conditions need to be met for this to take place? Where do new combinations of functions produce the most synergy, and where do conflicts arise? How should the process of policy vision or strategy development be organised, and what is the relationship with investment? What does the multiple use of space require from the government and other stakeholders? Although we have some of the answers to such questions, the scenarios show that knowledge gaps still exist.

There are also some more specific gaps in our knowledge. For example, we need to know more about the relationship between seabird and bat mortality and wind turbine location, blade size and rotor technology. In addition, little is known about the use of decommissioned oil and natural gas platforms for nature (hard substrate) and sea farms (anchoring points). Furthermore, knowledge is required of the conditions under which wind turbines can be built in or near nature reserves or under which fishing or aquaculture activities are possible inside wind farms. Much of this knowledge can be gained through pilot projects. Multiple use of space also raises the question as to what the cumulative effects are of these human activities on biodiversity and ecosystems.

Note

1 The actual amount of space required takes into account current methods for bundling cables and pipelines, done for efficiency reasons.

References

BZK (in prep.). *Nationale Omgevingsvisie*, [Dutch National Integrated Environmental Policy Strategy] www.rijksoverheid.nl/onderwerpen/omgevingswet/nationale-omgevingsvisie.

CEFAS et al. (2017). *Climate change and European aquatic resources*, Lowestoft: CEFAS.

Cooper Ph. et al. (2008). *Socio-economic scenarios of European development and integrated management of the marine environment*. University of Bath, Bath.

CLO (2017). *Environmental Data Compendium, Wind energy capacity in the Netherlands, 1990–2016 indicator, 11 July 2017*. To the CLO indicator.

CPB (2015). *Melting ice caps and the economic impact of opening the northern sea route*. CPB Netherlands Bureau for Economic Policy Analysis, The Hague.

CPB and PBL (2015a). *Nederland in 2030 en 2050. Twee referentiescenario's* [The Netherlands in 2030 and 2050; two reference scenarios (in Dutch)]. CPB Netherlands Bureau for Economic Policy Analysis / PBL Netherlands Environmental Assessment Agency, The Hague.

CPB and PBL (2015b). *Welfare, Prosperity and the Human Environment (WLO). Climate and Energy dossier*. CPB Netherlands Bureau for Economic Policy Analysis / PBL Netherlands Environmental Assessment Agency, The Hague.

CPB and PBL (2016). *Valuation of CO_2 emissions in CBA: implications of the scenario study Welfare, Prosperity and the Human Environment*. CPB Netherlands Bureau for Economic Policy Analysis / PBL Netherlands Environmental Assessment Agency, The Hague.

Dammers E. et al. (2013). *Scenario's maken voor milieu, natuur en ruimte: een handreiking* [Developing scenarios for the environment, nature and spatial planning (in Dutch)]. PBL publication number 713, PBL Netherlands Environmental Assessment Agency, The Hague.

Danish Government (2012). *Denmark at work*. Copenhagen.

DHV and TNO (2008). *Potential for CO_2 storage in depleted gas fields at the Dutch Continental Shelf, Phase 1: Technical assessment*, 2008-U-R0674/A.

Van Dorsser C. (2012). *Scheepvaartscenario's voor Deltaprogramma: 100 jaar later* [Shipping scenarios for delta programme: 100 years later (in Dutch)]. Rijkswaterstaat Dienst Verkeer en Scheepvaart, Delft.

EBN (2016). *Netherlands masterplan for decommissioning and re-use*, Utrecht: EBN.

EBN and Gasunie (2010), *CO_2 transport- en opslagstrategie* [CO_2 transport and storage strategy (in Dutch)]. Energie Beheer Nederland (EBN), Utrecht / Gasunie, Groningen.

Ecofys, PWC and Tractebel Engineering (2014), *Study of the Benefits of a Meshed Offshore Grid in Northern Seas Region*, Brussels: European Commission. ec.europa.eu/energy/sites/ener/files/documents/2014_nsog_report.pdf.

EZ (2014). *The Natural Way Forward - Government Vision 2014*. Ministry of Economic Affairs, The Hague.

EZ (2017). *Noordzeekustvisserijakkoord 2017, VIBEG2*, Visserij in Beschermde Gebieden 2 [Fishing in protected areas 2 (in Dutch)], Publication no. 100028. Ministry of Economic Affairs and Climate, The Hague.

EZK and IenW (2018). 2030 Offshore wind energy Road Map, www.noordzeeloket.nl/functies-en-gebruik/windenergie/vervolgroutekaart/.

EU (2008). *Marine Strategy Framework Directive*, Directive 2008/56/EG of the European Parliament and Council, Official Journal of the European Union L 164/19.

EU (2014a). *Maritime Spatial Planning Framework Directive*, Directive 2014/89/EU of the European Parliament and Council, Official Journal of the European Union L 257/135.

EU (2014b). *A policy framework for climate and energy in the period from 2020 to 2030*, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2014) 15 final.

EZ and IenM (2014). *Roadmap, Ministers of Economic Affairs and of Infrastructure and the Environment*, The Hague: Parliamentary letter about offshore wind energy, 26 September 2014.

Van Geuns L, Juez-Larré J and De Jong S. (2017). *Van exporteur naar importeur. De verander(en)de rol van aardgas in Nederland* [From exporter to importer. The changing role of natural gas in the Netherlands (in Dutch)], TNO Whitepaper 17–9022, Netherlands Organisation for Applied Scientific Research (TNO), Delft.

Port of Rotterdam Authority (2017). *Havenbedrijf, Gasunie en EBN doen haalbaarheidsstudie naar CCS in Rotterdam* [Port Authority, Gasunie and EBN conducting feasibility study on CCS in Rotterdam], News item (in Dutch): www.portofrotterdam.com/nl/nieuws-en-persberichten/havenbedrijf-gasunie-en-ebn-doen-haalbaarheidsstudie-naar-ccs-in-rotterdam.

IMARES (2017). *Cumulative effects assessment. Proof of concept marine mammals.* Institute for Marine Resources and Ecosystem Studies, Den Helder.

IMARES and LEI (2016). *Haalbaarheid mosselteelt binnen offshorewindparken in de Nederlandse kustzone,* Yerseke [Feasibility of mussel farming in offshore wind parks within the Dutch coastal zone (in Dutch)]. Institute for Marine Resources and Ecosystem Studies / Landbouw Economisch Instituut, The Hague.

IMO (2016). *Verdrag inzake de Internationale Bepalingen ter voorkoming van aanvaringen op zee,* 1972 [Treaty concerning the international agreement to prevent collisions at sea, 1972], London, 20 October 1972; Valid from 1 January 2016 to the present day, wetten.overheid.nl/BWBV0001014/2016-01-01.

IPV (2010). *Verkenningen. Houvast voor de krijgsmacht van de toekomst* [Outlook study. Basis for the armed forces of the future (in Dutch)], Interdepartementaal Project Verkenningen, The Hague.

IenM (2015). *Uitwerking besluit doorvaart en medegebruik van windparken op zee in het kader van Nationaal Waterplan 2016 – 2021* [Implementation of the decision on ships passing through and using wind parks, in respect to the National Water Plan 2016–2021 (in Dutch)], December 2015, Ministry of Infrastructure and the Environment, The Hague.

IenM and EZ (2012). *Eerste cyclus Mariene Strategie 2012-2018,* Mariene strategie voor het Nederlandse deel van de Noordzee 2012-2020, deel I, II en III [Maritime strategy for the Dutch part of the North Sea 2012–2020, parts I, II and III], www.noordzeeloket.nl/beleid/europese/nationaal-niveau/mariene-strategie/.

IenM and EZ (2014a). *North Sea 2050 Spatial Agenda.* Ministry of Infrastructure and the Environment / Ministry of Economic Affairs, The Hague.

IenM and EZ (2014b). *Government Structural Vision on the Designation of Additions to the Coast of Holland.* Ministry of Infrastructure and the Environment / Ministry of Economic Affairs, The Hague.

IenM and EZ (2015a). *National Water Plan 2016–2021,* The Hague.

IenM and EZ (2015b). *Policy document North Sea 2016–2021,* The Hague.

IenM and EZ (2015c). *Framework for Assessing Ecological and Cumulative Effects of Offshore Wind Farms - Part B: Description and Assessment of the Cumulative Effects of Implementing the Roadmap for Offshore Wind Power,* The Hague.

IenW and EZK (in prep.). *2030 North Sea Strategy,* www.noordzeeloket.nl/beleid/noordzee-2030/

Koelemeijer R et al. (2017). *Analyse regeerakkoord Rutte-III: effecten op klimaat en energie* [Dutch Government Coalition Agreement Rutte III, analysis of the impact on climate and energy (in Dutch)], PBL Netherlands Environmental Assessmen Agency, The Hague.

LEI (2014). *Bodemberoerende visserij op de Noordzee* [Demersal fisheries at the North Sea (in Dutch)], Agricultural Economics Research Institute (LEI), The Hague.

LEI (2016). *Blauwe groei* [Blue growth (in Dutch)], Agricultural Economics Research Institute (LEI), The Hague.

LEI (2017). *Visserij in cijfers* [Fisheries data (in Dutch)]. Agricultural Economics Research Institute (LEI), www.wur.nl/nl/project/Visserij-in-cijfers.htm.

Matthijsen J, Aalbers R and Van den Wijngaart R. (2016). *Achtergrondrapport bij WLO-cahier Klimaat en energie* [Background document WLO dossier on Climate and Energy (in Dutch)], PBL Netherlands Environmental Assessmen Agency / CPB Netherlands Bureau for Economic Policy Analysis, The Hague. http://www.wlo2015.nl/wp-content/uploads/pbl-2016-wlo-achtergronddocument-klimaat-en-energie-1775.pdf

Matthijsen J, Dammers E and Elzenga H. (2018). *Achtergrondrapport bij De Toekomst van de Noordzee; Verhaallijnen en onderliggende gegevens, aannames en onderbouwing* [Background document to the Future of the North Sea]. PBL Netherlands Environmental Assessmen Agency, The Hague.

NIOZ et al. (2015). *De staat van de Noordzee.* [The state of the North Sea (in Dutch)], Texel / Utrecht / Den Helder / The Hague: NIOZ Royal Netherlands Institute for Sea Research/ Deltares / IMARES / Rijkswaterstaat.

NISS (2016). *Blauwdruk 2050* [Blueprint 2050 (in Dutch)], Rotterdam: Stichting Ondersteuningsfonds NISS.

PBL (2012). *Nature Outlook 2010–2040*. PBL Netherlands Environmental Assessment Agency, The Hague.

PBL (2013). *Nature Outlook 2010–2040*, background report. PBL Netherlands Environmental Assessment Agency, The Hague.

PBL (2017). *European nature in the plural,* PBL Netherlands Environmental Assessment Agency, The Hague.

PBL and ECN (2011). *Exploration of pathways towards a clean economy by 2050: How to realise a climate-neutral Netherlands.* PBL Netherlands Environmental Assessmen Agency, The Hague.

Pinnegar JK et al. (2006). *Alternative future scenarios for marine ecosystems,* Lowestoft: DEFRA.

Political Declaration (2016). *Political Declaration on energy cooperation between the North Seas Countries,* ec.europa.eu/energy/en/topics/infrastructure/north-seas-energy-cooperation.

Port of Rotterdam (2011). *Havenvisie 2030* [Port vision 2030]. Port of Rotterdam, Rotterdam.

Ros J and Daniëls B. (2017). *Verkenning van klimaatdoelen, van lange termijn beelden naar korte termijn actie* [Exploration of climate targets, from long-term images to short-term action (in Dutch)]. PBL Netherlands Environmental Assessmen Agency, The Hague.

Rozemeijer MJC et al. (2017). *Bouwen met Noordzee-natuur* [Building with North Sea nature (in Dutch)], Agricultural Economics Research Institute (WUR-LEI), The Hague.
Schoots K, Hekkenberg M and Hammingh P. (2017). *Nationale Energieverkenning 2017* [National Energy Outlook 2017], PBL Netherlands Environmental Assessment Agency, The Hague.
SER (2013). *Energy Agreement for Sustainable Growth*, The Social and Economic Council of the Netherlands (SER), The Hague.
STT (2016). *Een oceaan vol mogelijkheden* [An ocean of possibilities (in Dutch)]. Netherlands Study Centre for Technology Trends (STT), The Hague.
Tennet KCD (2017a). *Kwaliteits- en Capaciteitsdocument 2017, Deel II: Investeringen Net op Land 2018 – 2027* [Quality and capacity document 2018–2017, Part II: Net onshore investments (in Dutch)]. https://www.tennet.eu/fileadmin/user_upload/Company/Publications/Technical_Publications/Dutch/TenneT_KCD2017_Deel_II.pdf.
Tennet KCD (2017b). *Kwaliteits- en Capaciteitsdocument 2017, Deel III: Investeringen Net op Zee 2018 – 2027* [Quality and capacity document 2017, Part III: Net offshore investments (in Dutch)]. https://www.tennet.eu/fileadmin/user_upload/Company/Publications/Technical_Publications/Dutch/TenneT_KCD2017_Deel_III.pdf.
WA Yachting Consultants (2016). *Prognose ontwikkeling recreatievaart in 2030, 2040 en 2050* [Prognosis development recreation boating in 2030, 2040 and 2050 (in Dutch)]. WA Yachting Consultants, Lelystad.
WindEurope (2017). T*he European offshore wind industry, Key trends and statistics 2016*, Brussels. windeurope.org/about-wind/statistics/.
WOZEP (2016). *Wind op Zee Ecologisch Programma* [Offshore wind energy Ecological Programme], www.noordzeeloket.nl/functies-en-gebruik/windenergie/ecologie/wind-zee-ecologisch/.
QinetiQ, Lloyds Register Group Limited and University of Strathclyde (2013). Global marine trends 2030. QinetiQ / Lloyds Register Group Limited / University of Strathclyde; Hampshire / London / Glasgow.

PBL Netherlands Environmental Assessment Agency

PO Box 30314
2500 GH The Hague
The Netherlands

www.pbl.nl
@leefomgeving

July 2018