WORLD ENERGY COUNCIL | THE NETHERLANDS

The North Sea Opportunity

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World Energy Perspective

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Preface

The World Energy Council (www.worldenergy.org) is the principal impartial network of leaders and practitioners promoting an affordable, stable and environmentally sensitive energy system for the greatest benefit of all.

The following report is published by the World Energy Council, the Netherlands (www.wereldenergieraad.nl) in collaboration with project partners DNV-GL, EBN, ECN, PwC, Rabobank, Shell, TenneT and TNO, and with contributions from the World Energy Council in the United Kingdom, Germany, Belgium, Norway and Denmark.

This report aims to identify and facilitate the next steps needed in order to realise the full potential of the North Sea. Increasing activities for offshore wind and decreasing activities for hydrocarbon production offer challenges and opportunities to unlock the full potential of the North Sea.

The 2017 WEC North Sea Conference was organised by the World Energy Council, the Netherlands to support the findings of the report.

Core team

International review team

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Introduction

The North Sea has played an important role in Europe’s history…

Historic overview

The North Sea is a part of the Atlantic Ocean located between the United Kingdom, the Netherlands, Scandinavia, Germany, Belgium, and France. It measures approximately 570,000 km^2, and is a relatively shallow sea, with an average depth of 65 metres and a maximum depth of 700 metres. As a comparison, the Mediterranean Sea is 1,500 metres deep on average.

The North Sea has played a vital role in the development of the economies around it – supplying food, energy and transportation routes. It is also a popular tourism and recreation area, as well as a nature reserve.

The Romans where the first to intensively use the North Sea to expand their empire. The Romans conquered large parts of England, the northern parts of Germany and the Netherlands via the North Sea. They were followed by the Vikings, who used the North Sea to raid and conquer the surrounding countries.

From the 12th century onward, the shipping lanes of the North Sea became increasingly important. The Hanseatic League – the world’s first free trade agreement – were the first to make extensive use of the North Sea to trade between the different Hanse cities.

Many battles have been fought over who controlled the North Sea shipping lanes, for instance the famous Anglo-Dutch Wars during the 17th century, and major battles in World War I and II took place in the North Sea.

…and continues to be an important source of economic activity today

Functions of the North Sea

Current functions of the North Sea

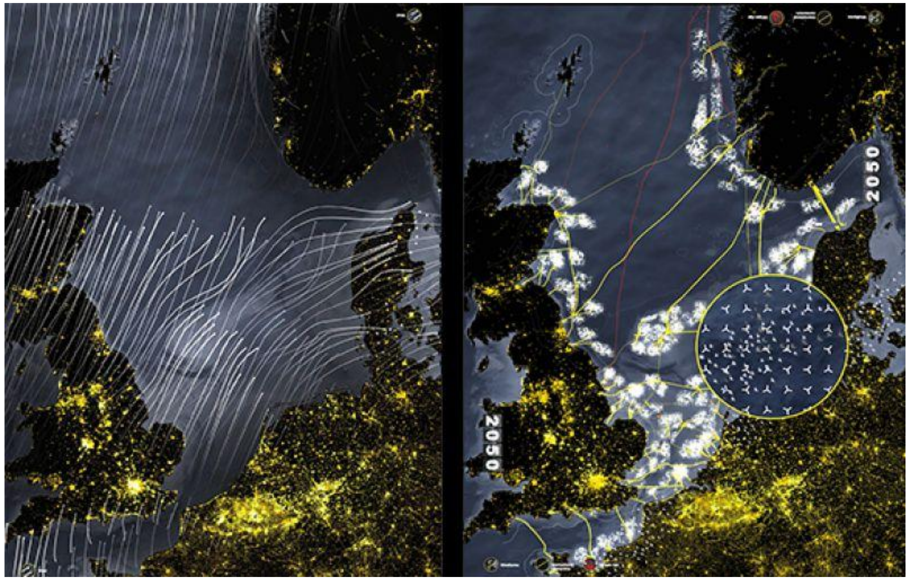
Today the North Sea continues to be an important source of economic growth for the countries around it. The countries around the North Sea are among the wealthiest in the world, making the North Sea region one of the richest regions in the world.

- The North Sea became an important **source of energy** in the late 19th century when oil and gas fields where discovered. Large oil fields were found in the territorial waters of the UK and Norway, while the Netherland holds substantial natural gas reserves. Today, the North Sea is increasingly important as a source of wind power.
- **Maritime transport** through the North Sea is still vital today. Three of the world's largest seaports are located here: Rotterdam, Antwerp and Hamburg. Other large ports are Bremerhaven and Felixstowe. Consequently, the North Sea is one of the busiest seas in the world.
- The North Sea is still a significant **supplier of food** today. The European Commission coordinates the fisheries policies in the North Sea, to ensure that the sea will remain an important fishing area, with a vibrant ecosystem, also in the future.

The amount of activity in the North Sea is likely to increase. While some activities may co-exist, or even enhance one another, other activities may be mutually exclusive and require tough choices to be made between competing interests.

The North Sea will play a vital role in the transformation to a low carbon energy system

An energetic Odyssey – the North Sea and the energy transition (potential for offshore wind in the North Sea in 2050)



Source: IABR, Tungsten Pro

The North Sea could contribute to substantial CO_2 reductions

In view of climate change and the unsustainable level of greenhouse gas (GHG) emissions, as well as the depletion of oil and gas (O&G) resources in some parts of the sea, the North Sea is faced with a new set of challenges.

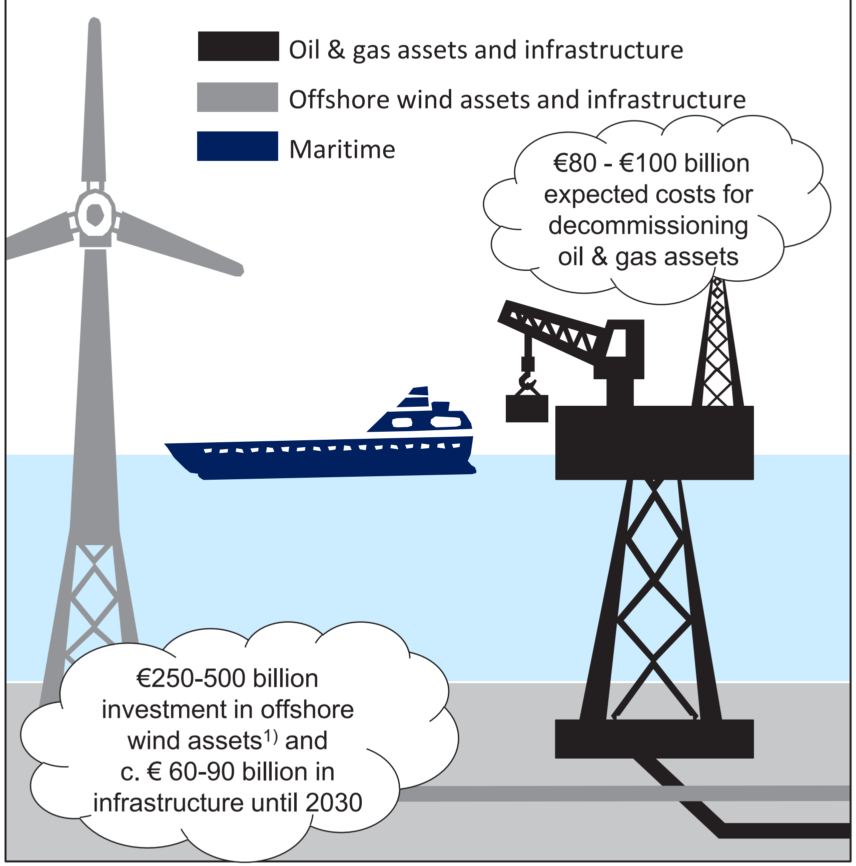
The current energy system needs to be transformed from a fossil fuels based system to a low carbon system, based on efficient energy use and renewable energies. During the United Nation's COP21 conference, over 190 countries committed to limiting the increase in the global average temperatures to well below 2 °C, compared to pre-industrial levels. Those countries have also said they will make efforts to limit the temperature increase to 1.5 °C.

Within this context, we see a clear opportunity for the North Sea to become a key energy resource and support the energy transformation. We believe that in 2050 the North Sea will no longer be dominated by oil and gas. Instead we see the North Sea of the future as a clean sea with substantial renewable production, a flourishing marine life, including aquatic farming, and clean shipping.

The North Sea presents concrete business opportunities for those willing to harness its long-term potential, but it increases the need for cooperation and coordination across borders and sectors. Timely action is vital, as the required investments have a long technical life time. Decisions made today, and in the coming 15 years, will be crucial for progress towards the 2050 CO_2 reduction targets.

Synergy effects from collaboration can reduce costs, open up new markets and reduce CO_2 emissions in the North Sea

Three layers of activity in the North Sea



Note: current cost level, investments have not been discounted
1) Based on the current known pipeline of offshore wind farms, and a growth to 180GW in 2050
Source: PwC analysis. Includes the UK, Denmark, Norway, Germany, the Netherlands and Belgium.

Decommissioning and building renewable assets – two parallel processes

The coming decades will see two parallel and important developments in the North Sea. Large investments will be needed to decommission old oil and gas assets, while at the same time renewable energy projects (the majority in offshore wind) will be developed in the North Sea. These developments also interact with other activities in the North Sea, such as shipping, and affect the ecosystem of the sea.

It is estimated that together the removal of old oil and gas platforms and infrastructure, as well as building new renewable energy assets will need a total investment of anywhere between of €390-690 billion[1] in the coming decades. As some North Sea countries are yet to confirm additional plans for offshore wind, we expect this number to continue to increase.

The large investments needed lead to high societal costs in the form of missed tax income from hydrocarbon production, decommissioning tax deductibility, and subsidies to renewable energy. In this light, the energy transition poses an important problem to citizens and policy-makers alike, who would like to see energy prices remain at an affordable level, and decommissioning costs to be contained as far as possible. Harnessing cost-efficiencies from collaboration between governments and market parties, and across sectors, in the North Sea becomes absolutely vital. Synergy effects could not only reduce costs, but may also open up new markets (and profits), while reducing CO_2 emissions.

We have selected four main value pools, based on their potential to reduce costs and create value

The North Sea has a vast untapped potential to add value across the three dimensions of the energy trilemma: affordability, sustainability and security of supply.

Decommissioning optimisation

How to ensure cost-efficient decommissioning

In most countries around the North Sea, a large part of decommissioning costs are borne by the tax payers. As such, cost reduction is a great priority for all society. Adequate planning and economies of scale are important drivers to reduce the costs of decommissioning old oil and gas assets. For more details see pages 13-16.

Prolonging life and re-purposing O&G assets

Finding a new (renewable) life for existing oil and gas assets

After oil and gas production has ceased, operators may deem platforms and infrastructure worthless for further use. Nonetheless, those assets could find a new life and be used for the storage of renewable energy, as well as CO_2. This would support the transition to a low carbon energy system in the North Sea. For more details see pages 17-21.

Efficient offshore wind energy

How to develop wind energy at scale and cost-efficiently

The cost of offshore wind is rapidly decreasing, but further cost reductions are yet needed. Becoming cost-competitive is not only essential in its own right, but is also central to maintaining government support. Cost-efficient design and application of infrastructure in the North Sea is key. For more details see pages 22-26.

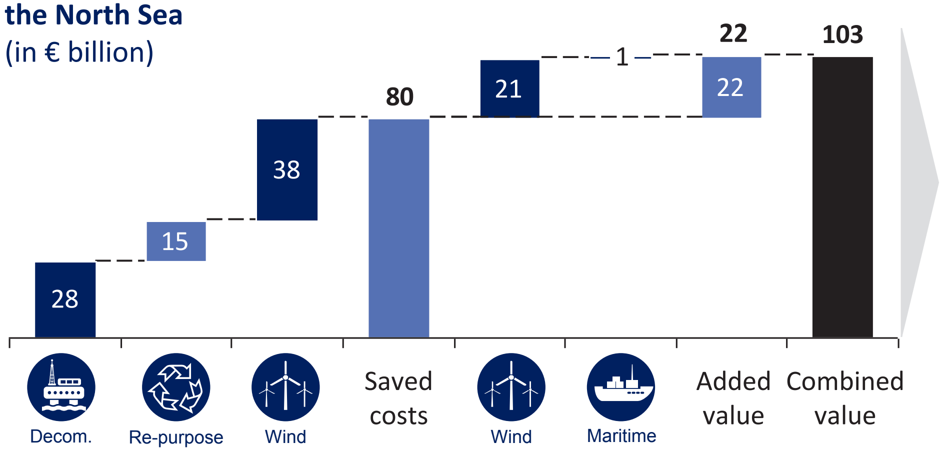
Maritime synergies and spatial planning

How to combine energy and maritime activities optimally

There are various maritime activities in the North Sea. Combining energy activities with other maritime activities may both add value and reduce costs. New ecosystems could be created in synergy with old and new energy assets if good spatial planning is applied. The opportunities are diverse and not yet fully identified. For more details see pages 27-33.

An initial high-level assessment shows an untapped value of €103 billion across the four value pools combined in the period 2017-2050…

Total discounted estimated value from cooperation and synergies in the North Sea
(in € billion)



Defining value:
For the purpose of this report, we define value as: how cooperation and synergy effects can help 1) save costs 2) open up new markets, thereby creating new value where there previously was none and 3) reduce CO_2

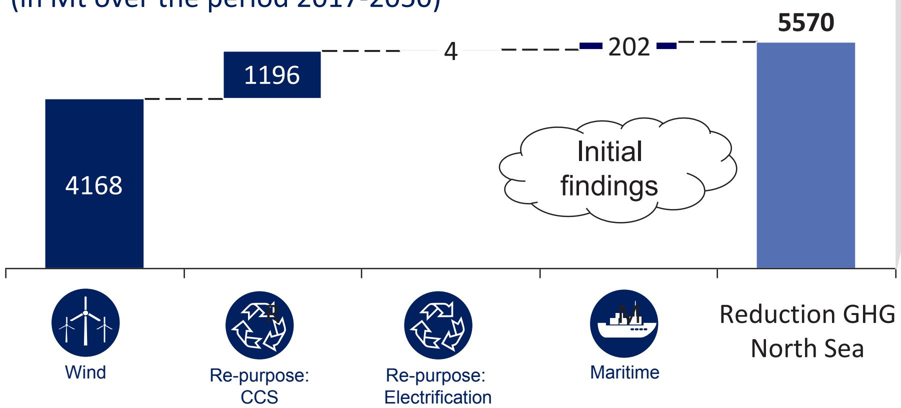
Affordability
By reducing costs and exploring synergies between old and new infrastructure, the cost of future energy production in the North Sea could become substantially lower. This would benefit consumers and businesses across Europe.

Short explanation (for details on the assumptions used in the calculations please see the appendix, pages 42-53)

- **Decommissioning:** c. 30-40% cost reduction from industry collaboration, efficiency gains due to standardisation of procedures, use of innovative approaches (materials and techniques) and international best practices.
- **Re-purposing old O&G assets:** Value creation through the delay of decommissioning costs (~€1 billion). Cost reduction for carbon capture and storage (~40% from 2017-2030, combined with the tonnes of CO_2 stored) could save €14 billion over the period 2017-2050. Other sources where value could be created by cooperation have not yet been quantified, including power-to-gas (PtG), gas-to-wire (GtW), geothermal energy, compressed air energy storage.
- **Efficient offshore wind energy:** Further cost reduction for offshore wind farms (of €55/MWh to €40/MWh from 2017-2030, taking into account the current pipeline of projects until 2030 and additional capacity after 2030 adding up to 180 GW in the North Sea in 2050). Further market integration through international offshore wind grids leads to cost savings and benefits.
- **Maritime synergies and spatial planning:** Sea weed production in wind farms could lower costs for sea weed production, and enable production further from shore. Producing sea weed at lower costs would create additional profits. Also, damages to offshore wind farms caused by fishing boats, and the costs associated, could be avoided. Spatial planning could help reduce costs by selecting the best locations for complementary and competing activities. This has not yet been quantified.

...and it shows a possible ~5570 Mt reduction of GHG across the four value pools in the period 2017-2050

Estimated GHG cuts due to energy transformation in the North Sea
(in Mt over the period 2017-2050)



Sustainability

By producing clean energy through offshore wind, electrifying oil and gas platforms (thereby reducing the carbon footprint of O&G production) and using old gas fields for carbon storage, the North Sea could substantially contribute to lowering GHG emissions and other fossil fuel related emissions. Offshore wind farms in the North Sea could reduce the amount of GHG by ~4200 Mt over the period 2017-2050. Furthermore, as an example, electrification of Dutch oil and gas platforms could reduce GHG emissions by ~4 Mt over the period 2017-2050. CCS could store an amount of GHG up to c. 1,200 Mt and the cultivation of sea weed could contribute to a CO_2 reduction of 200 Mt. If harnessed to the full, the North Sea has the potential to become the ‘renewable energy garden’ of Europe.

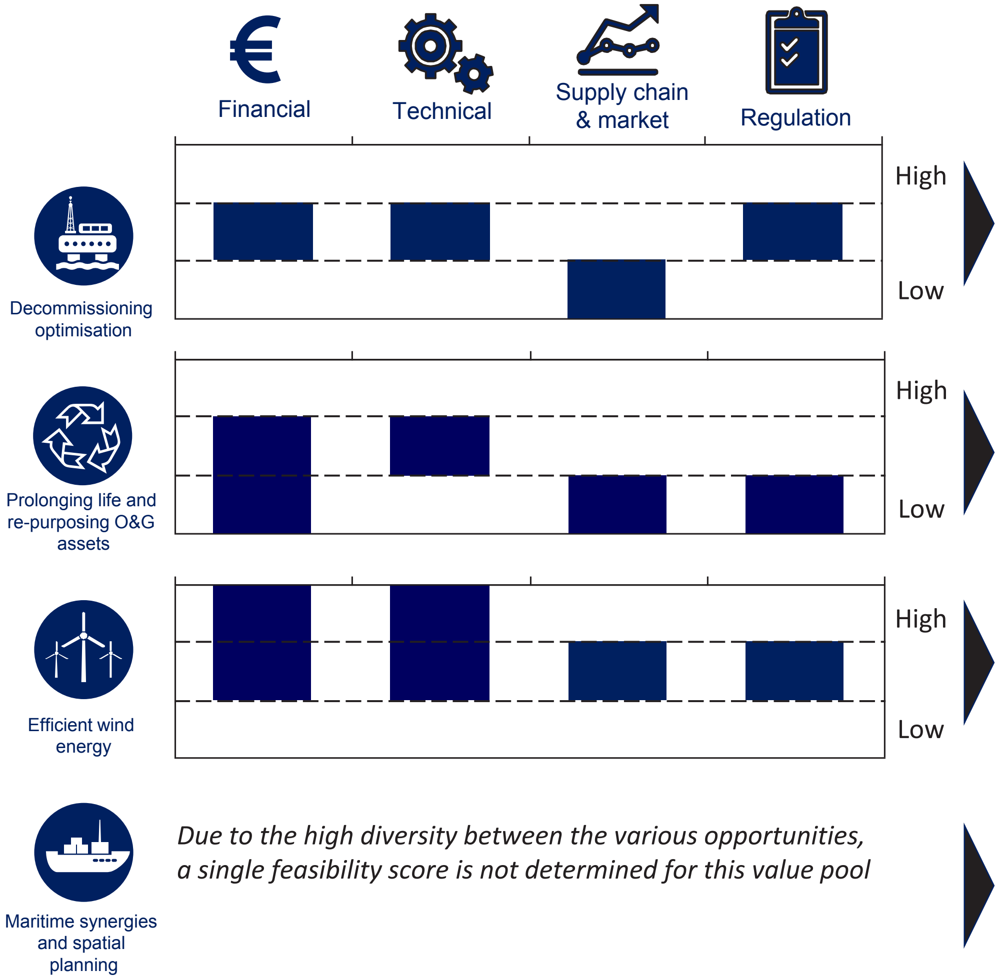
Short explanation of the assessment of GHG reduction (for details on the assumptions used in the calculations please see the appendix, pages 42-53):

- **Decommissioning:** no reduction of CO_2.
- **Re-purposing old O&G assets:** Carbon capture and storage, as well as electrification of existing O&G platforms contribute to reducing CO_2. If 25% of platforms would be electrified 4 Mt CO_2 could be avoided over the period 2017-2050. For CCS technology - based on a ‘medium’ roll-out scenario, CO_2 emissions could be reduced by approximately ~1200 Mt in the period 2017-2050.
- **Efficient offshore wind energy**: Developing offshore wind capacity according to the current pipeline, could reduce CO_2 by ~4200 Mt (compared to gas fired production of electricity).
- **Maritime synergies and spatial planning:** Sea weed can be used as a biofuel. Sea weed production within offshore windfarms could reduce CO_2 emissions by 202 Mt over the period 2020-2050.

N.B.: A third aspect of the energy trilemma is security of supply. By harnessing wind at sea, Europe could create a new local energy source. Europe currently imports more than 50% of the energy it needs (Eurostat 2016).

At the current juncture, not all value pools are feasible. Specific challenges differ strongly per value pool

Feasibility score



We have assessed the financial, technical, supply chain & market, and regulatory feasibility for each value pool. This gives and indication of what next steps would be taken in order to utilise the full potential of the North Sea.

Optimal decommissioning is possible if actors coordinate and align the timing of decommissioning projects so that the supply chain could organise itself optimally. Currently, imperfect timing leads to higher decommissioning costs than would be necessary. Some financial, technical and regulatory hurdles also still remain.

Prolonging the life of, and re-purposing the use of, O&G assets is still at a very early stage of development and therefore hurdles exist in all areas. In many cases there are no example business cases to learn from and often technologies are not yet available, or not designed for offshore use.

Offshore wind cost reduction has been materialising since 2010, and barriers for further cost reduction are relatively low compared to other value pools. For offshore wind energy some new technologies, such as floating wind farms, are not yet bankable. In some countries regulatory hurdles mean that TSOs are not allowed to invest in the offshore grid and therefore economies of scale is not realised.

The opportunities arising from maritime synergies and good spatial planning at sea are very diverse. This makes it hard to determine one single feasibility score. Opportunities are yet being identified and each opportunity has a different feasibility score.

Market and government failures show the importance of cooperation between governments and market players for the energy transformation in the North Sea

Market and government failures

Market failures	
Public goods	Public goods are goods that are not delivered by the free market. They are defined as goods that are non-rivalry and non-exclusive.
External effects	External effects of the production of goods or services, negatively or positively, affect third parties who are not involved in the production decision.
Information asymmetry	The different parties involved do not have the same access to information. This can result in coordination problems and unfair advantages.
Transaction costs	The cost of executing a transaction. If transaction costs are high, they can hinder the functioning of markets.
Market power	Market power exists if one party can profitably raise its prices above its marginal cost. This can arise from the three forms of market failure: barriers to market entry, economies of scale or scope, and network effects. These market failures limit competition and increase market concentration and hence market power.

Government failure

Government interventions can lead to undesirable distortions in the functioning of markets. Before a government intervenes in a market, it should carefully evaluate if the cost of the market failure is larger than the cost of the intervention. Only if the cost of the market failure outweighs the effects of government intervention should it choose to act.

Source: PwC and Rabobank analysis

Market failures related to the North Sea

The government has a vital role to play in the transformation towards a sustainable energy system as it seeks to protect its citizens from external effects – air pollution and climate change. Without government intervention excess GHG would be emitted. This is because the cost of the external effect – pollution – is not borne (fully) by the emitter and hence, the theory goes, it will not affect his decision to emit or not. Examples of how governments can chose to intervene to limit pollution (external effects) are the EU's Emission Trading Scheme and renewable energy subsidy schemes.

Next to external effects, a second market failure which could justify government intervention is information asymmetry. Coordination problems on the North Sea result principally from asymmetric information. The large and diverse group of stakeholders, who may also potentially have conflicting interest, can exacerbate this problem. Short-term strategic behaviour among stakeholders may prevent actors from pursuing synergy effects and thus limit the overall joint value creation.

Governments can take a facilitating role by facilitating cooperation between stakeholders to avoid information asymmetry and solve coordination problems to the benefit of all stakeholders.

For offshore renewable energy, and in particular offshore wind, the recently signed Political Declaration on energy cooperation between the North Sea countries (Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, the UK and Sweden) provides a framework for cooperation across borders. It helps to limit information asymmetries and facilitates a joint discussion on the consequences of external effects. The next step would be to convert this political commitment into practical actions that can drive change. This is particularly important for the development of international offshore electricity grids.

For each value pool there are a few important practical next steps that need to start tomorrow

Decommissioning optimisation

- Estimate the total market size and timing for decommissioning in the North Sea. Align the pipeline across countries to enable an efficient supply chain and asses the potential for joint decommissioning projects
- Estimate the type of removals needed – type of wells, platforms, pipelines, design of the right equipment and optimise contract size
- Evaluate rules and regulations for abandonment per country – both from a technical and societal point of view. Assess how those could be better synchronised

Prolonging life and re-purposing O&G assets

- Perform a technical assessment of the current infrastructure in order to understand its compatibility for new uses, such as the use of natural gas pipelines for transporting hydrogen, methane or CO_2
- More pilot projects are needed, such as the ENGIE rig-to-reef pilot, or NAM's solar power and battery storage pilot in the North Sea
- Identify regulatory hurdles per country and bring those to the attention of government(s)/the EU

Efficient wind energy

- Ensure government support for innovation programs such as the Offshore Wind Accelerator in the UK, or GROW in the Netherlands
- Implement ENTSO-e requirements and start harmonisation of grid standards. Coordinate planning and development of offshore wind farms and grid projects
- Develop demonstration sites to test new offshore wind technologies
- Assess existing pilot projects on international coordination for the offshore grid (Kriegers Flak and Ijmuiden Ver/East Anglia)

Maritime synergies and spatial planning

- Identify a long list of maritime and spatial planning options and select the most important ideas for further assessment
- Assess maritime synergies such as clean shipping and fisheries for the benefit of the North Sea area
- Increase the availability and interoperability of marine data. Develop a common environmental impact assessment framework
- Perform a regulatory gap analysis for sea weed cultivation, using recommendations from the EU's Horizon 2020 programme

For a long list of practical next steps per value pool please refer to the individual chapters

Important next steps for successful North Sea cooperation

Shortlist of next practical steps in order to harness the full potential of the North Sea

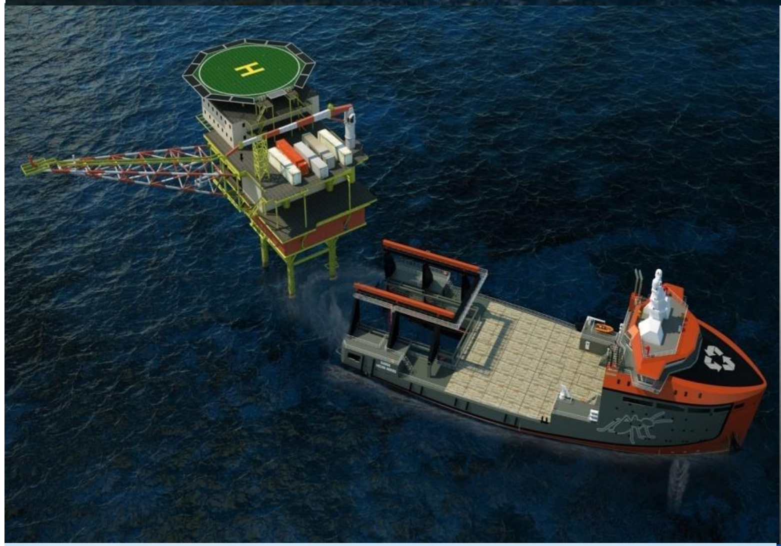
- Government should ensure a shared vision for the energy transformation in the North Sea, and invest in researching synergies
- Stakeholders, such as WEC, should organise an annual international North Sea conference to drive change
- Market players should share knowledge of business cases where international cooperation has been successful and financial benefits have been shared between companies
- Stakeholders should urge the EU to provide funding for offshore projects within its Interreg North Sea Region Programme. (Negotiations for the next funding cycle in 2020-2027 will start shortly)
- Market players should explore opportunities for EU funding through the European Fund for Strategic Investments (EFSI) and the Connecting Europe Facility (CEF)

Value pool descriptions

1 Decommissioning optimisation

Decommissioning optimisation



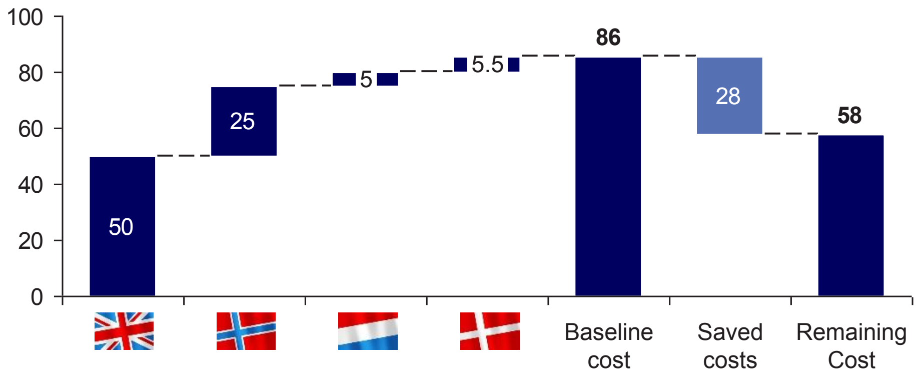






A large number of oil and gas installations in the North Sea need to be decommissioned over the next decades

Decommissioning costs per country and saved costs
(in € billion)



Decommissioning of oil and gas assets has started

The North Sea accommodates more than 300 oil and gas fields, with an infrastructure of over 5,000 wells, more than 500 platforms, and 10,000 km of pipelines (OSPAR 2010[1]).

An intergovernmental decision of 1998[2] requires all topsides as well as sub-structures/jackets to be removed, re-used, recycled or disposed of on land. Certain structures may be exempted from removal, such as steel jackets weighing more than 10,000 tonnes, gravity-based concrete installations, floating concrete installations and concrete anchor based installation.

For now, decommissioning has already started in the UK where some large structures have been removed. In the Netherlands approximately 23 small structures have been removed (EBN 2016). However, it will take until 2050 and beyond for all North Sea installations to be removed.

There is a need for cost reduction

The expected costs for decommissioning in the North Sea are substantial: c. €80 billion until 2050. However, these are estimates that could still increase. It is also estimated that 99% of the costs will fall on the UK, Norway and the Netherlands. In most countries the government has to pick up a large part of decommissioning costs, often both as a shareholder and because decommissioning costs are tax deductible (thus resulting in a reduced national income). Therefore from a societal perspective, cost reduction for decommissioning is of great importance. There are various ways in which costs could be reduced:

- *Effective industry collaboration*

Operators and contractors could coordinate work scopes and operations to create economies of scale.

- *Support quality and cost-effective standardisation*

Harmonisation of the decommissioning approach between operators and contractors facilitates collaboration and decreases inefficiencies.

- *Stimulate innovative decommissioning*

Innovation has the potential to decrease cost and enhance quality.

- *Build on international best practices*

Use available international experiences and share best practices between countries, companies and institutions.

- *Effective and efficient regulation*

Regulation should support optimal decommissioning planning and execution.

- *Support a professional supply chain by executing projects*

The supply chain matures through increased experience.

1) OSPAR is the mechanism by which 15 Governments and the EU cooperate to protect the marine environment of the North-East Atlantic.
2) OSPAR Decision 98/3

Companies and governments need to work together in order to reduce costs of decommissioning. Decommissioning is still mainly a national activity

International overview of decommissioning status

	GB	NO	NL	DK
Assets to be decommissioned	323 platforms, 370 sub-sea structures and 20,000 km pipelines to be decommissioned	119 platforms (12 concrete, 19 floating steel, 88 steel) and c. 350 sub-sea systems to be decommissioned	150 platforms and 200 km pipelines to be decommissioned	62 platforms (61 fixed steel and 1 gravity based structure) and 5 sub-sea installations to be decommissioned
Regulation	Operator is responsible for decommissioning installations. Infrastructure is made safe and abandoned	Licensee is responsible for decommissioning installations. Infrastructure is cleaned and disposed or abandoned	Operator is responsible for decommissioning installations. Infrastructure is cleaned and abandoned	Licensees is responsible for decommissioning installations, infrastructure and for post-decommissioning monitoring
Status	Active. The OGA has dedicated working groups. 95 platforms and 7,500 km pipeline will be removed in the period 2016 -2025	Decommissioning is not yet a high priority. Current focus on recovery and growth. 14 projects foreseen in the period 2016 -2025	Decommissioning masterplan in place since November 2016. 23 platforms have been decommissioned	Subsoil Act regulates decommissioning and financial security requirements. Guidelines for decommissioning to be released in 2017
Expected peak	Maximum activity is expected in the period 2020 -2030	Increased activity is expected after 2030	A peak is expected around 2025	Estimated between 2025 - 2035
Cost target used	Cost reduction target of 40% in place	No cost reduction target in place	No cost reduction target in place	The Danish Energy Agency has not set a target but expects cost reductions by industry over time
Societal costs	Shareholder: *none* Estimated % of cost borne by society: 50-80%	Shareholder: petoro Estimated % of cost borne by society: 80-90%	Shareholder ebn Estimated % of cost borne by society: 70%	Not yet estimated

Sources: EBN (2016), UK Oil & Gas (2016)
N.B.: Germany and Belgium are not analysed: Germany only has two platforms, Belgium no oil and gas production

Decommissioning is a high priority in some territories

The significance and timeline for decommissioning differs across countries. The costs of decommissioning will be highest in the UK and Norway due to the large size of the assets.

The regulatory framework for decommissioning vary across countries, and there are large differences in the timing and costs.

Stakeholders are strongly organised by country

Regulators are national regulators, and each country has its own licencing authority.

Industry organisations and decommissioning communities are organised at a local level.

Operators, however, work across borders but have to comply with a different set of regulations in each country.

Current decommissioning regulations do not ensure availability of cash to cover decommissioning costs. Thus the government is failing in its role to limit externalities

Market and government failure analysis

Market failures	
Public goods	NA
External effects	Society bears the cost of pollution if O&G assets are left in the sea
Information asymmetry	NA
Transaction costs	NA
Market power	NA

Government failure
Governments have made regulations, stipulating that O&G assets must be removed after their useful life. However, it does not oblige companies to set actual cash aside, thus falling short of incentivising companies to actually start the decommissioning process.

Applies

The economic incentives for decommissioning are lacking

Government intervention for decommissioning is needed because of the risk of **external effects**. In a case where there was no regulation to remove assets, operators would not have an incentive to do so. Those operators would not bear the (environmental) cost of leaving their assets in the sea, while decommissioning them comes at a high cost. Even if production has ceased, the cost of minimal maintenance needed for an asset in the sea is much lower (on an annual basis) than removing the same asset. Of course abandonment is the altogether less costly option. In either case the (short-term) economic incentive to decommission is not there.

Governments have therefore intervened by regulating the oil and gas industry, stipulating that assets have to be decommissioned after their useful life. However, governments have not made it a requirement for companies to set actual cash aside during the production years, and the regulations thus fall short on incentivising companies to actually start the decommissioning process. The lack of an adequate regulatory framework for cash provisions leads to two scenarios, both in which companies are reluctant to start decommissioning activities:

- At times when oil or natural gas prices are high, operators generate high cash flows. However, they are reluctant to use this cash to start decommissioning as the favourable market conditions mean that extraction is still highly profitable and everything is done to squeeze more value out of the field. Decommissioning is also relatively more expensive in this environment as prices for equipment rental, for example, are also higher.
- In an opposite scenario, decommissioning is relatively cheaper, but companies do not have the cash flow needed to start decommissioning activities.

To overcome this government failure an independent decommissioning fund could be set up for shareholders of the oil and gas fields (oil and gas companies and government) to make cash deposits during the production years. Cash payments could be made dependent on the oil price so that they are in line with the company’s cash flow generation.[1] The decommissioning fund would need to be set up as an independent body which can decide if and when assets need to be decommissioned.

[1] A risk with this set up would be that the total sum of cash donations could be insufficient after a long period of relatively low oil or gas price

Aligning the timing of decommissioning projects enables the supply chain to organise itself optimally

Feasibility assessment of cost reduction for decommissioning optimisation

Area	Comments / explanation	First practical next step
Financial Feasibility Low Medium High	• Currently there is no alignment between stakeholders on how to share cost savings from optimal of decommissioning	• Pilot project on the optimal phasing of decommissioning projects in order to share resources and reduce costs
Technical Feasibility Low Medium High	• There is a need for dedicated equipment and vessels for decommissioning. For now, insight into the type of removals and the equipment required is lacking	• Estimate the type of removals and equipment needed (type of wells, platforms, pipelines)
Supply chain & market Feasibility Low Medium High	• There is uncertainty regarding the timing of investments needed for decommissioning • A plan for how to optimally phase decommissioning is lacking. There is a risk of a boom and bust type of market due to imperfect timing and limited coordination. This could lead to an overheated market or a loss of professional expertise when the market is low	• Estimate the total market potential and timing for decommissioning in the North Sea across countries
Regulation Feasibility Low Medium High	• There is currently no harmonisation between governments, operators and NGOs across countries • Costs vary due to different interpretations of the legislation. Differences in the costs of well decommissioning can vary as much as 1:4. Clear standards and guidelines could avoid this	• Evaluate rules for abandonment per country • Assess how those could be better synchronised

Prolonging life and re-purpose of oil and gas assets

Prolonging life and re-purposing oil and gas assets in the North Sea have many benefits, including reduced CO_2 emissions

Options for value creation by giving new life to oil and gas assets

Prolong	Re-use	Re-purpose
• **Electrification of O&G platforms**: Large CO_2 reduction, which could also open up re-purpose options *First analysis shows a modest to moderate positive return on case-by-case assessments for electrifying platforms* • **Enhanced recovery of reserves** (EOR/EGR) *Indicative assessment: CO2 injection produces more oil /condensate*	• **Platform marketing** for re-use in other fields • **Hotel accommodation** for offshore wind installation and maintenance in a new location	• **Carbon capture and storage (CCS):** *Value: €14.4 billion (discounted)* **Geothermal energy:** *Not quantified yet* • **Power-to-gas:** *Not quantified yet* • **Gas-to-wire:** *Not quantified yet* • **Compressed air energy storage (CAES):** *Not quantified yet*

In scope of this chapter

Out of scope of this chapter

If all platforms would to be re-purposed there would be a time value of €1,14 billion due to delayed decommissioning costs

The economic incentive

As of 2020 a large number of oil and gas platforms in the North Sea will need to be decommissioned. Faced with a large bill in an industry downturn, operators are seeking alternative arrangements to keep costs as low as possible. New technologies make more options available to prolong the life of, re-use or re-purpose platforms for different activities.

Prolonging the life of an asset means keeping it in production for longer. Electrification is one option which could help achieve this while reducing the CO_2 emissions of the oil and gas production itself. When an asset is re-used, it means that an asset is used for the same original purpose but in a different location. When an asset is re-purposed it is instead used in the same location, but for a new use. This would be the case if for example an oil platform was converted into an offshore hub for electricity or a processing plant for power-to-gas technologies.

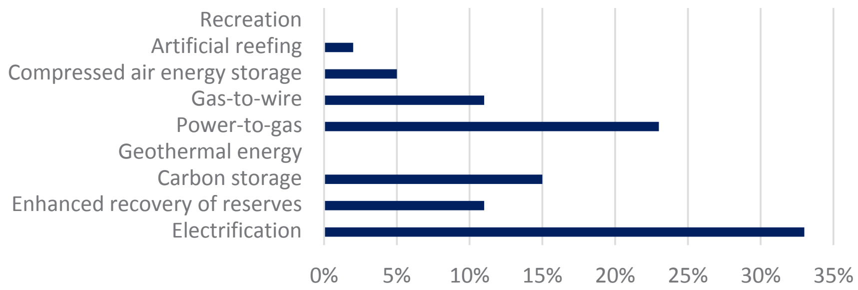
This chapter looks in particular at the potential to **prolong** the use of assets or use them for **new purposes** in a low carbon energy system.

Within the value pool prolong and re-purpose we have identified a number of sub-value pools which are described in more detail on the following pages. As can be seen in the results of the WEC 2017 North Sea conference, market parties consider the electrification of platforms and power-to-gas (PtG) to hold the most potential. Electrified platforms mean that energy is consumed at sea rather than transported to shore, while PtG technologies enable energy storage and efficient transportation to shore.

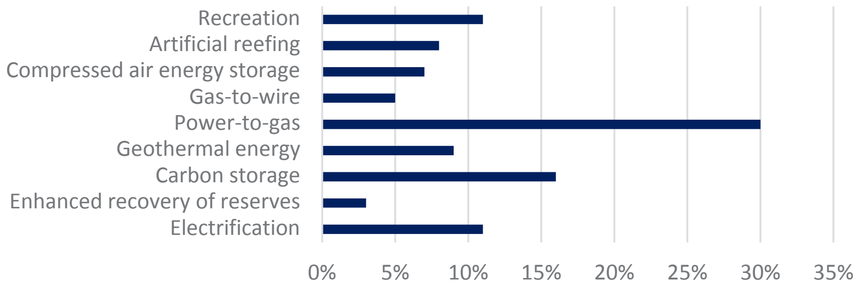
There are several options that can optimise value in the North Sea by prolonging life of, or finding a new purposes for, old oil and gas assets

Opinion of market parties on Prolong and Re-use options
Results of WEC North Sea Conference Jan 2017

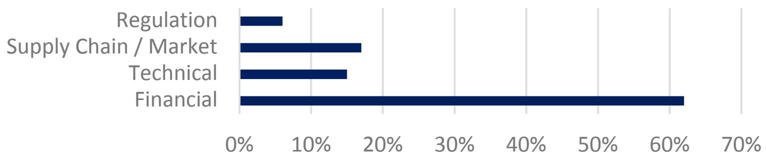
What do you consider most valuable and realistic for the re-use of assets?



What do you consider the most inspiring option for re-use of assets?



What do you consider the biggest hurdle to PtG and CCS technologies?



- **Electrification of O&G platforms (prolong)**

Electrification of oil and gas platforms is one way in which energy can be consumed in an efficient way at sea. Platforms are currently using gas generators to produce their own electricity supply. Due to the space and weight limitations of platforms, the energy generation is in most cases designed with minimum power generation facilities (single cycle power generation). This means that the energy conversion efficiency rate is low and emissions relatively high. As a comparison, this generation emits more CO_2 than an onshore combined cycle gas plant.

Electrifying platforms by connecting them to offshore wind farms or grids would cut emissions of the oil and gas production process to zero and increase energy efficiency. After the end of field life, platforms could serve to supply or tie in offshore electricity. Electrified platforms opens up for re-purposing and could give rise to new (sustainable) businesses at sea. As such, electrification would minimise the value destruction associated with decommissioning and open up options for the creation of new value.

- **Power-to-gas (PtG) (re-purpose)**

Offshore power-to-gas[1] production provides a solution to efficiently transport energy to shore, and for energy storage. With PtG technology, surplus electricity produced at offshore wind farms could be converted into hydrogen, methane or other gases, and transported to shore using already existing pipelines. There is a web of pipelines at the bottom of the North Sea which could be put to a new productive use. This would avoid the installation of new offshore power cables.

[1] Hydrogen, methane and other products

There are several options that can optimise value in the North Sea by prolonging life of, or finding a new purposes for, old oil and gas assets (continued)

Because the transportation capacity of pipelines is much larger than that of power cables, transportation losses are less, and grid stability is not a concern. PtG technologies would ensure that the energy produced at sea gets to shore in an efficient way. This would bring economical advantages compared to transporting energy to shore via new AC or DC connections.

However for now, the business case for offshore power-to-gas is not viable, due to inter alia, large efficiency losses, and therefore there is limited real life experience available.

- **Carbon capture and storage (CCS) (re-purpose)**

Empty oil and gas fields could be used for subsurface storage of CO_2. This would be a vital asset when developing the CCS technology. CO_2 could be transported from shore in existing pipelines, and if platforms are already electrified, offshore compression could easily be installed. This would also increase the CO_2 capture rate substantially.

CCS has been a subject of research for many years now. Concrete pilot projects are currently under development in Norway and the Netherlands. For the coming years however, government subsidies are still needed in order to support projects. Cooperation between governments and market parties could help reduce costs and make CCS a viable business case. Early strategic planning of large-scale CO_2transport infrastructure is vital to reduce costs (Zero Emissions Platform, 2011).

- **Gas-to-wire (GtW) (re-purpose)**

Gas-to-wire could increase the viability of developing smaller marginal gas fields. For shallow fields without pipeline infrastructure, gas may still be produced economically, if combined with a floating gas-to-wire facility. The floating GtW station would generate electricity from the gas produced. If connected to the offshore power grid, the power produced could easily be transported to shore. There are no pilot projects for GtW yet.

- **Geothermal energy (re-purpose)**

Old oil and gas platforms could be used to extract geothermal energy. The energy generated could then be used, for example, to desalinate water which is needed for the power-to-gas process, or for other uses on the platform. So far, the potential to exploit geothermal energy at the location of O&G platforms has not been studied.

- **Compressed Air Energy Storage (CAES) (re-purpose)**

Natural gases stored within the wells and in oil and gas pipelines could be compressed (using locally generated energy) when there is low energy demand on shore, and decompressed when there is a shortage of energy on shore. Old oil and gas infrastructure would thus serve to store energy. The deployment of this technology is at an early stage of development.

- **Wave energy (re-purpose)**

Electrified platforms could be used as tie-in locations for all power generated offshore, such as wave energy. Currently, energy generation at sea is hampered by the lack of power connections. Electrified platforms could serve as hubs for of renewable energy produced offshore. The implementation of this technology is at an early stage of development.

To realise new ways to make use of oil and gas platforms in the North Sea, companies in different sectors need to work together

International overview of prolonging and re-purpose status

	GB	NO	NL	DK
No. of platforms to be decommissioned	323 platforms, 370 sub-sea structures and 20,000 km pipelines to be decommissioned	119 platforms (12 concrete, 19 floating steel, 88 steel) and c. 350 sub-sea systems to be decommissioned	150 platforms and 200 km pipelines to be decommissioned	62 platforms (61 fixed steel and 1 gravity based structure) and 5 sub-sea installations to be decommissioned
Potential	% of platforms fit for prolonging or re-purpose activities has not yet been identified	% of platforms fit for prolonging or re-purpose activities has not yet been identified. Low potential for electrification using wind energy due to deep waters	0-30% of the operational rigs are suitable prolonging or re-purpose activities	No synergies between wind farms and O&G as the distance between oil fields and wind farms is too large, and future wind farms will not be developed near O&G assets
Status	Activity is low • One recent study on the potential of gas-to-wire	Activity is low • Electrification of some platforms from shore • One pilot project on floating wind energy • Statoil's Sleipner project for CCS	11 satellite topside steel structures have been re-used Some pilots: • Pilot Engie rig-to-reef • Power-to-gas pilot Ameland (Gasterra, Eneco/Stedin)	No activity. In Denmark there is no good CO_2 source. The oil reservoirs theoretically could be used for CO_2 enhanced oil recovery/storage. The business case of a previous study with CO_2 tankers from Finland failed
Stakeholders	Oil and gas operators, wind operators and offshore transmission system operators, the Oil and Gas Authority	Oil and gas operators (Statoil as a major operator), Ministry of Petroleum and Energy, Norwegian Petroleum Directorate (permitting)	Oil and gas operators, TenneT, industrial players and wind operators	Oil and gas operators (Dong and Maersk as major players, but are selling of assets)
Joint industry projects	Beatrice field project by Scottish and Southern Energy, and Talisman Energy. Electrification by using wind energy	Statoil-GE Hywind floating wind project. Floating wind farms could enable electrification of platforms further from shore	North Sea energy program (five year program co-founded by Dutch innovation platforms TKI Wind op Zee and TKI gas)	No projects. Denmark is keen to see the first opportunities for wind and CO_2 mature in the Netherlands

Sources: EBN (2016), Hywind and Beatrice field websites, OGA (UK), DEA (Denmark) and NPD (Norway).
N.B.: Germany and Belgium not analysed: Germany only has 2 platforms, Belgium has no oil and gas production

In most countries there is little experience

The potential for re-purpose oil and gas infrastructure for offshore wind, is largest in the southern and central North Sea where waters are shallow, and in places where offshore wind and O&G assets are in close proximity.

To date, there is little experience, with only a few pilot projects in the Netherlands and Norway.

A wide stakeholder field

For re-purposing, market players are the main stakeholders. These include O&G operators, grid operators, utilities, CCS operators, wind operators, offshore service companies and sea ports. From an environmental standpoint NGO's and the society at large are also important parties.

The government's role would be to facilitate efficient spatial planning.

Re-purposing and prolonging the life of oil and gas platforms is a new market. Government involvement is warranted to avoid future market failures

Market and government failure analysis

Market failures	
Public goods	NA
External effects	Society bears the cost (through taxes) if assets are not optimally re-used
Information asymmetry	Good spatial planning reduces information asymmetry
Transaction costs	Good spatial planning reduces initial (high) transaction costs
Market power	NA

Government failure
The government needs to address how the responsibility to decommission would be shared between old and new owners and users of the assets

Possibly applies

Potential market and government failures

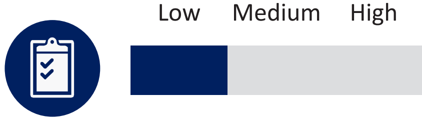
The activities to re-purpose and prolong the life of oil and gas platforms represents a new market segment. As such there are no market failures yet. Potentially though, external effects, information asymmetry and transaction costs could all hinder the optimal functioning of this market. Much in the same way as for decommissioning, market parties would not bear the cost (of pollution) incurred if assets were abandoned in the sea rather than re-used. The difficulty of gathering information at sea also lends the situation to potential information asymmetries, while the size of the projects mean that transaction costs are high. To avoid market failures in this segment, governments have a clear role to play.

- Effective and efficient regulation would avoid the **external effects** of pollution being passed on to society. Provisions should be made to allow companies to re-use or re-purpose their assets in cases where this would be desirable for the broader society. This regulation would, however, also need to address the responsibility of ultimately decommissioning the assets and how this responsibility would be shared between old and new owners and users. The financial incentives to either decommission straight away or to re-use an asset will evidently differ depending on how this responsibility is shared.
- Governments also play a crucial role in spatial planning to avoid **information asymmetries**. As discussed in this chapter, for example, an old an oil and gas platform can be of great value if an offshore wind farm is built in its vicinity. As the government posits the overall information of all maritime activities in its territory, its role is to share this information with the market parties and make sure that space is used optimally, while taking into account competing interests, as well as those activities that may enhance one another.

  To avoid a scenario where one original owner profits from its assets being re-used (based on the location of this asset), while another owner is faced with the full bill for decommissioning, an independent decommissioning fund could be set up. This would overcome this type of arbitrary distribution of costs. All original owners would need to make cash deposits during the production years of oil and gas field.
- In taking on the task of spatial planning the government also reduces the initial **transaction costs** related to soil investigation and other preliminary works which could act as a barrier to market entry.

Prolonging the life of, and re-purposing, O&G assets is still at an very early stage of development and therefore hurdles exist in all areas

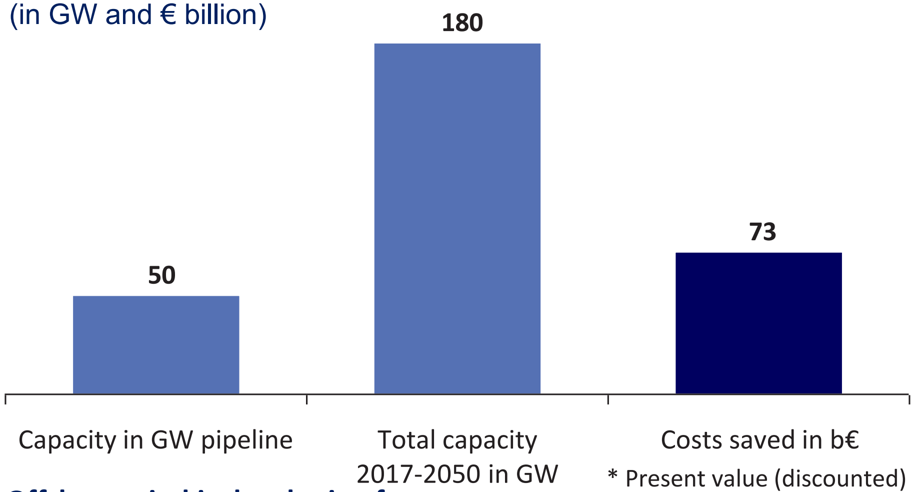
Feasibility assessment of re-purpose of oil and gas assets and infrastructure

Area	Comments / explanation	First practical next step
Financial — Feasibility: Low, Medium, High 	• CCS and PtG still have a lower financial feasibility and need cost reduction in order to become viable • There is a medium feasibility for electrification • Since these technologies have often not been used offshore, financing risks are high	• Operators should develop the business case for electrification of O&G platforms • Set up public private partnerships for CCS
Technical — Feasibility: Low, Medium, High 	• Often, the technology required is not yet available. If available, it has not been scaled up to the level needed for economic offshore use. One example is electrolysers • End-of-life considerations would need to be taken into account when designing rigs and other equipment	• Research institutes should assess the current infrastructure's suitability for alternative uses
Supply chain & market — Feasibility: Low, Medium, High 	• The market potential and size is currently unsure. For example the business case of PtG depends largely on the value of the hydrogen produced and the development of a value chain and market for hydrogen (there is currently no market) • The economic viability of new offshore energy generation, such as wave and geothermal energy is currently unclear	• More pilot projects are needed. Examples are Engie rig-to-reef and NAM solar and battery power storage pilots
Regulation — Feasibility: Low, Medium, High 	• Current regulation is not aligned with the new technological solutions available. • Timing is essential as once old assets have already been decommissioned it will be too late to think about re-purposing those	• Identify regulatory hurdles and bring those to the attention of the governments/ the EU

Efficient offshore wind energy

Offshore wind capacity is growing as costs are coming down, but further cost reductions are needed for the technology to become cost-competitive

North Sea offshore wind capacity and value pool*
(in GW and € billion)



* Present value (discounted)

Offshore wind is developing fast

The market for offshore wind is favourable, and offshore wind is needed to substantially contribute to the COP21 and European renewable energy goals. Offshore wind is becoming increasingly competitive and more and more jobs are created in this industry.

The North Sea has a vast potential for offshore wind energy. It has the potential to add up to 250 GW by 2050 (IABR 2016). The surrounding countries are planning to install up to 62 GW until 2030, and this pipeline is expected to grow, if costs decrease further.

The costs of electricity produced by offshore wind are rapidly declining, making it increasingly competitive compared to fossil fuel alternatives. A number of developments in the offshore wind sector have brought down costs significantly. In July 2016 Dong won a bid to develop the Borssele 1 and 2 sites with a bid price of €7.27 cents per kWh, and in December 2016 a Dutch consortium, consisting of Shell, Van Oord, Eneco and Mitsubishi/DGE, won the bid for the Borssele 3 and 4 sites with a bid price of €5.45 cents per kWh. In more shallow waters, Vattenfall won a bid for the Danish Kriegers Flak at €4.99 cents per kWh. These bids are excluding grid connection costs.

Coordination could provide further cost reductions

Within this value pool we have identified a number of sub-value pools which are described in more detail below.

- **Support frameworks and finance for offshore wind farms are crucial to lower costs**

In the recent past, several systems have been used to provide financial support to offshore wind energy and lower financing risks. These systems ranged from pre-determined feed-in tariffs, “green” certificates markets and, more recently, Contracts for Difference.

With the maturing offshore wind technology, direct tenders for subsidies on pre-defined sites have entered the policy domain. This strategy has proven successful in Denmark and the Netherlands, where it has led to substantial savings on subsidies due lower bids driven by increased competition and pressures to lower costs. The Dutch and Danish models (which vary slightly in detail) could serve as a examples of best practice to other countries around the North Sea. Germany is currently in the process of changing its system to a tender-based system.

Care should be taken that sufficient R&D money is spent under the new tender regimes as there will be extensive pressure on margins. As offshore wind technology is still in an early development phase, this could lead to suboptimal utilisation of the cost reduction potential.

A number of sub-value pools could provide further cost reductions

- **Economies of scale and a stable policy environment are key**

Economies of scale and a stable policy environment, driven by a clear project pipeline set by governments, is key to bringing costs down further. Clear future targets for offshore wind capacity and a roll-out plan contribute to this. It allows market players to plan their activities years in advance.

- **Standards, technical rules and regulations need to be aligned**

The offshore wind sector is developing rapidly. Standards have mainly focused on the structural integrity (strength) of turbines and foundations. Standardisation of other requirements and regulations, particularly in the area of operation and maintenance, health and safety, and the environment could be beneficial.

There are large differences between the countries around the North Sea both in relation to requirements (set by companies who develop and operate wind farms[1]) and regulations (set by governments[2]), as well as ways in which the relevant authorities operate. Since offshore wind energy is an international business, there is a significant need for standardisation of requirements and regulations. This could lead to further cost savings.

In the electricity grid domain, further standardisation is needed when moving to internationally integrated offshore (HVDC) grids. ENTSO-e and the EU play important roles in the adoption of a new set of requirements for generators that will be adopted in the coming two years. Further reliability standards for grids could be an important next step to reduce risks for generators and off-takers.

- **Coordinated grid development and other offshore infrastructure**

Large investments in an offshore grid are needed to connect the growing amount of offshore wind farms to the onshore network. Currently, wind farms are mainly connected on a point-to-point basis. Substantial savings could be achieved if regional and point-to-point grid planning and development was more coordinated, and projects with regional benefits promoted. In order to do so models for cost allocation (compensation) would need to be developed for (sub)regional cooperation.

Grid integration would minimise the costs of the grid, and increase the efficiency of the energy market by connecting the grids of the North Sea countries. The following solutions could facilitate grid integration:

- **Offshore hubs for an integrated North Sea infrastructure**

  With an integrated grid, several wind farms could be connected to one hub. These hubs would be connected to each other across borders. This would contribute to the integration of the European electricity markets. Areas with high wind generation, and areas with a high electricity demand, could be connected, also resulting in more efficient use of transmission assets.

- **Offshore islands**

  An offshore island strategically located near wind farms could host onshore equipment such as converter stations. This would decrease installation costs as well as operation and maintenance costs for the grid. This island could also be used for other functions such as a port from where installation, operation and maintenance work on the wind farms could be arranged. Additionally it could serve as a location for power-to-gas storage.

[1] Such as company requirements for access to the turbine
[2] Such as health and safety regulations of governments

Companies and governments need to work together in order reduce costs of wind farms and infrastructure

International overview of offshore wind status

	GB	NO	NL	DK	BE	DE
Installed capacity	5 GW 25 wind farms	0 GW 0 wind farms	0.95 GW 3 wind farms	1.3 GW* 13 wind farms	0.7 GW 6 wind farms	3.9 GW* 15 wind farms
Capacity planned	25.8 GW planned (timeline unknown)	Currently no project pipeline	10.45 GW planned until 2030	1.4 GW* planned (time line unknown)	1.6 GW planned (time line unknown)	11.2 GW* planned pipeline until 2030
Cost reduction	Explicit government cap of £85/ MWh by 2025	No cost reduction target in place	Cost reduction target of 40% (2010-2020). Target has already been met	No government cost reduction target in place. Companies use cost reduction targets	No government cost reduction target in place. Companies use cost reduction targets	No government cost reduction target in place. Companies use cost reduction targets
Owner grid	Developer constructs point-to-point connection and sells to offshore transmission grid operator (OFTO)	n/a	TSO TenneT appointed offshore TSO for new grids. The old grid remains with the generators	Energinet	Developers have a choice: either Elia, or develop themselves and receive compensation	TSO TenneT for the offshore substations and connection to shore. The connection to an offshore substation is the responsibility of the developer
Subsidy regime	Contract for difference (CfD market difference) subsidy. Sites are selected by the Crown Estate and awarded in a two step auction process	n/a	Competitive government tender of designated sites (selected by the government). A market premium subsidy is used	Two parallel systems: government tender of designated sites (selected by the Danish Energy Agency), or an open door procedure. CfD equivalent (market difference) system	Concession model. New subsidy scheme is in place since 2016 (applicable to next two wind farms to be built/ existing concessions)	Transition to a centralised tender regime in 2026-2030. Transition period 2021-2025 with first tenders in 2017

Sources: PwC (2017), *Unlocking Europe's offshore wind potential*
*Including Baltic Sea for Germany and Denmark

There is an urgency for cost reduction in all countries

Cost reduction has been an important topic in all countries. Significant cost reduction has been achieved in the past due to scale benefits, technical innovation (turbine size increase), competition and favourable financing conditions.

Offshore grids are organised by country

Developers and the supply chain work internationally. Offshore grids are still largely a local activity. As countries start to designate sites located further from shore, international cooperation is required to harness potential synergies.

Government still has a clear role to play in supporting efficient offshore wind energy

Market and government failure analysis

Market failures	
Public goods	NA
External effects	A positive external effect is reduced GHG emissions
Information asymmetry	Good spatial planning reduces information asymmetry
Transaction costs	Good spatial planning reduces high transaction costs
Market power	NA
Government failure	
Offshore wind farms are built with a time horizon of more than a decade, so it is essential that operators can rely on the government not to change subsidy schemes too frequently or too drastically.	

Applies (green)

Some hurdles to the optimal functioning of the offshore wind market remain

Offshore wind is yet a relatively young technology. As such it relies on government subsidies for its existence. External effects, information asymmetry and transaction costs are all potential hurdles to the optimal functioning of the offshore wind market, and governments have a clear role to play.

- Offshore wind is not yet at par with fossil fuel based alternatives in terms of price competitiveness. Because developing offshore wind energy is considered socially desirable – it has the positive **external effect** of lowering GHG emissions -, governments support offshore wind through various subsidy schemes. As the technology matures and becomes increasingly cost-competitive subsidies can gradually be phased out.
- As in the previous chapters, the difficulty of gathering information at sea also lends the offshore wind market to potential **information asymmetries**, where one market party may have access to better information than the others. Governments can intervene to limit information asymmetry through adequate spatial planning.
- Offshore wind projects are large-scale capital intensive projects. The size of the projects mean that **transaction costs** are high and can constitute a barrier to market entry.

One example of how the Dutch government has played a role is through its preliminary works. The Dutch government carried out soil investigations and took an active role in spatial planning. Additionally it assumed the responsibility for grid connections by appointing its TSO TenneT to also become the offshore TSO. By carrying out these activities, the government helped avoid information asymmetries, and substantially lowered the financial risks, as well as transaction and tendering costs for the interested parties.

As with any subsidy scheme the government should take care not to change those too frequently or too substantially. Offshore wind farms are built with a time horizon of more than a decade, so it is essential that operators can rely on the government to make sure that subsidy regimes are not changed in this period.

Further cost reduction for offshore wind development is feasible and within reach. Some barriers remain for offshore grids

Assessment feasibility score

Area	Comments / explanation	First practical next step
Financial Feasibility Low Medium High 	• With the right scale and innovation, cost levels for support could come down further and financial support could slowly be phased out • Ensure that R&D is sufficiently stimulated financially (competition in tenders could lower profits and the ability to innovate) • Floating wind energy solutions would need technical qualification in order to become bankable	• Research the impact of phasing out subsidies • Government support for innovation programs such as Offshore Wind Accele-rator in UK or GROW in NL
Technical Feasibility Low Medium High 	• Limited technical barriers for further development of offshore wind. Floating wind is still in a demonstration phase and needs to be developed in order to build in deep waters. For grids to become further integrated, technology and standards would need further harmonisation. • Developing high power multi-terminal HVDC solutions allow for lower transmission cost per MWh and more efficient use of transmission assets	• Start harmonisation of grid standards • Pilots on multi-terminal HVDC solutions
Supply chain & market Feasibility Low Medium High 	• A clear view on the project pipeline stimulates development of the supply chain • Economies of scale and a stable policy environment are key to bring down costs further • Island solutions can allow for CAPEX and OPEX reduction in large-scale far offshore wind deployment • Supply chain needs to develop to support larger structures	• Set targets, project pipeline, roll-out rate (governments) • Study the most beneficial scale (capacity) per government tender (gov) • Develop island solutions (TSOs)
Regulation Feasibility Low Medium High 	• Offshore wind farms still need government support. Adopting international best practice support schemes and auctions could help lower costs • International cooperation is key for deployment of areas further from shore. By making more efficient use of transmission infrastructure (e.g. combining offshore wind transmission with interconnection), TSOs could bring down costs further. Harmonisation is needed for the offshore electricity grid (technology, subsidies and target setting)	• Harmonisation of support schemes towards best practices • Learn from existing pilots on international offshore grid coordination

Maritime synergies and spatial planning

WEC Netherlands

Maritime synergies and spatial planning bring benefits to all

Using existing expertise is essential when developing new functions

Coordination and optimisation of the synergies between current and future activities in the North Sea could reduce costs, generate new value and reduce CO_2 emissions. As described in the introduction to this report, currently the North Sea is used for the transportation of goods and people, fisheries, oil and gas production, offshore wind energy, as well as for recreational purposes and part of the sea is classified as a nature reserve to safeguard its ecosystem.

For the current functions, there is essential offshore expertise available. The offshore industry in the North Sea can rely on 40 years of experience. By drawing on existing know-how, stakeholders could make the best use of existing assets (platforms, cables, pipelines and dedicated maintenance vessels) when developing new functions in the North Sea.

Under the umbrella of maritime synergies, we have identified several sub-value pools which have the greatest potential for reducing costs and creating new value in the North Sea through synergy effects.

- **Coordinated spatial planning**

Coordinated spatial planning is key to reducing risks and lowering investment costs. Good spatial planning combines old and new functions and infrastructure in order to make optimal use of all assets available. It creates a stable environment for businesses to invest, and would enable the introduction of new innovations.

- **Sea weed cultivation within wind farms**

Sea weed farming in offshore wind farms has the potential to replace 350PJ fossil fuel with biomass. In comparison this is more than 10% of the total Dutch energy consumption. For now however, there are many regulatory gaps in the system, which never envisaged large-scale sea weed cultivation.

- **Aqua farming**

There are several processes that may be performed on platforms. One example would be biomass processing from sea weed cultivation which would minimise transport costs to shore.

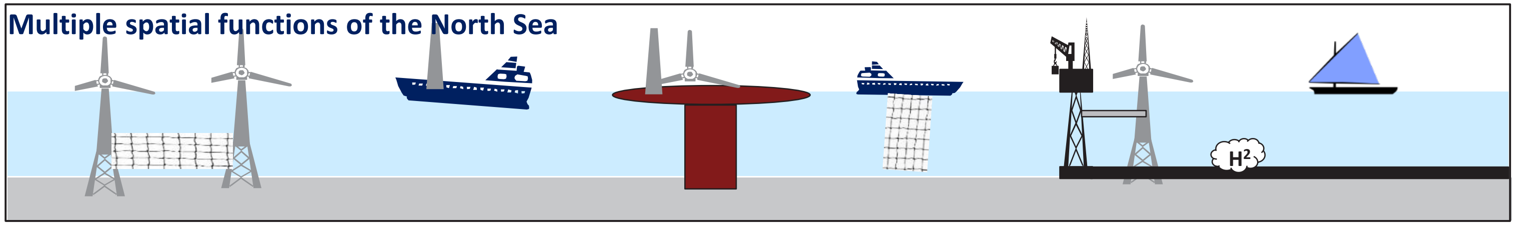
- **Artificial reefing**

Hard substructures may be re-used to stimulate marine life, and help create a new ecosystem below sea level. Top parts of platforms could be used to improve the conditions for bird life, acting as an island and providing a nesting place for sea birds.

- **Clean shipping**

Maritime transport is one of the most environmentally friendly modes of transport, measured in goods per unit, but it is still a significant source of air pollution. As ships need to change to lighter fuels,[1] this will increase fuel costs. It is therefore important to reduce air pollution and GHG by looking into available technologies and implement a cost-effective cleaner energy supply infrastructure for ships.

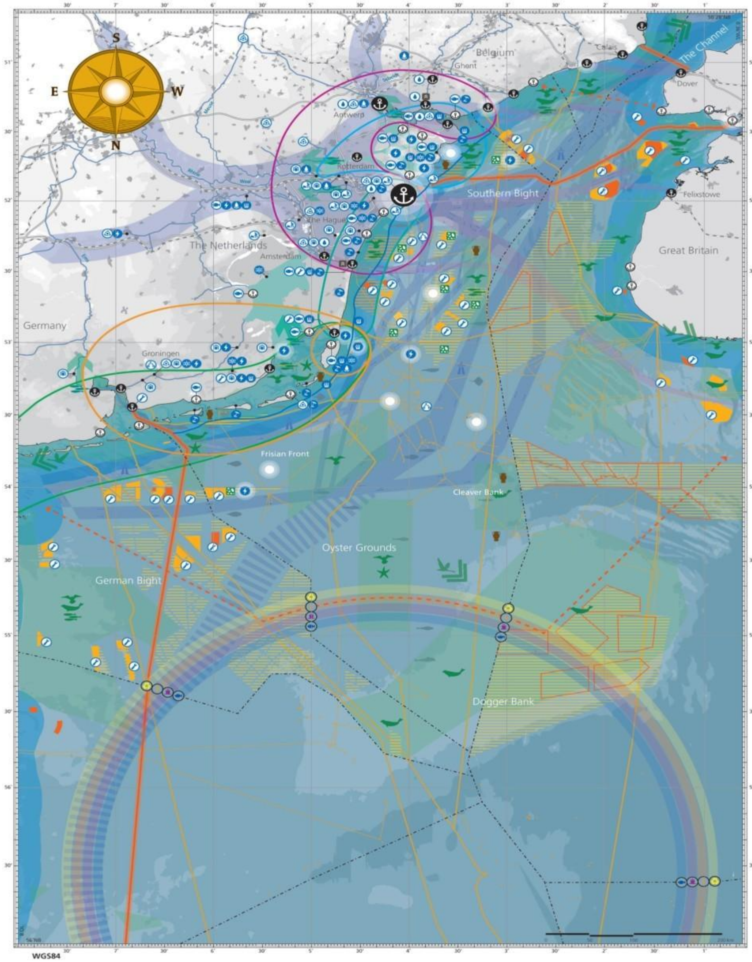
Multiple spatial functions of the North Sea



[1] Current EU legislation puts a 0.1 % limit on sulphur level in fuels for ships at berth in EU ports since 2010. In the North and Baltic Seas, this limit applies to ships at sea from 2015.

Coordinated spatial planning is key to optimising costs for all sectors active in the North Sea

North Sea 2050 spatial map



Source: Dutch Ministry of Infrastructure and the Environment and Dutch Ministry of Economic Affairs, *Policy Document on the North Sea 2016-2021*

The value of spatial planning for offshore wind

Since the beginning of offshore wind energy the valuation of construction and financing risk has been an important element of the costs. Those risks can be substantially reduced if developments are properly planned and prepared. Governments have recently realised this and taken a more active role in spatial planning and project development. Coordinated planning would also eventually result in lower government expenses for renewable energy as those would become more cost-competitive and need less subsidies.

Recent examples in Denmark and the Netherlands prove that spatial planning is a successful road to further cost reduction. Offshore wind energy projects are growing in power and investment capital and will, in the (near) future, involve cross-border spatial planning.

Spatial planning does not exclusively create value for offshore wind. Planning impacts all functions of the North Sea: shipping, oil and gas production, electrical infrastructure, harbour facilities and more.

The value of spatial planning for shipping

It is estimated that traffic on the North Sea will get busier and more diverse in the future. There will be increased coastal shipping traffic, and an increased movement of vessels to and from offshore sites due to the construction and maintenance of offshore wind farms.

The economic value of shipping for the North Sea countries is high. In addition to the direct economic significance of shipping itself, sea ports are an important source of economic activity in many of the countries around the North Sea. Spatial planning will need to balance the economic value of shipping and the interests of other users, while also protecting the ecological value oft the North Sea.

Due to its complex nature, the value of this sub value pool has not been quantified.

Adequate spatial planning avoids information asymmetries and reduces transaction costs

Market and government failure analysis

Market failures	
Public goods	NA
External effects	NA
Information asymmetry	Good spatial planning reduces information asymmetry
Transaction costs	Good spatial planning reduces high transaction costs
Market power	NA

Government failure

Spatial planning should be the responsibility of national governments. Where governments fail to provide a offshore spatial plan, information asymmetries and high transaction costs could lead to market failures.

Applies

Spatial planning should be the responsibility of national governments

As mentioned in previous chapters, good spatial planning can help solve problems of information asymmetry and transactions costs. Spatial planning is essential to uncover potential synergies between various maritime activities, and thereby unlocking additional value.

- Governments play a crucial role in spatial planning to avoid **information asymmetries**. It posits the overall information of all maritime activities in its territory, and is able to share this information with market parties. This creates a level playing field for all stakeholders as no one party has access to more information than the other. The government needs make sure that space is optimally used, while taking into account competing interests, as well as those activities that may enhance one another.
- Spatial planning also helps reducing **transaction costs**. For many offshore activities, preliminary works require substantial capital and could act as a barrier to market entry. When governments intervene and take on tasks such as soil investigation they lower the transaction costs for the market players. In effect the government picks up some of the initial transaction costs which would otherwise need to be paid for by the interested parties. High initial transaction costs would potentially mean that only large players would have the scale advantage needed to win tenders and enter the market.

Spatial planning is the responsibility of national governments, but the EU Maritime spatial planning directive (2014) requires member states to cooperate across borders when developing spatial plans. Cooperation when developing spatial plans has clear benefits for businesses and citizens alike. For example, an integrated offshore electricity grid would reduce the risk of a black-out.

Spatial planning is an enabler. If space is planned well, it enables the development of other functions like offshore wind and CCS

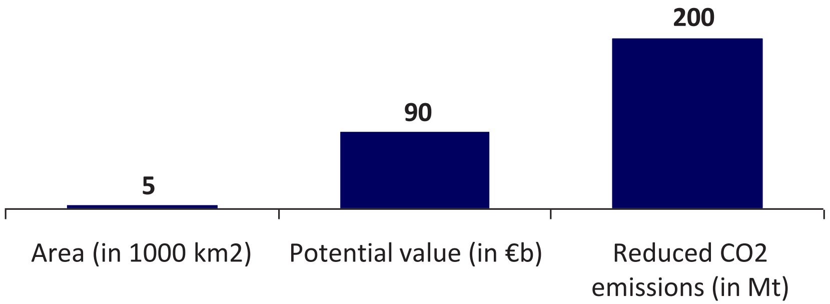
Assessment feasibility score

Area	Comments / explanation	First practical next step
Financial – Feasibility: Low Medium High 	• Clear spatial planning for offshore wind can help develop low cost sites first (close to shore) • A clear spatial plan on the development of the North Sea can help lower risks and therefore financing costs • Improving logistics will demand high investments	• Quantify the benefits of spatial planning in order to make the right choices. • Share and adopt international best practices
Technical – Feasibility: Low Medium High 	• There are no technical barriers for spatial planning. Spatial planning is an enabler. If space is planned well, it enables the development of electrical infrastructure, ports, artificial islands and more	
Supply chain & market – Feasibility: Low Medium High 	• The supply chain needs to develop further in terms of facilities, equipment, personnel and education. A lack of a clear roadmap leads to investments in the wrong locations, which could lead to facilities not being utilised as planned • Economies of scale and a stable policy environment with clear visibility for the market is key to bringing down the costs of offshore wind	• North Sea countries should develop a North Sea roadmap (goals, zones, infrastructure to be developed) to give a stable long term outlook
Regulation – Feasibility: Low Medium High 	• Some countries coordinate spatial planning for offshore wind development, but others leave the initiative to developers. Spatial planning should be a government task. The new MSP Directive[1] requires cross-border cooperation when developing spatial plans • Spatial planning should include all stakeholders in order to optimise the use of the North Sea	• Continued work on the North Sea Political Declaration in order to harmonise the spatial planning process

[1] EU Directive 2014/89/EU on maritime spatial planning

Large-scale cultivation of sea weed within offshore wind farms could create an annual revenue of c. €7 billion and reduce carbon emissions by 13 Mt per year

Potential benefits from sea weed cultivation within wind farms at the North Sea



Sea weed cultivation within offshore wind farms can create value in the supply of biofuel

Sea weed is the only large biomass resource that has not yet been exploited. Sea weed could become an essential part of the transition to a low carbon energy system as a raw material for the production of CO_2 neutral energy carriers and products. It offers prospects for the sustainable use of the North Sea and the creation of jobs and economic activity for the fisheries and offshore sectors. In addition large-scale sea weed cultivation could also provide a sustainable protein for human consumption.

If cultivated in an area of 5,000 km^2, and integrated with offshore wind farms, the production of sea weed could reach 25 Mt dry biomass per year (350 PJ_{th}). If this biomass replaced fossil fuels, it could reduce greenhouse gas emissions by approximately 13 Mt CO_2 per year in 2050.

Stakeholders involved

For the successful development of a value chain for sea weed, cooperation is needed between wind farm operators and sea weed growers, as well as cooperation with other stakeholders. There is also a role for governments to play: to select the right mix of legal, environmental, social and economic incentives to encourage businesses to take up the initiative.

Why cooperation adds value

It is clear that the North Sea, with its unused sea weed resources, could play a substantial role in the transition to a low carbon energy system. However, to do so in both a sustainable and profitable way, requires a multidisciplinary approach. Key to such a development is a well developed sea weed value chain.

Offshore wind farms provide a cost-effective way to develop sea weed farms further from shore. The co-use of offshore wind farms by sea weed growing companies will require a thorough risk assessment and the development of safe operating practices in order to mitigate financial risks.

Sea weed cultivation represents a new market segment. As such there are no market failures yet.

The market for sea weed is not yet developed at a large scale. The absence of a developed supply chain constitutes the biggest hurdle

Assessment feasibility score

Area	Comments / explanation	First practical next step
Financial Feasibility Low Medium High 	• The cost and benefits of sea weed production are currently based on very crude estimates • Large investments in farms and the industrial processing of sea weed are necessary • The entire value chain for sea weed needs to be involved. Need to start with small scale operations to de-risk the next steps	• Research organisations and companies should expand current fields to develop critical know-how for the next step (expand by c. 10%)
Technical Feasibility Low Medium High 	• Large steps still need to be taken by researchers and businesses to go from pilot to production phase (development of simple, efficient cultivation systems, increase the robustness of infrastructure and developing and upscaling the processing of sea weed) • Automated harvesting is being prototyped	• Integrate current research activities on wind farms, sea weed farms and sea weed processing to maximise synergies
Supply chain & market Feasibility Low Medium High 	• Sea weed is the only large untapped biomass resource that may still be exploited, and could become an essential component in the transition to a low carbon energy system • The market for sea weed is not yet developed at a large enough scale • Market demand for sea weed energy products is key to develop a bankable business case	• Use the momentum of small market initiatives to gain large-scale market support • Introduction of sea weed products by entrepreneurs could increase demand
Regulation Feasibility Low Medium High 	• There are many regulatory gaps in the current system, which never envisaged large-scale sea weed cultivation • Spatial management which considers all functions of the North Sea could create a stable environment for businesses to invest	• Perform a regulatory gap analysis, using recommendations from the EU's H2020 programme

Appendix: Calculations

General approach for the calculations of the size of the value pools

Methodology

- For each value pool a high level value analysis was performed, based on existing research.
- The value of cooperation can be split into two components:
  - The cooperation and synergy effects can lead to **cost reduction** (for example in the case of decommissioning optimisation, efficient offshore wind (farms and grids) and re-purposing assets)
  - The cooperation and synergy effects lead to new markets being developed. This leads to **additional profits**.
- We have estimated the value over the period 2017-2050
- We have discounted the value based on three discount rates to asses the value per value pool today, and to make them comparable

Discount rate used in the calculations

- We are using **three different discount rates** in order to determine the value today, driven by the varying characteristics (and therefore risk) of the various value pools:
  - For decommissioning and the time value of delayed decommissioning (part of the re-purpose value pool), a discount rate equal to the risk free rate of 0.85% is used (Bloomberg). The risk free rate is chosen because those decommissioning costs will certainly be realised.
  - For the calculation of sea weed production a discount rate of 14% is used. The rate is based on a start-up setting, since the cultivation of sea weed is a new, which means relatively more risk.
  - For CCS and offshore wind a social discount rate, set by the European Commission, of 4% is used (European commission, 2015).

Efficiency gains in the decommissioning of wells and platforms could result in cost reductions of €27.6 billion, but will likely not result in any CO_2 reduction

Calculation of the potential value and CO_2 reduction

- Cooperation when decommissioning oil and gas wells and platforms has a potential **value of €27.6 billion** over the period 2017-2050. This value is calculated based on the current expected costs and cost reduction estimations and targets that have been, or are likely to be, set in the respective countries (our calculations start from 2017).
- The **saved costs** of decommissioning in Denmark, Norway and the UK are based on the following assumptions:
  - Total costs in Denmark of €5.5 billion are spread over time as follows: 20% in period 2018-2030; 45% in 2030-2040; 35% 2040-2050 (source: DEA).
  - Decommissioning costs in the UK are £17.6 billion between 2016-2025 (based on future investments in the central North Sea, northern North Sea & west of Shetland, and southern North Sea & Irish Sea). Decommissioning expenditures equal £1.7 billion per year in the years 2016-2020. With the remainder of a total of £47 billion costs being assumed in 2026-2050.
  - Decommissioning costs in Norway equal €1.25 billion in the years 2016-2021 (source: NPD, €1-€1.5 billion per year). The remaining €25 billion will be assumed in 2021-2050. Probably this is a conservative estimate.
  - The development of cost reduction over time is not clear yet. Market sources indicate that some cost reduction is already materialising, and the pace is expected to accelerate until 2021. We therefore assume a cost reduction in 2010 of 10%, 30% in 2021 and 40% in 2023, which then remains at the same level up until 2050 (OGA).
- The **saved costs** of decommissioning in the Netherlands are based on the following assumptions:
  - The total costs for decommissioning of offshore assets in the Netherlands are €5.0 billion between 2016 and 2050.
  - These costs are divided over the years based on the COP estimations by EBN, corrected for the more costly platforms to be decommissioned at the end.
  - The costs for well plug and abandonment (c. 73%) are reduced by 37%, as result of a 30% reduction due to a learning curve and 10% due to contracting.
  - The costs for platform decommissioning (c. 27%) are reduced by 10% due to improved contracting.
  - The development of cost reduction over time is not clear yet. Like for the UK, Norway and Denmark, we assume, that the majority of cost reduction to materialise in 2021.

The value of prolonging life of and re-purposing oil and gas assets is assessed in two ways. Firstly, it leads to delayed decommissioning costs which represents a value of €1.1 billion

General comment prolong and re-purpose value pool

- For the re-purpose value pool we have been able to assess the size of the value pool in two ways:
  1. For all assets that are being re-used the decommissioning is delayed, which results in a time value. A euro spent now has a higher value than a euro spent at a later point in time.
  2. Secondly, we have assessed the value for one specific sub-value pool within the prolong and re-purpose value pool: Carbon capture and storage. CCS costs are still too high to enable a viable business case. Government subsidies are needed in order for market parties to invest and for the technology to develop. If market and governments cooperate cost reduction is possible.
  - Other sub-value pools, like power to gas, have not been quantified within the limited scope of this report, so the total value for re-purposing of assets would be much higher than what is assessed

Calculation of the potential value of delayed decommissioning

- Prolonging the life of or re-purposing oil and gas assets leads to delayed decommissioning of these oil and gas assets, and hence to a time value which we have assessed at €1.1 billion.
- The time value of delayed decommissioning costs for the Netherlands, UK, Norway and Denmark is based on the following assumptions:
  - Percentage of oil and gas assets for re-purpose equals 25%;
  - Therefore, 25% of the total decommissioning costs (i.e. the sum of decommissioning costs in all four countries) is postponed by 10 years, starting to be payed in the year 2026: the decommissioning costs for 2016 are payed in 2026, the decommissioning costs for 2017 are payed in 2027 etc.

The sub-value pool carbon capture and storage has a potential value of €11.6 billion due to cost reductions. It could help to store 1,196 Mt CO_2 in the North Sea over the period 2020 to 2050

Calculation of the potential value and CO_2 reduction

- Carbon capture and storage (CCS) in the North Sea has a potential **value of €14.4 billion** over the period of 2020 to 2050. The value consist of **saved costs resulting from decreased CCS costs**. Cooperation and synergy effects could help reduce costs, which lowers the need for subsidies.
- **The value** is based on the following assumptions:
  - The cost of CCS vary strongly depending on specific technologies or applications in different sectors, and also depends on if the capture of emissions are taken into account.
  - The cost of CCS are estimated at €70/per ton CO_2 in 2017 and decrease to €45/ton CO_2 in 2030
    - CCS association indicated a range of 60-90/ton and 30-50/ton in early 20's (http://www.ccsassociation.org/why-ccs/affordability/)
    - Other studies CCS association (2011), Global CCS institute (2015) indicate cost reduction range of 30-40%
    - We have used a 40% cost reduction starting at 70/ton CO_2
  - We assume a linear decrease since it is currently not specified in studies when cost reductions will materialise.
  - The CCS cost remain at €45/per ton CO_2 from 2030 to 2050. The cost might decrease further but detailed assessments of cost reduction in this period are lacking
  - From 2020 to 2030 the annual storage increases linearly from 4 Mt to 46 Mt storage per year, using the medium scenario of the Carbon Capture & Storage Association (2010). From 2030 onwards the storage remains constants at 46 Mt per year.
- The gap between the costs at €70/per ton CO_2 and the reduced costs are the estimated **saved costs**.
- CCS contributes to a total **aggregated CO_2 storage of 1,196 Mt** in the period 2020-2050.
  - We have not incorporated the effect of CCS on the ETS carbon prices. We expect that the ETS price will decrease due to the additional carbon certificates being available due to the storage possibilities. CCS does not decrease the overall emissions but prevents that all CO_2 emitted ends up in the atmosphere.

The value of electrification of oil and gas platforms has not been quantified, yet electrification of these assets could potentially reduce CO_2 emissions by 3.84 Mt

Calculation of the potential CO_2 reduction

- First indications show a modest to moderate positive return on case-by-case assessments for electrifying platforms. But a case by case analysis would be necessary to assess the value of electrification in monetary terms.
- Electrification of oil and gas platforms in the Dutch part of North Sea could contribute to a total **aggregated CO_2 reduction of around 3.84 Mt** in the period 2019-2050.
    - In the base case scenario, the annual emission of platforms in the Netherlands decrease over time and is half of the current CO_2 emission in 2036. This is caused by the decreasing production of the platforms;
    - Only the platforms that are suited for re-purpose usage will be electrified. This is assumed to be 25% of the current platforms;
    - In 2030 all suitable platforms are assumed to have been electrified. Electrification starts in 2019 and increases linearly until all remaining platforms are electrified in 2030;

The value of efficient offshore wind deployment is assessed in two ways. A more efficient way of realising offshore wind farms could result in saved costs of ~€38 billion…

General comment on efficient offshore wind energy value pool

- For the efficient wind energy value pool we have been able to assess the size of the value pool in two ways:
    1. We asses the value of cost reduction of the construction and operation of wind farms. Currently subsidies are still needed in order to convince market parties to invest in offshore wind. In the future grid parity might be reached and the offshore wind business case becomes viable without subsidies. We assess the value of cost reduction until a level where subsidies are no longer required.
    2. Secondly, we have assessed the value of creating joint offshore grids (please refer to the next page for the assumptions).

Calculation of efficient offshore wind energy potential value and CO_2 reduction

- Efficient offshore wind energy has a potential **value of ~€38 billion** over the period of 2020 to 2030 (saved costs compared to base case scenario). After 2030 the saved costs are not quantified.
- These **costs of offshore wind farms** are based on the following assumptions:
    - Additional capacity is implemented based on the latest insights into the offshore wind pipeline (operational date) in Belgium (until 2024), Denmark (until 2024), (Germany (until 2030), UK (until 2030), Netherlands (until 2030). Norway is not taken into account.
    - Electricity is generated for 20 years (conservative estimate) based on a capacity factor of 45-50% (47,5% used);
- The base case scenario costs are estimated based on an average of the last three bids, (Kriegers Flak, Borssele I and II, and Borssele III and IV), converted to an LCoE (based on TKI Wind op Zee 2016, conversion rate of bid to LCoE of Borssele 1 and 2 used). This results in an LCoE of 55 €/MWh. We assume this materialises in the year the farm is operational (4 years after the bid). From 2017-2020, a linear cost reduction from the initial Borssele I and II bid is assumed (€68/MWh in terms of LCoE).
- The **reduced costs** are similar to LCOE in the base scenario until 2020. From 2020 onwards the LCOE will linearly reduce from 55 to 40 €/MWh in 2030, representing grid parity and remain stable at 40 €/MWh after 2030.
- The gap between the costs and the reduced costs are the estimated **saved costs**.

The current pipeline for offshore wind energy means a c. 4,168 Mt reduction in CO_2 emissions

Calculation of the potential CO_2 reduction

- The current planned capacity of offshore wind farms could contribute to a reduction of CO_2 emissions of c. 4,168 Mt. The reduced emissions come from a shift from conventional energy sources towards wind energy which is a clean energy source and does not emit CO_2.
- The main assumptions are as follows:
  - A windmill is operational for 20 years (conservative estimation). After 20 years no electricity is produced any more by the windmill;
  - Electricity generated by windmills replaces electricity produced by gas fired power plants;
  - CO_2 emission of the production of electricity by gas fired power plants is estimated at 0.55 ton/MWh
- We do not take into account any effects on the EU ETS price and the subsequent effects on other sources of emissions.

… and an integrated North Sea infrastructure could create €21.4 billion of value due to cost savings and increased the efficiency of the (local) energy market(s)

Calculation of the potential value and CO_2 reduction

- Efficient offshore wind energy has a potential **value of €21.4 billion** over the period of 2020 to 2050 in the form enhanced efficiency of the (local) energy market(s) and cost savings.
- The benefits in the form of **enhanced efficiency and cost savings** are expected to be **€1.9 billion per year from 2030** onwards (PwC, Tractebel Engineering and Ecofys 2016). The €1.9 billion per year is the average of the three scenario's used in the study.
- We assumed that the meshed grid will be **constructed from 2020 until 2030**. Therefore the benefits will gradually increase from 0 in 2020 to 1.9 in 2030 (we assume linearity).
- **We did not calculate the CO_2 reduction** resulting from a more efficient energy market due to the limited scope of our assessment.

Sea weed cultivation within offshore wind farms has a potential value of €1.14 billion…

General comment on maritime synergies and spatial planning value pool

- For this value pool we have been able to assess the size of one sub-value pool (sea weed cultivation). Other sub-value pools, like artificial reefing or clean shipping have not been quantified within the limited scope of this report. This means that the total value for maritime and spatial planning synergies is much higher than what we have assessed in this report.

Calculation of the potential value and CO_2 reduction

- Sea weed cultivation within offshore wind farms has a potential **value of €1.14 billion** over the period of 2017 to 2050.
- The main value is created by the additional revenue resulting from the **cultivation of sea weed** and from preventing ships from fishing within offshore wind farms and **potentially damaging array cables**. There is no positive business case of sea weed cultivation far out off the coast if it is not cultivated within the wind farms. Therefore the entire revenue of sea weed cultivation is included.
- The additional revenue is based on the **revenue resulting from the sea weed cultivation**. The main assumptions are the following:
    - In 2050 5,000 km^2 is expected to be covered by sea weed within wind farms (TNO, ECN, Deltares, Marin, WUR 2016). The sea weed production starts in 2020 and grows linearly until 5,000 km^2 of windmill farms is used for sea weed cultivation in 2050. This 5,000 km^2 fits in the area covered by offshore windmill farms of about 8,400 km^2 in the year 2050 (based on the amount of projects assessed under the offshore wind pool value).
    - 50 ton of dry matter is produced per ha sea weed farm and sold for €250 per ton dry matter (ECN 2005).
- The **profit of sea weed production** is calculated by subtracting the **cost of sea weed production** from the **additional revenue** resulting from the sea weed production. The **cost of sea weed production** is based on the following assumption:
    - Cost of sea weed cultivation equals €10,000 per hectare over the period 2016 to 2050 (ECN 2008), which is then multiplied by the amount of produced sea weed.

Sea weed cultivation within offshore wind farms has a potential value of €1.14 billion…

Calculation of the potential value and CO_2 reduction

- Saved cost result from a decrease in the damages of array cables, and thereby less **repair costs,** and from **missed revenue**. The **number of prevented damages** is based on the following assumptions:
    - Per 1,000 km, a cable is damaged 1.75 times per year and 70% of these damages are caused by fishing activities (Allianz 2014);
    - On average 3 wind turbines are placed on one km^2 with an average array distance of 846 meter;
- **Repair cost** account for **€13 million**, based on average repair cost of **€500,000 per damage** (The Crown Estate and Scottish Enterprise 2013).
- **Missed revenue** accounts for **€27 million** based on the following assumptions:
    - Electricity price of €40 per MWh (European Commission 2016)
    - 1,200 hours of downtime per damage assuming a down time of 50 days (Transmission excellence ltd 2015)
    - 16 MWh of missed energy production based on the assumption that 10 turbines are down with an average capacity factor of 41% and a capacity of 3.9 MW. The average capacity increases linearly over time to 5.7 MW in 2030 and is constant afterwards.

…and could reduce CO_2 emissions by 202 Mt over the period 2020 to 2050

Calculation of the potential CO_2 reduction

- Sea weed cultivation within offshore windfarms could **reduce the CO_2 emissions by 202 Mt** over the period 2020-2050. Sea weed is used as a biofuel and would therefore replace conventional fuels.
- Using biofuels instead of conventional fuels could result in an **annual CO_2 reduction of 13 Mt** at a production of 25 Mt dry matter of sea weed a year. This production rate is reached in **2050** (North Sea Weed Chain Report, 2016).

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