The Valuation of Oil Reserves in a Complex, Carbon-Constraint World

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The valuation of oil reserves in a complex, carbon-constrained world

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Executive Summary

In December 2015, the United Nations Climate Summit in Paris resulted in the commitment of 197 countries to the 'Paris Agreement' in order to prevent the environment from exceeding the 2°C norm for global warming. Upstream oil and gas companies face challenges in a world in which the emissions of greenhouse gas (GHG) is limited to 2°C and is held as a hard constraint. The Paris Agreement leads to a situation in which the oil production is forced to decrease, resulting in the fact that many reserves that are currently on the balance sheet of oil companies must remain unproduced and get stranded in the ground. This situation has raised the question of how to valuate oil reserves knowing that in a carbon-constrained world not all reserves can be produced in order to stay within the limit of 2°C. Beside the Paris Agreement, there are more developments in the oil sector that are currently disturbing the upstream oil sector such as the sustaining low oil price and increasing usage of renewable energy and electric vehicles. These developments have negative consequences on the outlook for oil companies because they will impact the value of oil reserves and the way in which the reserves should be valuated. Hence, the challenge and the goal of this research is to:

'Identify the developments that are apparent in a carbon-constrained world, to determine how the developments influence the value of oil reserves and to account for these developments in the valuation method'.

The main knowledge gap that is identified using existing literature is the lack of knowledge and insight regarding the developments in a carbon-constrained and the effect of the developments on the value and the method of valuing oil reserves. Scientific value is created through answering the following research question that fills in the knowledge gap.

'How to valuate oil reserves in a complex, carbon-constrained world?'

The above research question is answered using varies methods. Existing literature is studied to get insight in the currently used valuation methods and the developments that evolve in a carbon-constrained world. Interviews with experts serving the oil industry are conducted to provide insight regarding the functioning of the oil market, the practical use of the valuation methods and the future of the oil sector in a carbon-constrained world. A desk research is conducted, based on literature and data of the oil sector, and a scenario-based impact analysis is carried out to determine the consequences of the developments on the value of oil reserves in order account for the developments in the value of the reserves.

The currently used valuation methods make use of Discounted Cash Flows and Net Present Values. At the basis of the method is the perception that the oil available in the reserve can be sold for the market price. This generates a return that should be corrected by the costs that are made to extract the oil and the timing of the cash flows. The method is capable of assigning a monetary value but it still builds upon the perspective that all oil will be sold. However, the developments in a carbon-constrained world challenge this perspective resulting in oil reserves getting stranded due to fundamental changes in the market. If the consequences of the developments are not incorporated in the value of a reserve then it may lead to severe losses during the productive lifecycles of these reserves due to lower returns or reserves that are getting stranded. Hence, the currently used valuation method should be adjusted and extended because the currently used valuation methods do not work properly in a carbon-constrained world.

The main developments that are associated with the carbon-constrained world and influence the value and valuation method of oil reserves are determined to be the following:

- Large improvements should be made to stay on track to achieve the goals of the Paris Agreement. Governments must set the right incentives for companies and individuals in order to change the current course of action and to stay within the carbon budget of 2°C. These incentives should be aimed at decreasing the use of oil (and other fossil fuels) to limit the emission of GHG. Taxation of GHG emissions is one of the most effective measures to reduce the emissions. Environmental regulation such as a carbon tax will result in reserves with a large environmental footprint to get less competitive compared with cleaner reserves. This may result in reserves with a large environmental footprint to get stranded due to the additional cost of the tax.
- The global use of oil should be reduced to meet the goals from the Paris Agreement. Such a declining oil market changes the perspective of the market from a scarcity-based oil market in which supply is limited to a market in which oil is abundant and the demand will be limited. Oil reserves will be less valuable in the

future when there is no demand for oil and oil companies are left with their abundant reserves. Hence, a declining market and oil demand may result in reserves with long lifetimes to get stranded.
- The perspective of the abundance of oil will increase the competition among oil producers because they want to get rid of as much oil as possible before the oil is worthless. The increased competition will cause a global oversupply resulting in a depressing effect on the oil price. These low oil prices may cause reserves with high breakeven cost to get stranded.

The consequences of the developments are explored through analyzing and operationalizing the developments and conducting a scenario-based impact analysis based on the three pillars of competitiveness (technology, lifetime and breakeven cost). The outcome of the scenario-based impact analysis makes it possible for reserve owners to determine the impact of the developments on different type of oil reserves and the competitiveness of a reserve. Combining these insights together with the knowledge of the current valuation approach has resulted in the following three measures that should be adopted to account for the developments in the value of a reserve:

- Companies should implement a shadow tax in the valuation method to account for the additional cost of future government regulations inclined by the emission of GHG. This shadow tax should be applied when valuing all type of oil reserves, both future prospects, reserves under development and already producing reserves. Companies should estimate the expected level of future regulation. This level determines the rate of the shadow tax and may vary per government. This rate remains uncertain and may vary per government. But valuing a reserve based on a higher shadow tax makes the reserve more resilient for the implementation of environmental regulation.
- Oil companies should account for lower than expected output as the result of the declining oil market. The least competitive reserves will get imposed with the highest reduction of the output when the market starts to decline. The value of oil reserves should be correct for the declining output relatively to its competitive position. The amount with which the output should be declined is hard to determine because it is based on many market factors. Therefore, oil companies should create a dynamic model to get more insight in the future demand and the supply in the market.
- Oil companies should adjust and reshape their long-term oil price forward curves in line with the projections of the carbon-constrained world and according to the perspective that oil will be abundant. Resulting in lower oil prices that will contract over time. This decreases the value of their reserves and therefore reassessment of all reserves is necessary to determine their viability in a carbon-constrained world with increased competition.

The added value of the new valuation approach lies in the fact that the method incorporates the developments in the value of the reserves when the world actively addresses climate change and global warming. The method accounts for the developments by operationalizing the developments, designing and analyzing scenarios of the developments and identifying the reserves that are vulnerable for the developments. The incorporation of the developments in the value of the reserves makes the value more accurate and resilient when the developments materialize. Less competitive reserves are more vulnerable to get stranded and therefore benefit more from the new valuation method because early valuation with the new method enables the owner to prevent the reserves from getting stranded through increasing the competitiveness of the reserve.

The new valuation approach also holds a secondary application that makes it possible to define strategic measures to enhance the competitiveness of oil reserves and prevent them from getting stranded. The secondary application of the valuation method uses the outcome of the scenario-based impact analysis as a framework to identify the competitive position of an oil reserves in the market. Measures can be formulated based on this framework and the competitive position to increase the competitive position in order to prevent the reserve from getting stranded. The measures to increase competitiveness are aimed at achieving 'competitive growth' and creating 'added value'. Competitive growth can be achieved through acquiring or developing new competitive reserves while divesting from reserves that are not competitive. Added value can be created through applying: supply chain efficiencies, strategic alliances, innovations and technological developments. Achieving competitive growth and creating added value can prevent oil reserves from getting stranded.

The recommendations of this research are twofold: first, valuation methods should be adjusted in line with the developments in a carbon-constrained world to reflect a representative value of oil reserves. Second, companies should use the secondary application of the valuation method to adopt appropriate strategies to cope with the developments in a carbon-constrained world and prevent their reserves from getting stranded.

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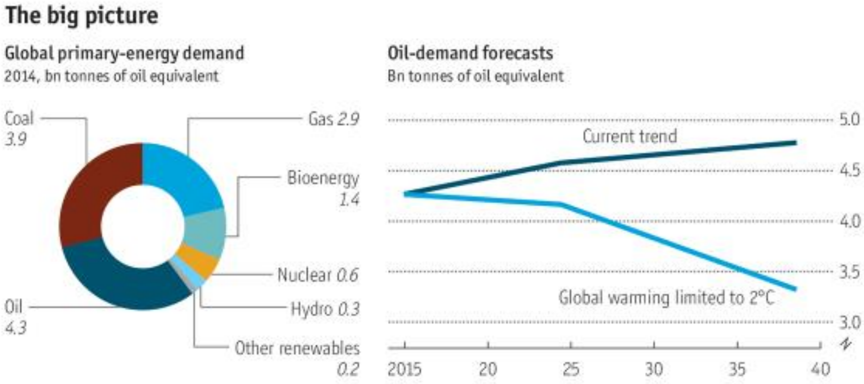
PART I – Introduction

1. The Research Problem

1.1 Context

The age of oil

Since the beginning of the Industrial Revolution, fossil fuels such as coal, oil and natural gas have played a central role in economic development and transportation in everyday life. Oil had been the fundamental resource that made the development of modern society possible. It even goes that far that the 20th century is often referred to as the Oil Age. Even today, oil and natural gas play a vital role in the production of energy around the globe, where oil and natural gas together are responsible for approximately 52% of the total energy supply (van der Veer & Myers Jaffe, 2016). Within this 52%, oil based fuels count for around 31% and natural gas for 21% (van der Veer & Myers Jaffe, 2016) see figure 1, 'the big picture'.



Source: International Energy Agency

Figure 1 - The big picture

Until recently, many oil companies and oil-producing countries assumed that society would gradually use up all the available oil resources. OPEC (Organization of Petroleum Exporting Countries) believed that the oil-constrained world had arrived and due to the limited amount of reserves, the oil was more valuable under the ground than on the market, since the prices would gradually increase over time as the result of scarcity. Therefore, OPEC used a revenue-oriented strategy during the last two decades. As a reaction to the revenue-oriented strategy of OPEC, oil companies pursued the business model of maximizing the total amount of reserves on their balance sheet through many expensive exploration projects (Myers Jaffe & Van der Veer, 2016). However, the Paris agreements and the increasing competition from renewable energy technologies may severely change this view.

The Paris Agreements

In December 2015, the United Nations Framework Convention on Climate Change in Paris (COP-21) resulted in the support of 197 countries to adopt a climate plan which is aimed to prevent the environment from exceeding the 2°C norm for global warming and to pursue efforts to limit the temperature increase to 1,5°C. A cap with a maximum of 2°C must prevent the environment from severe disasters to happen such as irreversible climate effects like melting ice caps and rising water levels. The current state of global warming is according to the NASA climate institute around 1°C. This means that there is little spare room if we are willing to succeed in reaching the 2°C target.

The hardest challenge of the environmental targets is that the targets must be achieved in the face of an increasing demand for energy. Especially China and India are vastly increasing their energy demand due to the speed with which they are industrializing their economy, the increasing living standards of their inhabitants (Omer, 2008), and the increasing global population. The global population is forecasted to grow to 8,5 billion by 2030 and 9,7 billion in 2050. Currently there are approximately 7.3 billion people living today (United Nations, 2015). The only viable way to prevent the exceeding of the 2°C norm is by a rigorous change in paradigm, from using oil, gas and coal to a new paradigm where renewable energy should be the standard for the generation of energy and where fossil fuels stay in the ground.

Oil and gas companies are responsible for generating a significant part of the greenhouse gas emissions. Hence new developments regarding climate change will have large effects and create many uncertainties for the future business of oil and gas companies. Oil and gas is used at a large scale in multiple sectors, such as, electricity and heat production, transportation and industry. These three sectors together are responsible for approximately 60% of the production of greenhouse gasses (figure 2). In the next decades, oil and gas companies will most probably see sharp declines in their market share due to the rising competition from renewable energy producers. In the transportation sector the market share of oil and gas is already threatened by the faster than expected roll-out of Electric Vehicles (EV's) and in the electricity and heat production sector renewable energy technologies are developing with a quick pace gaining a lot of market share as well. Hence, oil companies must face large challenges and are confronted with major changes if they are willing to continue their business and cope with the uncertainties that lay ahead.

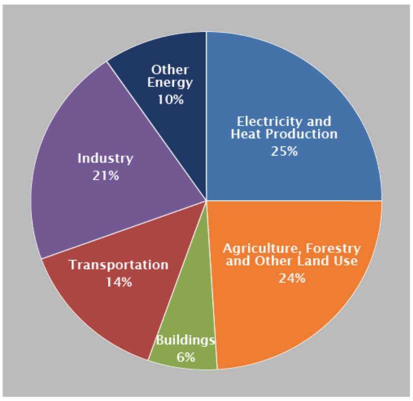


Figure 2 - Global greenhouse gas emission per economic sector. Adopted from IPCC (2014) climate change 2014 mitigation of greenhouse gasses

Impact and size of oil and gas companies

The oil and gas industry is, based on revenue, the largest industries in the world. Put together the top 10 largest oil companies and they will generate a combined revenue of around 2.9 trillion dollars. This is approximately 11% of the S&P 500 and 20% of the FTSE 100 (Ansar, Caldecot, & Tibury, 2013). These statistics show the impact that the oil and gas companies have regarding the global economic prosperity. If these companies suddenly suffer great losses, then global economic stability would be significantly influenced with the chance for a global recession. Hence the oil and gas companies have a substantial economic impact but their impact on the environment is even more significant. Oil and gas together with coal and cement producers are, according to Heede (2014), responsible for two third of the greenhouse gas emissions. However, the positive side of the oil and gas companies is that due to their size and impact they may use their resources when the moment arises and for instance change their focus to renewables. With the large amount of resources such as capital and knowledge they can have a high impact on increasing the sustainability of the energy sector and therefore on the emission of greenhouse gas when it is necessary.

1.2 The problem statement

Oil companies used to have the view that they would be able to exploit all their reserves, but due to the Paris Agreement there is a maximum cap of CO_2 that can be emitted. This cap of 2°C makes, according to the Carbon Tracker Initiative (CTI) and Leaton, Campanale, & Leggett (2013), 70% of the current oil and gas reserves abundant and therefore cannot be produced without exceeding this 2°C cap. Any additional exploration projects will add up to this 70% and increase the amount of reserves that cannot be produced. However, the projections for the demand of hydrocarbons foresee a growth in the energy demand with a peak somewhere around 2030 (McKinsey & Company, 2016). Thus people demand more energy due to economic and population growth while the environment needs a decrease in greenhouse gas emissions. This sketches the problem that society must face and may put the business model and corporate strategy of oil companies under pressure.

Upstream oil and gas companies face challenges in a carbon-constrained world where the 2°C norm is held as a hard constraint. This leads to a situation where there is no room for a large increase in oil and gas production resulting in the fact that many reserves that are currently on the balance sheet of oil and gas companies are forced to stay unproduced. The prospect of a maximum cap for global warming changes the way in which oil companies must operate. This maximum cap, that represents the cumulative budget of carbon dioxide that can still be emitted, may add a time constraint to the value of oil reserves. When the limit is reached, the value of oil reserves face the chance of getting almost equal to zero and therefore uneconomically to extract. Hence, the perspective of the 2°C scenario, which is binding when adopting a carbon-constrained world perspective, changes the view on how oil companies should valuate their reserves, because they will not be able to produce all the reserves they have in their portfolio. This situation raises the question of how to valuate oil reserves knowing that in a carbon-constrained world not all reserves can be produced in order to stay within the limit of 2°C. This may result in a significant drop in the value of oil reserves and may even make them become economically unviable to exploit. Hence its key for oil companies, in order to operate efficiently and strive to optimize their profit, to produce their reserves before the limit is reached.

The Paris Agreement is an example how oil companies and the value of their reserves get affected by developments in the market. However, there are more developments that pose a threat for the business of oil companies such as continued low oil prices, stricter environmental regulation, changing customer preferences due to climate change, the penetration of electric transportation and other new technological developments. These developments include interaction in the socio-technical landscape of the oil and energy system, which affect the value of oil reserves.

The research challenge and goal

The challenge of this research lies in identifying the main developments that are apparent in a carbon-constrained world, to understand how the developments influence the value of oil reserves and to determine how companies should account for these developments through incorporating the development in their valuation method. In this process the perspective of a carbon-constrained world is adopted that considers the Paris Agreement as binding. With these goals set by the highest representatives of each country, it is presumable that at least the limit of 2°C will be met and regulation to meet these goals will be imposed. This result in the goal that is set for this research, which is formulated as follows:

'To identify, understand and account for the implications of the developments in a carbon-constrained world for the value and the valuation method of oil reserves'.

1.3 Knowledge gap

Recently numerous studies are published by scientists (Caldecott, Tilbury, & Carey, 2014; Myers Jaffe & Van der Veer, 2016), research institutes (Charriau & Desbrosses, 2016; IPCC, 2014) and oil and gas companies (Bentham, 2013; Melorose, Perroy, & Careas, 2016; Tobergte & Curtis, 2016) concerning the exploration and outlook of future market conditions. These studies conclude that there are many new developments that will have a large impact on the oil sector and the companies active in the sector. Many of these new developments such as the Paris Agreements, the ever more volatile and low oil price and the interference of OPEC in the oil market will increase the complexity and the uncertainty in the market. Of these developments, the Paris Agreements in particular pose a new and interesting challenge, and might change the business of oil companies. However, it remains unsure how governments will pursue the goals that are set, but it is clear that they have to come in action if they are willing to succeed in meeting their goals. The consequences of the governments actively addressing their goal to limit GHG remain unsure. Conducting research to these consequences by analyzing the developments that may result from the fight against global warming and determine their impact on the valuation method of oil reserves when the developments take place is one of the knowledge gaps that this research will fill in.

There are many papers and articles written about the valuation of oil reserves. These studies take into account the different valuation methods such as Discounted Cash Flows (DCF) with Net Present Values, Real Options Analysis (ROA) and Scenario planning (Wang & Halal, 2010). For every valuation method there are many additional studies that enrich these single valuation methods. In this research it is not possible to solely use one valuation method due to the different characteristics and uncertainty regarding the developments and the way how valuation methods cope with uncertainty (Courtney, Kirkland, & Viguerie, 1997). Hence the challenge and knowledge gap of this research does not lay in the use or the refinement of one of the existing methods, but in the integration of the developments in a carbon-constrained world and the valuation methods to determine whether the developments change how oil reserves should be valuated and if it affects the value of reserves. Hence, the underlying valuation theories and methods play a central role because the developments in a carbon-constrained world must be translated in consequences of the developments on the value for which the valuation method should account. Thereby combining qualitative and quantitative valuation methods in order to cope with the uncertainties surrounding the developments in a carbon-constrained.

Thus, the primary knowledge gap that this research addresses is the lack of knowledge regarding the developments in a carbon-constrained world and how these developments change the way in which oil reserves should be valuated. The next paragraph will state the research question that will address this primary knowledge gap.

1.4 Research questions

The research will be conducted following a series of research questions. The main research question is formulated as follows:

'How to valuate oil reserves in a complex, carbon-constrained world?'

The following sub-questions are composed to be able to give a well-founded answer to this question. Each question will be answered in a separate chapter and therewith provide the line of reasoning that will be used during this research.

Both sub-question 1 and 2 are concerned with the conceptualization part of the research. Sub-questions 3 and 4 address the operationalization part of the research and sub-question 5 the illustration part.

The first sub-question focuses on the identification of the developments that will be apparent in a carbon-constrained world. The first research question is formulated as follows:

SQ_1: Which developments in a carbon-constrained world will affect the upstream oil sector?

After the developments are identified the focus shifts to the valuation of oil reserves. Hence, by answering the second sub-questions insight is provided regarding the characteristics oil reserves that determine its value and regarding the different methods of valuation that can be used to come to a value for a reserve.

SQ_2: How are oil reserves valued and what are the implications of the carbon-constrained world for the current valuation method?

The operationalization part of the research will start when the second sub-question is answered. The third research question is formulated to further analyze the developments in the carbon-constrained world and to determine the consequences of the developments on the reserves. Hence the third research question is as follows:

SQ_3: What are the consequences of the developments in a carbon-constrained world and how do they affect the value of oil reserves?

The part of the research concerned with the fourth research question emphasizes on the identification of reserves that experience the highest impact from the developments and accounting for the developments in the value of oil reserves. The fourth research question is formulated as follows:

SQ_4: Which types of reserves will experience the highest impact from the developments and how should be accounted for these developments in the valuation method?

The last part of the research, the illustration of the method, focuses on measures to prevent oil reserves from getting stranded. The new valuation method is used to define the measures in order to cope with the developments in the carbon-constrained world. Hence the fifth and last sub-question is formulated as follows:

SQ_5: How to reduce the impact of the developments and prevent oil reserves from getting stranded in a carbon-constrained world?

1.5 Methodology

The research consists of four parts. Which are; the preliminary research, the conceptualization, the operationalization and the illustration. Each of the four parts is supported by different research methods, which are explained in this paragraph and presented in figure 3.

Methodological overview of the research

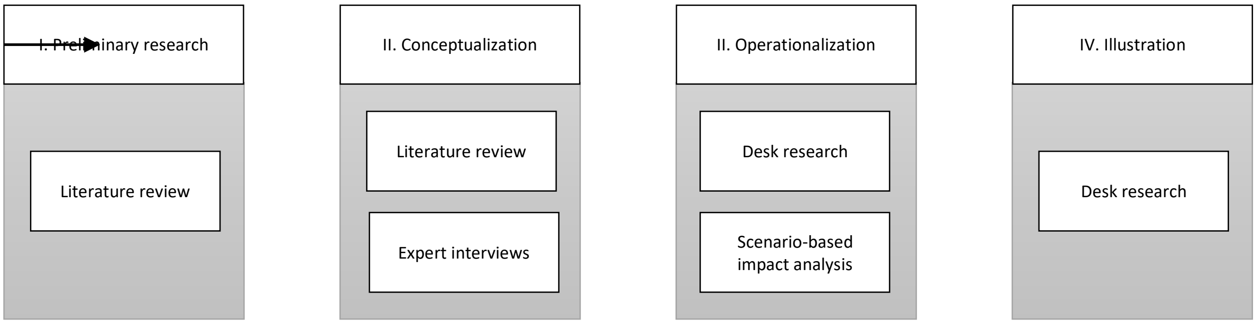


Figure 3 - Methodological overview

Preliminary research

The preliminary analysis focuses on the identification of applicable theories and concepts that can be used during the research to answer the main research question. The identification of these applicable theories and concepts occurs through a literature review. The preliminary research emphasizes on two fields of interest. The first is the identification of the developments that will be apparent in a carbon-constrained world. The second field of interest aims on getting insight and understanding of the different valuation methods that are able to assign a monetary value to oil reserves.

Literature review

The preliminary research is based on the review of existing literature. This literature review aims on formulating the problem statement, setting up the research design, determining the knowledge gap and formulating the research questions. The preliminary research is the result of this literature review.

Conceptualization

During the conceptualization, the theories and concepts from the preliminary analysis are further used and applied to the subject. In the conceptualization the developments in a carbon-constrained world are further identified and scoped based on theories and knowledge regarding the oil sector. Thereafter, the value of oil reserves and the components that determine the value of a reserve are studied to be able to compare the different valuation methods and the applicability of these methods for determining the impact of the developments on the value and valuation method of oil reserves. The insights that are gathered through analyzing how the oil sector functions, how certain factors influence the value of oil reserves and how the value of a reserve is determined are schematically depicted in an overview (Figure XL). This overview is based upon literature review and expert interviews and is verified and validated by the different experts during the interviews.

Literature review

The conceptualization also makes use of a literature review. However, the focus of this review differs from the literature review in the preliminary research because the conceptualization is much more focused on the specific theories and concepts instead of the broader view in the preliminary research. In the conceptualization the literature review is aimed on determining how oil reserves are currently valued an on the changes in the oil market.

Expert interviews

During the conceptualization, semi-structured expert interviews are scheduled to gather information from experts serving the oil industry regarding the functioning of the oil sector and the way in which oil reserves are valued. The interviews have provide deeper and more practical understanding of valuing oil reserves, making it possible to construct figure XL and to verify the valuation theories that are used. To allow multiple perspectives, experts with different backgrounds and different functions within the oil sector are approached and interviewed. The group of interviewees consists of 2 bankers serving the oil and gas industry and 3 experts working at an oil company. The experts are chosen based on their knowledge of the developments in the oil sector as a whole or on their knowledge of valuing oil reserves. The interviews can be found in appendix A_1, A_2 and A_3.

Operationalization

The operationalization is divided in two parts. The first part is the operationalization of the developments wherein the three developments that are identified in the conceptualization are operationalized and for which is determined what the consequences of the developments are and whether they change the valuation method of oil reserves. The first part of the operationalization is carried out through identifying the underlying components of the developments and determining their effect, by means of a desk research of the different developments. The second part of the operationalization is the incorporation of the developments and consequences of the developments in the value of the oil reserves. The incorporation first identifies which types of oil reserves are experiencing the highest impact from the developments by means of a scenario-based impact analysis. Thereafter, the incorporation uses the theories behind the valuation of oil reserves to determine how oil companies should account for the impact and consequences of the developments in a carbon-constrained world.

Desk research

The desk research in the operationalization aims on exploring and operationalizing the developments that are identified in the conceptualization. During the desk research data is used from sources such as Rystad Energy, IEA, EIA, BP statistical energy outlook and the US geological survey, which are considered trustworthy sources for data in the oil and energy sector. Besides the data that is used, existing knowledge is gathered through literature and through the analyses that are carried out.

Scenario-based impact analysis

The scenario-based impact analysis that is conducted in chapter 5 is based on literature regarding scenario-based impact analysis, scenario planning and impact analysis. The scenario-based impact analysis is conducted to determine the impact of the developments in a carbon-constrained world on the value of oil reserves. The method is fully explained in paragraph 5.2.

Illustration

The conceptualization and the operationalization build up to a method that is capable of determining the consequences of the developments in a carbon-constrained world on the valuation method of oil reserves. Hence, the last part of the research illustrates how oil companies can increase their competitive position to reduce the impact of the developments, which may prevent oil reserves from getting stranded. The measures to increase the competitive are composed based on the outcomes of the scenario-based impact analysis. Hence an illustration is provided how the outcomes of the conceptualization and operationalization can be used in practice and how they have formed an analytical tool to assess and analyze oil reserves on their viability in a carbon-constrained world.

After the illustration part the conclusions of the research are formulated, the research questions are answered and the method and added value are reflected upon. The following section gives an overview of the step-by-step approach of the methods that are used during this research. This overview can provide a handhold during the research process.

The step-by-step approach

Research part	Chapter	Step-by-step approach and methods used
I. Preliminary research	Ch. 2	1. Identification of the main developments in a carbon-constrained world. ➢ Literature review
II. Conceptualization	Ch. 2&3	2. Identification of the functioning of the oil sector and the factors and developments that influence the value of oil reserves. ➢ Expert interviews and literature review
	Ch. 3	3. Determination how oil companies valuate oil reserves. ➢ Expert interviews and literature review
	Ch. 3	4. Identification of the methods that can be used to determine the impact of the developments on the reserves. ➢ Expert interviews and literature review
	Ch. 3	5. Composition of an overview of the factors that influence the value and the valuation methods in one figure. ➢ Expert interviews and literature review
III. Operationalization	Ch. 4	6. Operationalization of the developments in a carbon-constrained world. ➢ Desk research
	Ch. 4	7. Definition of the possible consequences of the developments. ➢ Desk research and expert interviews from part II
	Ch. 5	8. Determination of the type of reserves that experience the highest impact from the developments. ➢ Scenario-based impact analysis
	Ch. 5	9. Definition of the approach of how the valuation methods should account for the developments in a carbon-constrained world. ➢ Desk research
IV. Illustration	Ch. 6	10. Illustration of how oil companies can use the outcomes from the scenario-based impact analysis to reduce the impact of the developments and increase the competitiveness of their oil reserves. ➢ Desk research based on analysis of scenario-based impact analysis and measures to enhance the competitiveness of the reserves.

1.6 Relevance

Scientific relevance

Climate change, environmental regulation, new technologies and many more developments will influence the future business of oil companies. This research analyzes these developments and determines their impact of the developments on the value of oil reserves. Analyzing the developments provides insight in the future state of the oil sector when the world actively addresses climate change. By incorporating these developments in the valuation methods, oil companies are offered a novel method of valuing their reserves that account for the developments in the value. This enables companies to more accurately valuate their reserves and to make well-considered decisions regarding the development of future oil reserves or to abandon the production of current reserves. Hence the scientific relevance of this research lies in the insights that are provided by the analysis and operationalization of the developments in a carbon-constrained world and in the novel method of incorporating the developments in the value of the reserve. These insights fill in the two knowledge gaps as stated in paragraph 1.3.

Practical relevance

The practical relevance of this research is threefold. First, companies active in and serving the oil industry can better understand the developments that are at hand when the world actively addresses climate change. Second, it enables these companies to valuate their oil reserves more accurately, which enhances the decision-making regarding the viability of the currently operated and new reserves. Third, the new valuation approach offers a framework that can be used to determine and enhance the competitive position of oil reserves in a carbon-constrained world, which reduces the impact of the developments and may prevent oil reserves from getting stranded.

1.7 Structure of the report

Figure 5 provides an overview of how this report is structured by showing the different parts and chapters of the research. The sub-questions corresponding to each chapter are also included in the overview, because the research is structured based on the sub-questions. In the next part, the conceptualization of the developments in the carbon-constrained world and the valuation methods of oil reserves are described. Moreover, the conceptualization will answer the sub-questions corresponding to chapter 2 and 3. In part three, an in-depth analysis of the developments will be carried out and the consequences of the developments are analyzed on their impact on the reserves. Part three will answer the sub-questions of chapter 4 and 5 after which part 4 will answer the sub-question associated with chapter 6. After chapter 6 the discussion and reflection and the conclusions and recommendations are presented. See figure 4 for the report structure

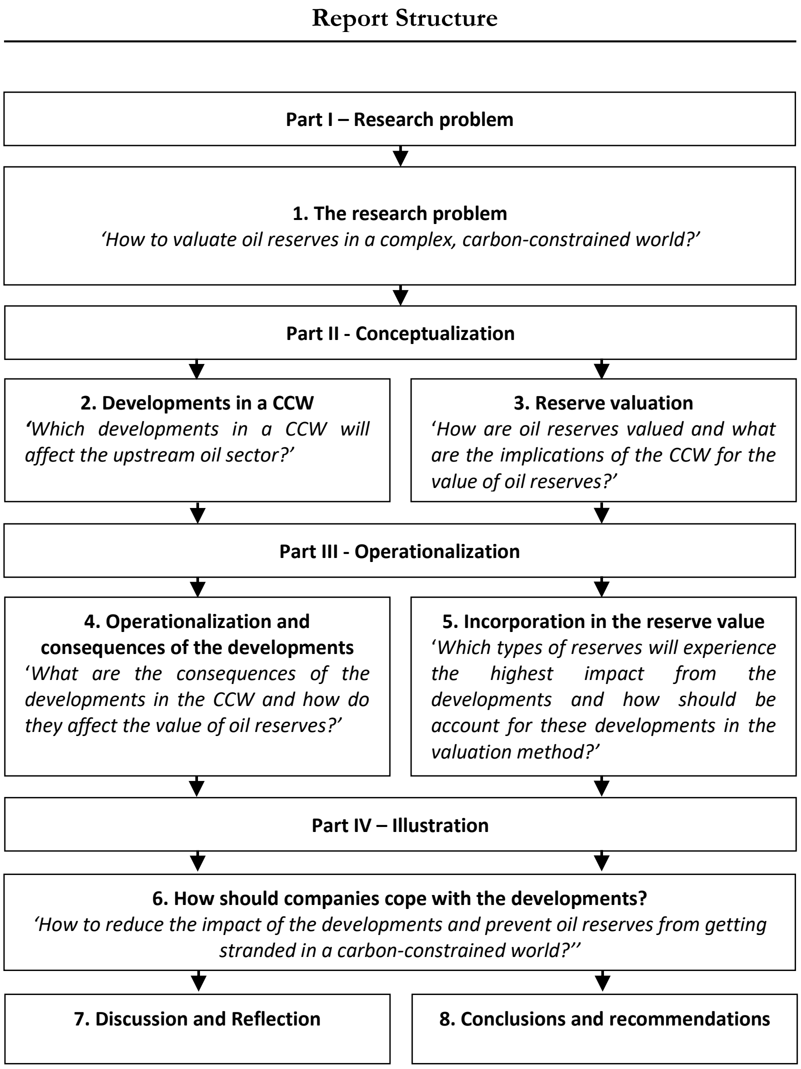


Figure 4 - Report structure

PART II - Conceptualization

2. The developments that affect the value of oil reserves in a carbon-constrained world

The previous chapter has introduced some of the problems that currently uphold the upstream oil sector and to which this research is dedicated. This second chapter will further define the developments that will affect the upstream oil sector in a carbon-constrained world. Hence the following question will be central throughout this chapter:

'Which developments in a carbon constrained world will affect the upstream oil sector?'

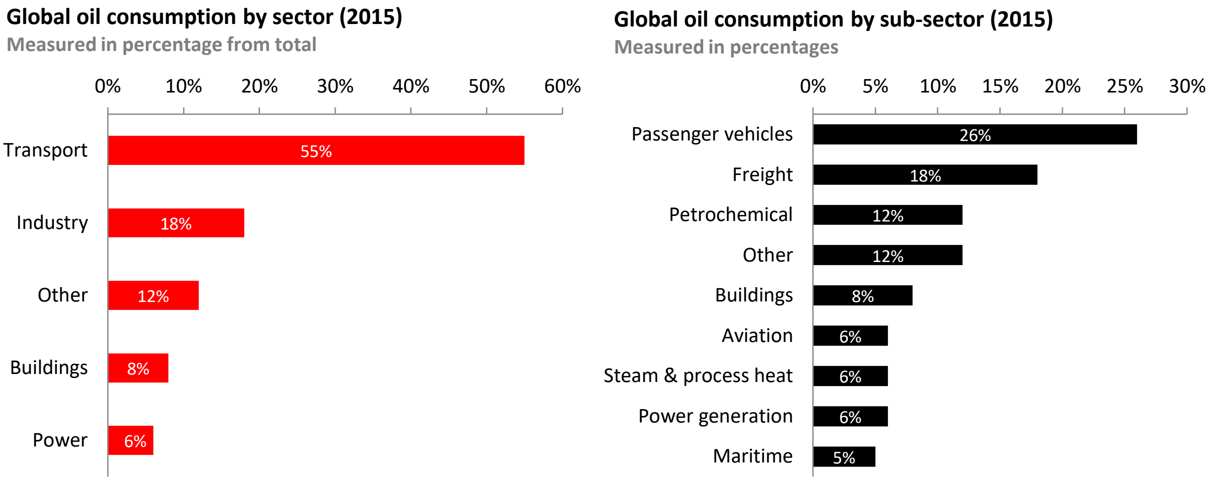
Paragraph 2.1 will focus on the general functions of the upstream oil sector to provide the necessary background knowledge for subjects that will be dealt with later on in this research. Paragraph 2.2 will emphasize on the developments that occur in a carbon-constrained world, which will form the basis of the remainder of the research.

2.1 The upstream oil sector

This paragraph briefly explains some vital knowledge regarding the oil sector. The subjects that are explained in this paragraph will be further used throughout this research.

Functions of oil

Oil has been used for several purposes in the past decade. At first, oil was primarily used for the lightening of houses and streets. However, with the arrival of the personal car and home electricity, the function of oil shifted from the lightening of buildings to the transport, industrial processes and for the generation of electricity and heating of buildings. Currently the main functions for oil are energy related and are used in transportation, in power generation & heating and in industrial processes (IEA, 2015). The figure 5 shows the consumption of oil by sector and by sub-sector in 2015.



Global oil consumption by sector (2015)

Measured in percentage from total

Source: IEA WEO 2016

Global oil consumption by sub-sector (2015)

Measured in percentages

Source: IEA WEO 2016

Figure 5 - Global oil consumption by sector and sub-sector (based on data from the IEA 2016)

Supply chain of the oil industry

The oil industry is divided in its three main components. These components are upstream, midstream and downstream. Upstream is concerned with the exploration for oil, the development of oil fields, and the extraction of oil form the ground, midstream includes the transport distribution and storage of oil and downstream involves the manufacturing of oil products and the production of energy from the products. Some companies are active in all three parts of the supply chain, these companies are often referred to as the Integrated Oil Companies (IOCs) such as Shell, BP, Exxon Mobil etc., while other companies are more specialized on one part of the supply chain. Figure 6 illustrates the different parts of the supply chain. The upstream component of the supply chain is the component that has to deal with the extraction of oil reserves; hence the focus of this research lays on upstream.

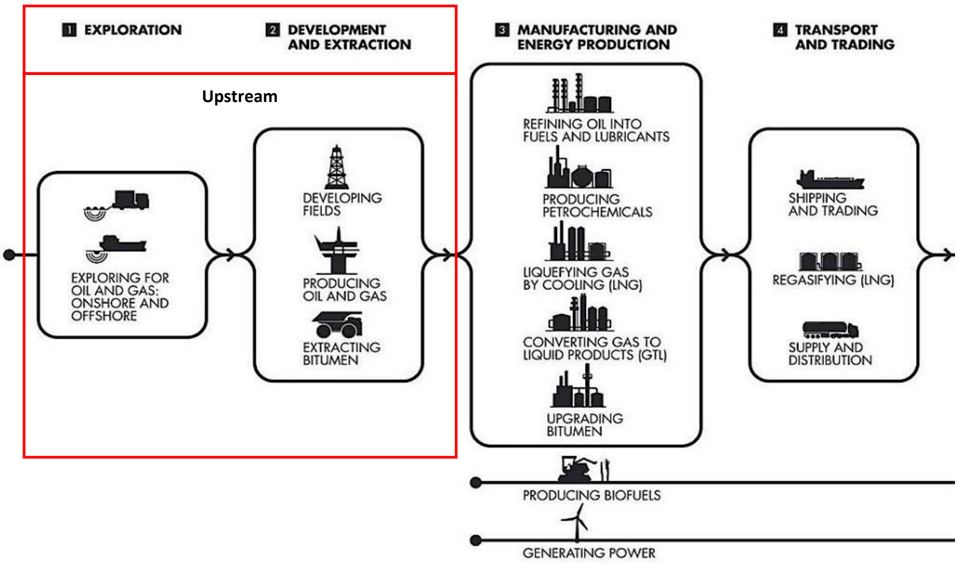


Figure 6 - Oil and gas supply chain (adopted from Shell Company Report 2015)

Life cycle of oil projects

The lifecycle of oil reserves is known to have 5 phases (Aduhene Tanoh, 2016). It starts with the exploration for oil reserves and ends with the abandonment of the reserve. The lifetime of reserves and the different phases vary greatly; some reserves only produce oil for 5 to 10 years while others stay active for decades. Table 1 shows the 5 phases of an oil project with its activities and the average duration of the phase. The exploration has no average duration because in some cases an exploration does not lead to the discovery of oil and may be aborted or continued in another area.

#	Phase	Activities	Duration
1.	The exploration phase	The oil company searches for oil reservoirs, which they may exploit in the future by drilling exploration wells at locations with possible oil reservoirs.	-
2.	The appraisal phase	The technical and commercial potential of the reservoir that is found in the exploration phase is calculated via additional research.	1- 3 years
3.	The development phase	The reservoir is prepared for production by drilling the production wells and installing production facilities and pipelines	2 – 5 years
4.	The production phase	The oil gets extracted from the reservoir and is sold on the market. In this phase the first income is generated	5 – 40 years
5.	The decommissioning phase	It is not economically viable to resume production, hence the wells are closed and the production facilities are removed from the wells	1 - 3 years

Table 1 - Life cycle of oil projects

Type of oil projects

Technology; conventional and unconventional

There are merely two types of oil projects, conventional and unconventional. Conventional oil is referred to when oil can be extracted from the ground using conventional drilling techniques. Examples of conventional oil are onshore oil, offshore oil (which can be divided in shallow water, deep-water and ultra-deep water) and Artic oil. Unconventional oils are production techniques such as shale oil/tight oil, oil shale, and tar sands/oil sands. The types of oil projects are summarized in Table 2 - Location, density, footprint and emission driver of different type of oil reserves

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Quality (light or heavy and sweet or sour)

Both conventional and unconventional oil projects have the intention to produce the same end product; crude oil. Although the end product may be the same, the process of generating this product differs in all sorts of ways. This difference is not only due to the drilling technique but also due to the quality of the oil. The quality of the oil differs per reserve. In some regions the crude oil that is extracted is very light and liquid, while in other regions the reserves produce a heavy or extra-heavy sludgy tar. The light, liquid oils are considered to be of higher quality because they need less refining and upgrading than the heavy or extra-heavy types of oil. Another indicator of the quality of the oil can be found in its contamination by Sulfur. The presence of sulfur in the crude oil makes the crude oil sour, while the absence of Sulfur is indicated as sweet oil. The Sulfur has to be removed from the sour types of oil before it can be further used and processed. Both the density of the oil (light or heavy) and the contamination of the oil (sweet or sour) represent the oils quality. The additional refining and upgrading of the heavy and contaminated oils result in a higher well (production) to wheel (usage) footprint on the environment.

Footprint

The different qualities and production processes of oil result in the fact that oil has a different environmental footprint. Gordon, Brandt, Bergerson, & Koomey, (2015) have analyzed 75 oil projects over their entire supply chain (upstream, midstream and downstream) in order to be able to make an Oil-Climate Index of the footprint of different oil reserves based on the emission of GHGs. They came to the conclusion that extra-heavy and heavy oils have a much higher GHGs footprint. In their research they did not only consider the quality, process techniques and treatment of the oil, but they also included the use of land. The findings from Gordon et al., (2015) are summarized in table 2.

Main emission drivers according to Gordon et al., (2015)

- Oil type; heavy oils needs more refining and upgrading than light oils. The difference in GHG footprint can be twice as much as light oils.
- Land use; the extraction of heavy and extra-heavy oils such as tar sands has a high impact on the landscape as the result of destruction and contamination.
- Flaring and fugitives; flaring of gas and gas that escapes while producing oil is often burned/flared or released. This flaring as well as the fugitive gasses generates a lot of CO_2, methane and other GHGs that go directly into the atmosphere; thus, highly gaseous reserves have a relatively high footprint. Installing more advanced production technologies can, for a large share, prevent the escape of fugitive gasses.
- Gas/water injections; depleted reserves often need high amounts of water or steam injections to make the oil that is left flow to the surface. These injections require an enormous amount of energy and may contaminate the soil.

Type	Location	Density	Footprint	Main emission driver
Conventional				
Onshore	OPEC countries and others.	Light to medium	Small	Flaring and fugitives
Offshore		Light to medium	Small to medium	Flaring and fugitives
• Deep	Mexico, Brazil and Norway, UK	Light to medium	Small to medium	Flaring and fugitives
• Ultra deep	Mexico, Brazil and Nigeria	Light to medium	Small to medium	Flaring and fugitives
• Arctic	Antarctica, Alaska	Light to medium	Medium to large	Location
• Shelf	Russia, Canada, USA	Light to medium	Medium to large	Flaring, land use
Unconventional				
Shale oil / tight oil	USA	Medium	Medium	Flaring, land use
Oil shale/ (extra) heavy	USA, Venezuela	Extra-heavy	Large	Oil type
Tar sands / oil sands	Canada, China and Venezuela	Extra-heavy	Large	Oil type, land use

Table 2 - Location, density, footprint and emission driver of different type of oil reserves

Oil 2.0 (Gordon et al., 2015)

The last decade the world has seen a vast increasing use and possibilities with unconventional oils. Especially the production of shale oil has resulted in a large amount of additional reserves, which was not considered to be possible 20 years ago. These oils not only increase the amount of oils that are available to exploit, but also changes the type of oil that comes to the market (Gordon et al., 2015). Oil refineries around the world have moved to the processing of heavier, dirtier types of crude oil, such as oil from the Canadian tar sands. These heavier types of oil are often cheaper to buy than light, sweet crude due to their substance and contamination. But, these heavy types of oil require more energy intensive and polluting cleaning methods, generating an increasing amount of emissions per barrel of oil. The reason why refineries switch to these dirtier type of oil is because they gain competitive advantage over other refineries and higher profits (Karras, 2011) because the oil that they purchase is cheaper and there are no taxes on the additional emissions and pollution. Other reasons why unconventional oil is used are the depletion of the conventional oils and the fact that most of the remaining conventional oil reserves are owned and exploited by National Oil Companies (NOCs). Because the IOCs do not own as much conventional reserves as the NOCs they must focus on the more technical unconventional oil types, which will be further explained in the next section.

The distribution and ownership of oil reserves

IOC's and NOC's

The oil reserves in the world are unequally distributed across nations. Countries such as Saudi Arabia, Venezuela, Iran, Iraq, Russia and Libya are in the possession of many large oil reserves, while other countries have none. The ownership of the oil reserves in these countries usually belongs to the government of the country. Petroleum rich countries usually have one or more state owned oil companies, the National Oil Companies (NOCs) whom extract the crude oil from the ground. These NOCs originate from, work for and are owned by the country that possesses the oil. Because the NOCs work for the country, they usually have the full ownership of, and access to the largest and easiest to exploit oil reserves in the world. NOCs also have a social role because they generate a large share of the countries income, employ citizens and pay for government programs and subsidies on petroleum and diesel (Thurber, 2012). Examples of NOCs are; Saudi Aramco, China National Petroleum Company (CNPC), Petroleos Mexicanos (Pemex), Rosneft, National Iranian Oil Company (NIOC). According to data from Wood Mackenzie (2015), OPEC and therewith the NOCs are in control of 73% of the total proved oil reserves and they supplied 43% of the world crude oil in 2015.

The Integrated (sometimes referred to as International) Oil Companies (IOCs) or 'oil majors' are the privatized counterparts of the NOCs. These companies are listed on stock exchanges around the world. Because of these listings on stock exchanges the IOCs have a commercial character and their primary mission is to let the company grow, optimize its profits and increase shareholder value (Kolk & Levy, 2001). IOCs do not have a government with easy to access oil reserves as an owner and are forced to focus on the more technically challenging projects in which they excel and outcompete NOCs. Examples of IOCs are; Royal Dutch Shell, Exxon Mobil, BP, Total, Chevron etc.

OPEC

The Organization of Petroleum Exporting Countries is an organization in the form of an international cartel that consists of countries that are net exporters of oil and in which the governments of these countries have full control with regard to the oil output of the countries oil resources. The mission of OPEC is to stabilize the oil market by coordinating the oil policies of the OPEC countries, in practice this result in controlling the output of the OPEC countries to drive up oil prices when needed (Persson, Azar, Johansson, & Lindgren, 2007). OPEC countries usually have a minister of oil that is also the chief of the countries NOC. This makes the oil minister fully qualified to adjust the countries oil output based on the policies made by the cartel (Thurber, 2012). The countries that are part of OPEC are: Saudi Arabia, Iran, Iraq, Kuwait, Venezuela, Qatar, Indonesia, Libya, United Arab Emirates, Algeria, Nigeria, Ecuador, Gabon, Angola.

Distribution of oil reserves among ownership types

An important distinction between NOCs and IOCs is that NOCs have access to the easiest, largest and least technical challenging oil reserves. This gives them a competitive advantage over the IOCs in both cost of production and amount of resources they have available (Kolk & Pinkse, 2004). Table 3 is adopted from Leaton (2014), it depicts the breakeven price band of production by different ownership types. Figure 6, which follow from table 3 shows that NOCs and OPEC own approximately ⅔ of the cheap exploitable oil reserves in the price band below $60. Hence, when it comes to competitiveness, the producers that are most cost competitive and own the largest share of reserves are the OPEC countries and the NOCs that operate on behalf of the oil rich countries as the following table shows. The numbers in the table represent the $GtCO_2$ that the different owners per ownership type have remaining in their portfolio.

	Ownership type				
Price band	OPEC	NOCs	Part-Listed	Private	Majors
$0 - $60	189	215	43	125	46
$60 -$80	22	39	19	70	21
$80 - $100	17	28	14	42	10
$100 - $120	7	12	4	24	4
$120 - $150	9	4	1	27	2
Above $150	8	5	2	42	1

Table 3 - Ownership type by breakeven price band

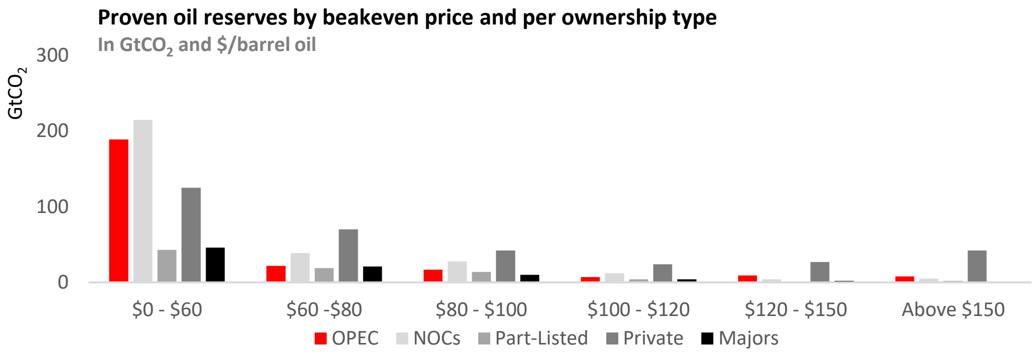


Figure 7 - Proven oil reserves by breakeven price and ownership type

The size of the oil majors compared to NOCs

Most peoples see the oil majors such as Shell, BP and ExxonMobil as the companies that produce and possess the largest amount of oil. However, when it comes to the possession of proven oil reserves IOCs own not a glimpse of what the oil producing countries and their NOCs possess. The picture below indicates the amount of reserves that the three largest privately listed oil companies (Exxon, BP and Shell) own, compared to the NOCs of the oil rich countries. The figure 8 shows the amount of oil reserves owned by NOCs and IOCs

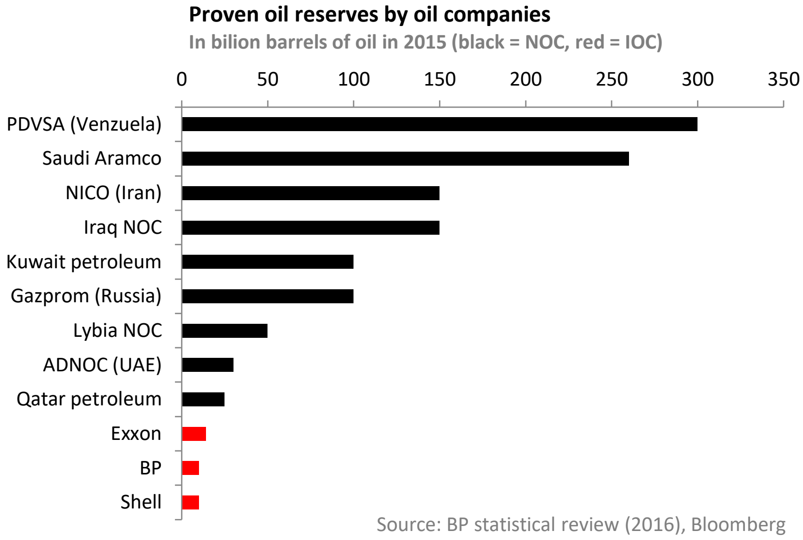


Figure 8 - Proven oil reserves by oil companies

Stranded oil reserves

According to Ansar, Caldecot, & Tibury (2013) stranded reserves are reserves that due to unanticipated developments face the risk of premature write-offs or are turned into liabilities of the company before the end of their economic life. Stranded assets are a regular phenomenon in economic systems (Caldecott, Lomax, & Workman, 2015). When reflecting the concept of stranded assets on oil reserves it means that the reserves will not be fully produced and have to remain 'stranded in the ground'. Reserves that are stranded have lost their value, and therefore cannot be traded or further exploited without facing losses.

Currently the value of oil reserves are based on the full exploitation of reserves for the production rate determined by the reserve instead of the market, and the price set at an average estimated market price over the entire lifetime of a reserve. This approach is based on the perspective that oil will become scarce (Leaton, Ranger, Ward, Sussams, & Brown, 2013). However with the developments identified and analyzed in chapter 2 and 4, full exploitation of the reserves may not be possible for some reserves due to environmental regulation, a decreasing oil demand and low oil prices. This will result in the devaluation of reserves and even reserves that are getting stranded.

2.2 The developments in a carbon-constrained world

The Paris Agreement and the 2°C pathway

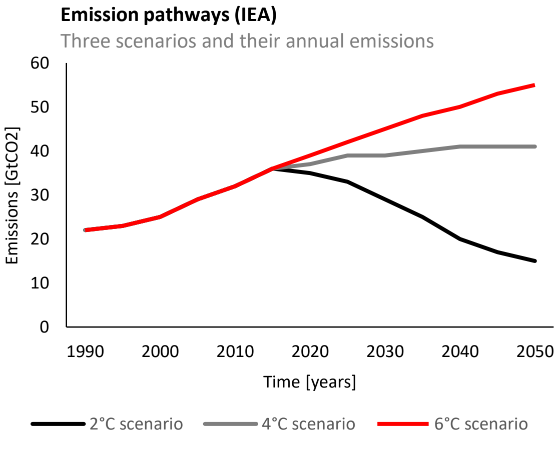


Figure 9 - Emission pathways (based on data from the IEA)

The Paris Agreements have shown that there is a worldwide urge to fight global warming and to limit the emission of greenhouse gasses. This urge to fight global warming and the dedication to the Paris Agreements is due to increasing environmental awareness and a change in public opinion. The Paris Agreement as the result of this growing environmental awareness result in the fact that the emission of greenhouse gasses such as CO_2 is limited. This limitation is set on a maximum of 2°C for average global warming and is reflected by the remaining 'Carbon Budget'. The emission pathway associated with the carbon budget is calculated by the International Energy Agency (IEA) and can be seen in figure 9. The red line in this figure reflects the scenario when the current trend is continued. This will result in an average temperature increase of 6°C for global warming. This 6°C scenario is often referred to as the current policies scenario. The grey line represents a change in policy and considers recent pledges of countries to limit emissions and improve efficiency. This scenario will result in an average of 4°C for global warming. The 2°C scenario, is the scenario consistent with the Paris Agreements and has a 50% change of limiting global warming and to stay within the carbon budget. The emission pathway of the 2°C scenario shows that should the goals that are formulated at the Paris Agreement be achieved, then society must immediately start to reduce the annual emissions of CO_2.

The question that arises in this situation is which developments will occur when society stays on track of the 2°C pathway in order to meet the goals of the Paris Agreements. The remainder of this paragraph will focus on answering this question.

Demographic developments

Increase in world population, prosperity and economic growth

The reduction of annual emissions must be met in the face of a growing demand for energy due to demographic developments. Population growth, growing prosperity and increasing living standards are the main drivers of a growing energy demand and have pushed the energy demand throughout the years. This trend is projected to continue during the coming century according to the IEA the World Bank and the OECD and is mostly driven by developing countries in Africa and Asia.

The global population is forecasted to grow from 7,3 billion people living in 2015 to 8,5 billion by 2030 and 9,7 billion in 2050 (United Nations, 2015). All these additional people need energy to fulfill their needs and from this energy a significant share will come from the use of oil. This growth in the world population is one of the main drivers of the increasing oil demand because it will increase the entire size of the market. The living standards of all these people will also continue to increase, especially in non-OECD countries. This increase in living standards results in a higher demand for energy and hence in a growing consumption of the oil market. Although on global scale the demand for energy will increase, the demand for energy will start to decline in OECD countries due to increased levels of efficiency.

The global recession has resulted in a reduction in the growth of the economies of developing countries such as China an India. Their growth rates are adjusted downwards from around 8% annually to the current 5%. The size of these countries has a large amount of impact on the world economy. The world economy is predicted to grow between the 2,7% (World Bank, 2017) and 2,9% (OECD, 2017) annually.

Policy changes that shape the transition

Policy and regulation that reduces emissions and stimulates low carbon technologies

To be able to meet these goals and to stay on track of the 2°C pathway, governments must set the right incentives for companies and individuals in order to change the current course of action from a 4 tot 6°C pathway to a 2°C pathway. To set these right incentives it is inevitable that governments should implement policies and environmental regulation that guide companies and individuals to limit the emission of GHG by changing their behavior regarding the environment. These policies and regulations should assure; security of supply, affordability of energy and environmental sustainability, while emissions of GHGs are discouraged and the adoption of low carbon technologies are incentivized.

With regard to the oil sector, there are two sides at which the regulation can be implied, at the supply and at the demand side. Regulation at the supply side should focus on discouraging or taxing the emissions of GHG and incentivize a shift towards cleaner production technologies or cleaner reserves. Regulation imposed at the demand side, should incentivize the users to adopt sustainable or low carbon technologies as an alternative for oil by means of subsidies. Adequate incentives implied by policies and regulation should set the start of a change in pathway towards the goal of 2°C. However, when this pathway is followed there are many other developments that will have a large effect on the oil sector.

A change in perspective of future demand

The urge for a declining oil market

The 2°C pathway for emissions represent the emissions of the entire energy system. Of the entire energy system, approximately 36% of the emissions are caused by the production and use of oil (EIA, 2015). Therefore, large improvements should be made in the oil sector to stay on track of the 2°C pathway and to be able to reduce global emissions. The 2°C pathway of the IEA projects the global demand for oil to peak in 2020 at 93,7 million barrels of oil per day after which it falls to 74,1 million barrels per day in 2040. To be able to stay within the carbon budget and comply with the goals from the Paris Agreements, the emissions and the demand in the oil sector should stop growing and start to decline in 2020 if the world wants to meet the goals and stay on track of the 2°C pathway. This implies that the entire oil sector that has been growing for decades has to meet its peak supply in 2020 and then starts to decline as an ex-growth sector (Van de Graaf & Verbruggen, 2015).

This decline in the use of oil is the preferred scenario for all environmentalists but remains in contrast with the current outlook due to projections by many renowned institutions of growing demand for energy as the result of growing population and increasing living standards. So how is the world supposed to let the oil market shrink while economic and demographic factors indicate a growth in the demand for oil? The world is caught between two frontiers according to data from the IEA; the western society (OECD) and the developing countries. In the western countries is a stable size of the population and the energy intensity per capita is declining due to increased efficiency and new technological developments (Melorose et al., 2016). Whereas the developing countries are characterized by a steep population growth, increasing living standards and old, less efficient technologies that generate and use energy. The population growth and increasing living standards in the developing countries will generate an increasing demand for energy, while increasing efficiency and renewable forms of energy generation and usage compensate (especially in the western society) this increasing demand for energy. When the right policies and regulation is set that incentivizes the widespread implementation of these technologies, then the oil market will start shrinking.

From peak oil supply to peak oil demand

The world always thought that there would be a race between oil producers to extract the last oil resources available (Klare, 2012). In this worldview (peak oil supply) oil prices were about to increase until the last drop of oil was extracted from the ground. Vast price increase due to scarcity is a common phenomenon in economics when markets rely on a scarce product. M. King Hubbert was the first who considered the rate of production of oil as a Bell-curve (figure 10). This Bell-curve depicts the oil production over time with in the middle, peak oil (supply), that characterizes the switch from plenty of oil to scarce oil (Verbruggen & Marchohi, 2010). At peak oil the production of oil is at its peak as the result of explorations that add to the resource base. When in time additional discoveries decline due to scarcity the production decreases and oil gets more expensive, up until oil gets more scarce and price skyrocket. (Verbruggen & Van de Graaf, 2013)
But the perception of peak oil is changing; scientists, bankers and people from the oil industry argue that the worldview with scarce oil resources has come to an end. They

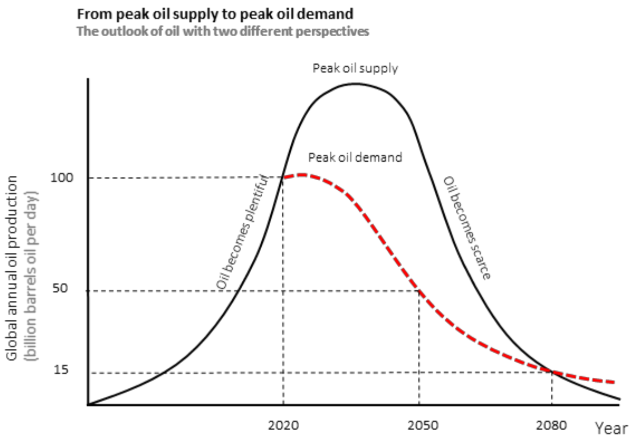


Figure 10 - From peak oil supply to peak oil demand (based on Hubbert peak)

argue that oil is abundant instead of scarce, with plenty of oil left to provide in the global energy needs without taking into account the increasing opportunities with unconventionals. This causes a shift in paradigm, from the perception in which oil is scarce, to a perception in which oil is abundant. However, new paradigms are not adopted overnight according to the theory of scientific revolution of Thomas Kuhn (1962). To cause a shift in paradigm, there must be sufficient scientific prove that the current dominant paradigm is incomplete or incompatible with the new developments. This scientific prove is built on the anomalies that cannot be resolved with the current dominant paradigm. When the anomalies add up and the paradigm proves unable to resolve the anomalies, then the paradigm shifts and new theories are established (Kuhn, 1962). The natural resource industry currently resembles such a shift in paradigm. In which the Peak Oil Theory of Hubbert can be seen as the old dominant paradigm and the situation in which there will be a demand peak the new paradigm. The adoption of the new paradigm may have large implications for the value of oil companies and to the oil system when the paradigm is adopted on global scale and oil turns out to be abundant. Hence, oil companies will benefit from denying such a shift in paradigm.

Increasing competition and changing oil prices

The race to sell oil (market share driven policy)

A change in the paradigm from peak oil supply to peak oil demand also changes the perception and the policy in the market. First, under peak oil, the perception was that oil in the ground would be much more worth in the future due to price increase and scarcity. However, with the change in perception from peak oil supply to peak oil demand, the tide will turn and oil in the ground is not like 'money in the bank' because these resources may someday be less valuable than oil that is already sold (Van de Graaf & Verbruggen, 2015). This change in perception will increase the competition and may trigger a "race to sell oil" among oil producers with large oil reserves such as petroleum states like Saudi Arabia, Iraq, Iran, Kuwait, United Arab Emirates etc. (Helm, 2016).

Increasing competition and the fight for market share

The vision that oil in the ground is worth less than oil that is produced will trigger a global race to sell oil. This vision is shared by multiple scientists (Helm, 2016) (Klare, 2012) (Myers Jaffe, 2016) (Van de Graaf & Verbruggen, 2015). This race to sell oil has a high potential to result in low and volatile oil prices due to oversupply caused by the race to sell oil. Oil producers with large amounts of potentially stranded reserves (mainly petro states) want to get rid of as much as oil as possible before the demand has declined to a point where the reserves become worthless (Van de Graaf & Verbruggen, 2015). Therefore, they flood the market with oil to try to sell as much as they have left and increase their market share with a lowering oil price as a result. This market share driven policy is hard to sustain for longer periods, only oil producers with low breakeven cost of oil production or companies with the largest bank accounts will be able to compete the longest in the race to sell oil (BP Group, 2017). Due to their large and relatively cheap reserves, Cherp, Jewell, Vinichenko, Bauer, & De Cian (2013) predict, that the market share of the main petro states will increase and especially the share of the Gulf states. This vision is shared in the latest energy outlook of BP (BP Group, 2017). Such a market share driven policy will become more common in the scenario where oil reserves face the chance of getting potentially stranded, oil producers want to prevent this by opening the valves. The only party that may be able to prevent such a race to sell oil is OPEC. OPEC has a history of setting production quotas for oil producing countries. However, the oil producing countries also have a history of undermining the agreements they have made because each member of OPEC will benefit most by not complying to the production quotas.

Intermediate conclusion

Although the demographic developments imply a growing demand for oil over the coming decade, there is a strong worldwide tendency to fight global warming and climate change. This tendency to fight global warming by decarbonizing the economy is reflected in the formulation of the Paris Agreements in December 2015. Governments will have to intervene and cooperate to change the current trends and limit the emission of GHGs. This intervention may result in the implementation of regulations that guide the transition towards a low carbon economy. Another important development that should occur to be able to meet the goals of the Paris Agreement is the reduction in the demand for and the usage of oil if the world is willing to succeed in fighting climate change. This reduction in the demand for oil will be the start sign of the shrinking oil market, which may further destabilize oil prices and increase the competition in the market. This will lead to market share driven policy, especially among petro states with large remaining reserves resulting in oversupply associated with low oil prices. Concluding, the main developments in a carbon-constrained world in which the world complies to the 2°C pathway and stay within the carbon budget will be shaped by;

- Increasing environmental regulation,
- Decreasing demand for oil
- Increasing competition and lower oil prices.

The developments in a carbon-constrained world that have come to light in this paragraph will influence the value of oil reserves. The influences on the reserves are perceived to be negative because regulation, decreasing demand and low oil prices are all threats to their value. The developments are all individual developments but there are also relations between the developments that make the situation more complex. To be able to determine how they influence the value, the underlying theories of valuing oil reserves need to be studied; hence, the following chapter will focus on the valuation of oil reserves.

3. The valuation of oil reserves

Chapter two has focused on the developments that affect the oil sector in a carbon-constrained world. These developments will have their effect on the value of oil reserves. This chapter, chapter 3 will emphasize on the fundamentals of oil reserve valuation by breaking down the value of oil reserves into its components and to determine how these components add to the value of a reserve. Hence the focal question of this chapter is formulated as follows:

> 'How are oil reserves valued and what are the implications of the carbon-constrained world for the current valuation method?'

To answer this question there are three main focus points that aim to answer the why, what and how question regarding valuations. Paragraph 3.1 will focus on the reasons behind oil valuations by emphasizing on the difference between the classifications of oil reserves and the different kind of values of oil reserves. Paragraph 3.2 analytically breaks down the value of oil reserves to determine which factors influence the value of oil reserves in order to provide insight in the physical system of oil reserves. Paragraph 3.3 will analyze the methods that can be used to compose a value for oil reserves. The last paragraph of this chapter, paragraph 3.4, will integrate the developments as explained in the previous chapter and the valuation of oil reserves of this chapter and define a suitable approach for the remainder of the research to incorporate developments in the valuation of oil reserves. The methods that are used to gather the information presented in this chapter are a literature review and (semi-structured) interviews with experts serving the oil sector.

3.1 The classification of oil reserves

Oil companies must constantly update the value of their reserves to determine how much the company is worth on paper, to determine if reserves are still viable and to make investment decisions regarding new assets that are about to be exploited or acquired. Oil companies have made comprehensive calculation models to determine the value of the reserves under certain market conditions to be able to make these investment decisions and monitor the value of oil reserves. This paragraph emphasizes on the different type of reserve values and the different classifications of oil reserves to provide the necessary information regarding the valuation of oil reserves. First the distinction is made between two types of reserve values that are calculated by oil companies and after the types of value the classifications of oil reserves used in the industry are explained.

Book value vs. equity value

The book value

The main purpose of the book value is to update the value of the reserves in the financial statements to determine the value of the company at the moment of valuation. Oil companies are required by the Securities and Exchange Commission (SEC) (2009) to report their oil reserves. All companies listed on the New York stock exchange must comply with the rules and guidelines of the SEC. This makes it possible for shareholders to compare the book values of different oil companies, since they are all composed using the same standards (Henry, 2015). The guidelines of the reporting of these reserves are listed in the ruling by the SEC (Securities and Exchange Commission, 2009).

The book value is the value that the reserves are currently worth and are based on the current market conditions with the current knowledge regarding the reserves. This book value does not have to give insights in values under future market conditions and therefore doesn't have to be very accurate on the long run. Companies know that this value will change and the book value is only the value at that certain moment in time when the value is used for the financial statements of that year. The book value is often composed at the end of the year and takes the numbers and figures from the past year into account for the composition of the book value. Thus, companies make certain assumptions and estimates regarding prices and other uncertain factors for the composition of the book value of oil reserves (Henry, 2015), such as the average oil price of past year. These assumptions and estimates are made in line with the rulings by the SEC to comply with their rules of reporting and to provide insight in the outcomes and the way how the reports and figures come about. Since the book value is composed at the end of the year, all estimates and uncertainties that influence the oil company can be filled in. Therefore, uncertainties are excluded since the uncertainties are based on industry and company figures from the past year. The methods that are used for determining the book value are Discounted Cash Flows based on Net Present Values (Aalbers, 2017), (Lechner, 2016), (Sisouw de Zilwa, 2016).

The equity value

The equity value is the value that the reserves might be worth in the future when extracting the oil. Companies use this value primarily for their investment decisions regarding certain projects but they also use the equity value to monitor projects and to determine their viability under future market conditions (Lechner, 2017). The equity value incorporates uncertainties and future projections of market developments to be able to calculate the value of reserves over their future life cycle. Certain scenarios and decision trees are composed to be able to take these developments and uncertainties into account and to test the equity value under different market scenarios. It would be ideal that the equity value is as accurate as possible, but the uncertainties in the market prevent the value from being accurate. Hence, the equity value often has p90, p50 and p10 values to distinguish in the scenarios regarding these future market conditions (Aalbers, 2017).

Based on these equity values the decision is made whether to acquire or exploit a certain reserve. This decision is based on the outcomes of the different scenarios and whether these outcomes give a positive value for the most obvious and certain market conditions. However, there are few projects that function well in both a p90 and p10 scenario, since the range between these values is most often very large. Thus, when the market conditions severely change, the profitability of the project may come at stake. This is in line with the current situation in the market where the oil price used to be $120 per barrel in 2014 and has been around the $30 per barrel in 2015 and 2016.

Hence, the difference between the book and the equity value lays in the level of uncertainty. The book value represents the current value of the reserves for the current state of the market. Thus, most uncertainties that are apparent when composing the equity value can be filled in when determining the book value.

In this research, the emphasis lays on gathering insights regarding the equity value instead of the book value. Reason for this focus is that when assessing future investments and business opportunities the equity value is more comprehensive, while the book value is mainly used for reporting and doesn't provide any insight in future scenarios. All interesting developments that lay ahead about the future developments in the oil sector, the Paris Agreements and the challenge to decarbonize the economy are left out of the scope when determining the book value, while they play a major role in the equity value.

To be able to determine how to valuate oil reserves on their equity value, it must be clear what exactly is valuated. Hence in the next paragraph the focus lays on the different classifications of reserves that are valuated.

Resource classification

To be able to assign a value to a specific reserve, one must know what type of reserve is to be evaluated, because the value depends on the type of reserve. In the oil sector, there are different type of reserves and terminologies for reserves and resources. There are discovered, undiscovered, produced, unproduced and many more classifications of reserves and resources. These different terms for just an oil field often confuse people. Hence the World Petroleum Council, supported by numerous technical societies and regulatory bodies, came up with one universal classification of oil resources to standardize definitions and concepts. These standardized concept can be found in the Petroleum Resources Management System (World Petroleum Council, 2007). The most important definitions are explained below and used throughout this thesis. Figure 11 is a schematic overview of the definitions and concepts.

Reserves

The most important distinction in the classification of oil reservoirs is between reserves and resources. Reserves in the petroleum sector are classified as quantities of petroleum that are anticipated to be *economically viable* to extract by development projects under defined market conditions from a given date forward (World Petroleum Council, 2007). Resources are reservoirs with oil that are *not economically viable* or not yet economically viable to extract. To be classified as a 'reserve', petroleum reservoirs must meet four criteria: they must be discovered, recoverable, commercial and remaining based on the development projects as applied. Reserves can be further classified as proved, probable and possible (1P, 2P, 3P) in accordance of the level of certainty that is associated with its development. The 'proved' and 'probable' reserves together are sometimes referred to as the 'expected reserves' because they have the highest likelihood of getting produced.

Proved reserves (1P)

Reserves are proven if they are economically producible in the future with reasonable certainty under the existing economic conditions and if the producibility is supported by actual production or formation testing. Reserves whom might be produced economically through the application of established improved recovery techniques are included in the classification as proved reserves, but only when testing was successful through a pilot project and when it is reasonable certain that the project proceeds (Garb, 2004). Proved reserves are associated with a probability of 90 percent of getting exploited. The proved reserves are often referred to as the 1P reserves.

Proved developed (PD)
The proved developed are a subcategory of the proved reserves classification and can be expected to be operating through existing wells and with existing technology. Because the reserves are already producing they do not require major capital expenditures to continue producing (Garb, 2004).

Proved developed producing (PDP)
The proved developed producing reserves are those reserves for which the wells are drilled and completed and which reserves are currently being produced. These reserves have the highest value and have the lowest adjustment for risk when the reserves are evaluated.

Proved developed non-producing (PDNP)
The proved developed non-producing reserves are those reserves for which the wells are drilled and completed but which are currently not producing. This type of reserves requires no or little capital expenditure to be able to produce. A reason that the reserve is not producing may be for instance that the reserves are pending for better market conditions.

Proved undeveloped (PUD)
Another subcategory of the reserves are the proved undeveloped reserves. These reserves are expected to be recovered through the construction of a new well, deepening of existing wells or through the installation of improved recovery systems (Garb, 2004).

Probable reserves
Probable reserves are almost similar to proven reserves but they are less certain to be recovered and therefore lack the certainty to be classified as proved reserves. Probable reserves may even be in the same reservoir as proved reserves but due to technical difficulties cannot yet be exploited and therefore awaits technical developments. Reasons for this type to be more uncertain than proved reserves are often based on economic or regulatory uncertainties, which make their business case less viable and attractive. For purpose of reserve classification probable reserves have an associated probability of 50 to 90 percent for getting recovered (Warne, Campbell, Drury, Robertson, & Tutt, 1993). The probable plus the proved reserves together are better known as the 2P reserves.

Possible reserves
Possible reserves are quantities of petroleum reserves that are less certain to be recovered than proved or probable reserves. For purpose of reserve classification, they are associated with a 10 to 50 percent probability of getting produced (Warne et al., 1993). The term P3 reserve is used when referring to the total of proved plus probable plus possible reserves, hence all reserves.

Resources

Resources, instead of reserves, are oil reservoirs that are *not economically viable* or not yet economically viable to extract. The group of resources can be further divided in three sub-groups, namely contingent resources, prospective resources and unrecoverable resources. It is possible for resources to shift from the resources group to the reserves group when for instance new technologies are invented which makes the reservoir economically viable to extract.

Contingent resources
Contingent resources are reservoirs of petroleum that are potentially recoverable, but the applied projects are immature for the time being due to one or more contingencies, which make them economically unviable to extract (sub-commercial). These contingent resources may for instance include projects for which there is currently no viable market, or for which technologies still have to be developed to make them economically viable (World Petroleum Council, 2007). Contingent resources are again further categorized based their maturity, economic status and the probability of getting developed. These categories are known as 1C, 2C and 3C resources.

Prospective resources
The prospective resources are the petroleum reservoirs that are potentially recoverable from undiscovered resources. This means that they still must be discovered and are therefore associated with a chance of discovery and a chance of development. Prospective resources are also further categorized based on a level of certainty and associated with an estimate of getting discovered, in which a low estimate represents a higher level of certainty (World Petroleum Council, 2007).

Unrecoverable resources
Unrecoverable resources are a certain portion of discovered and undiscovered resources and reserves that are not recoverable by future development projects. A part of these resources may become recoverable in the future when

commercial circumstances change or technologies develop. The remaining part may never be recovered due to physical or chemical constraints (World Petroleum Council, 2007).

Shifting between reserve and resource status

When resources become economically viable to extract, the status of resources changes from resource to reserve. This may happen when for instance new technologies are invented, the cost of production is reduced, or the oil price is at a high level. In contrary, reserves may also shift from reserve to resource status when for instance the oil price is at a low level and remains at this level. Only when the price increases the resource again becomes a reserve. Hence, one of the most important factor regarding the classification is the economic viability of a reserve and if its able to profitably produce oil for the given market conditions. Figure 11 summarizes the previous in one figure.

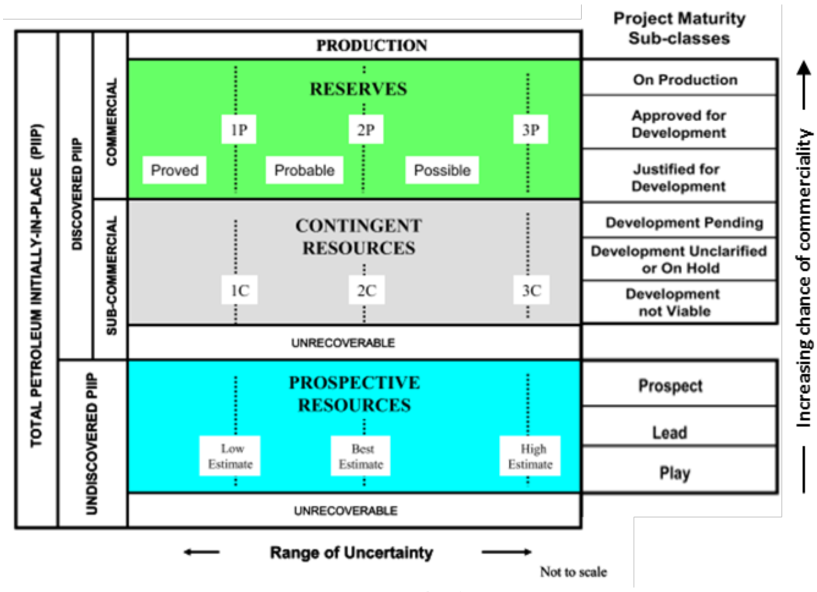


Figure 11 - Reserve classification

Why these classifications?

One of the reasons for this classification is that the reserves have a different function and value, both practically and financially. On paper, only the proved reserves and probable reserves (2P) have a monetary value and must be mentioned in financial reports. These reserves have a chance of at least 50% to get exploited and therefore must be accounted for. Of these 2P reserves, the sub-category, proved developed producing reserves have the highest value and the probable reserves the lowest. The possible reserves are not registered because their chance of production is not high enough to be accounted for.

There are two ways how the reserve value of oil companies can grow; the first is when the company finds oil, and the second is when the probability of extracting oil gets greater. So, without even finding oil the value of the reserve and therewith the company might increase when the probability of extracting oil increases.

Another reason is because the SEC demands aligned of methods used to report oil reserves so they are based on the same facts and figures. This makes it possible for shareholders to compare stocks. The SEC also checks the reports of the oil companies; thus, the classifications are strictly monitored and must be thoroughly substantiated by the oil companies to comply with the rules and guidelines of the SEC.

Focus on reserves

During this thesis, the emphasis lays on the valuation of reserves instead of resources. The reason for this focus is because resources are not often used for investment decisions since they are not yet economically viable. Thus, there is no point of valuing the reserves for investment decisions because it is already known that they are not viable. Only when the resources become reserves they make a possible business opportunity and then they get assessed and valuated for possible development. However, these resources do get monitored based on estimates of their breakeven cost of production, to determine when the time has come that the resources become reserves and investments are considered.

3.2 The analytical breakdown of the value of oil reserves

The previous paragraph explained the different type of resources that can be valuated as well as the motives of reserve valuation. This paragraph focuses on the factors that influence the value of oil reserves. To be able to do so, the valuation methodology must be closer examined on an analytical and structural way to determine which factors influence the value of the reserves. The content of this paragraph is based on a literature review and on interviews with experts serving the industry regarding the developments in the oil sector (Hans and Eric) and the valuation of oil reserves (Mark, Maarten and Remco). The highlights of the interviews can be found in appendix A_1.

What determines the value of an oil reserve?

Oil companies invest in and exploit oil reserves because oil reserves generate a cash flow that is created by the crude oil that is produced from the reserve and sold against the market price. Hence the cash flow or in other words 'revenue' is generated by the oil price (P) and the quantity of oil (Q) that is being sold. This cash flow minus the costs (C) associated with the production of the quantity of oil reflects the net benefit for the company of investing and exploiting the oil reserve at this moment. When a future cash flow is considered, then the cash flow gets discounted into a present value of the size of the cash flow, hence the timing (T) is important as well. This analytical approach to the value of oil reserves can be displayed by the following generic equation:

$$Net\ benefit = (Price * Quantity - Costs) * Timing$$

This equation can be translated into the following influence diagram (figure 12) where the value of the oil reserves is influenced by the *oil price* for which the oil is sold, the *production profile* that represents the quantity of oil that can be extracted and sold, the *costs* associated with the extraction and the *timing* when the activity takes place. The following sections will further breakdown these four components that influence the value of oil reserves.

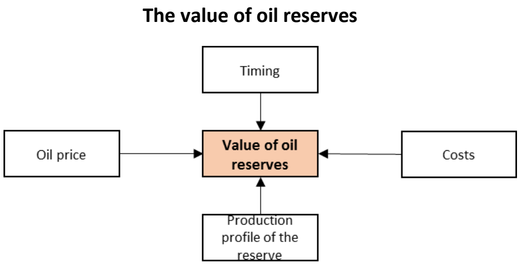


Figure 12 - The value of oil reserves

The oil price

One of the complexities of the oil industry is the fact that the oil price is established in the market. Which has as a consequence that oil companies are not able to or can only slightly influence the price of oil. Hence companies have no choice but to sell their oil to the market price. The main factors that influence the oil price are the *supply* and *demand* on the market (Hamilton, 2009). The balance between the supply and demand determine whether there will be an under- or oversupply with respectively increasing and decreasing prices as a result. The supply and demand in the market are the long-term drivers for *the oil prices* (Baumeister & Kilian, 2016a). The oil supply is the result of the total *number of producing reserves* multiplied by the *production rate of the reserves* and complemented by the *stored reserves*. Whereas the demand is established by the *size of the market* multiplied by the *oil consumption of the market*. Besides supply and demand there are more short- to medium-term factors that influence the oil price. These factors are; *speculation* in the market, *exchange rates* for companies using currencies other than the Dollar and to some extend by *OPEC* and their agreements regarding production quotas. The previous is schematically depicted in figure 13.

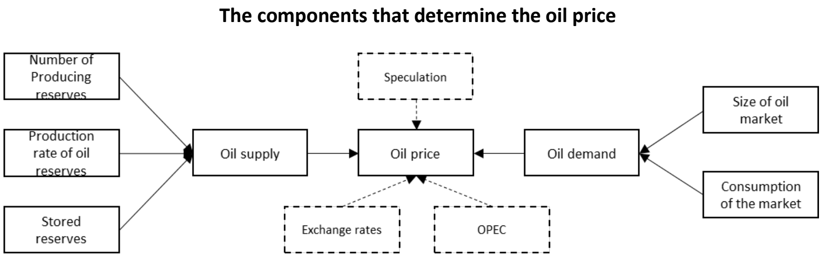


Figure 13 - The components that determine the oil price

The supply side

The entire supply side of the market is dependent on the market conditions. This includes the current market conditions, as well as the forecasted conditions. The supply side of the oil market is the result of the total *number of producing reserves* multiplied by the *production rate of the reserves* and complemented by the *stored reserves*.

Number of producing reserves

The *number of producing oil reserves* can be increased or decreased. The increase occurs through the *development of new oil reserves*, and the decrease through reserves that are facing *downtime*, are *mothballing* or are being *abandoned*. The increase of the number of producing oil reserves through the *development of new oil reserves* is in turn dependent on other factors. These factors are the *size of the resource base*, *investments in the oil sector* and *new exploration projects*. When additional capital is invested in the oil sector, more new projects can and will be developed. The *size of the resource base* influences the number of projects that can still be developed. Hence, more resources available increase the number of possibilities for the development of new resources, which may also increase the amount that will be developed. A decrease in the number of producing reserves due to downtime and mothballing may be evoked by bad *market conditions*, heavy *weather conditions*, *conflicts* and *maintenance*. *A*bandonment of reserves is most often due to the *depletion of the reserve* as the result of the production from the reserve and due to changing *market condition,* when for instance the oil price remains at a low level, then certain projects may not be profitable anymore and prematurely ended.

Production rate of the reserves

The *production rate of the reserves* is in some form dependent on the market conditions of the sector, logically bad market conditions should result in lower production rates, however during the oil price slump in 2014, 2015 and 2016, the reserves and companies where all maximizing their production to produce higher volumes to regain some of the lost profits inclined by the low oil price which in turn put even more pressure on the oil price. During this period of low oil prices *competition between oil producers* increased which affected the production rate and resulted in a *market share driven policy*. The market share driven policy sustained until OPEC intervened and implemented *production quota's* for the oil producing countries. Other factors that influence the production rate of the reserves are *geopolitical stability* and *(climate) regulation*. In countries that are more stable, the oil producers are able to produce more oil than countries that are less stable. Countries like Iraq, Syria, Nigeria and Iran have suffered from the local *conflicts* and international oil embargo taken against them in case of Iran these conflicts may have two results; or they may fully set of the production of oil and create downtime, or the production rate is reduced because they cannot operate at full capacity. Climate regulation may also have severe influence on the production rates of oil producers because new forms of regulation will be aimed at decreasing the total supply of oil to reduce the emission of GHGs.

The stored reserves

Another way how oil reserves add to the supply of oil is when they are stored and come to market. The amount of stored reserves is dependent on the *storage capacity* of midstream oil companies and the *market conditions*. When there is an *oversupply* in the market, the amount of reserves that are stored will increase. This oversupply is dependent on the market conditions such as the oil price and the competition in the market and the policies of the oil producing countries.

The demand side

The long-term *demand* of market is the product of the *size of the market* and the *consumption rate of the market*. The demand is in the short-term influenced by the *exchange rates* of different currencies and the *current oil price*.

The size of the market

The *size of the market* is influenced by three factors, the size of the *world population,* the *global economy* and *substitute products*. A growth in population means a growth in the global oil demand because the additional people need energy and oil to live and move around. The same holds for the *global economy*, when the economy grows, the demand for oil grows as well because of the additional economic activity, however the correlation between the growth in economy and the demand for oil starts to weaken due to an increase in sustainable growth of the economy and efficiency gains caused by technological advances (increasing fuel efficiency, electric transportation, digitalization). The global economy is also dependent on the *growth of developing countries*, which is currently influenced by the *global recession*. *Substitute products* reduce the size of the oil market. Examples of substitute products are *renewable energy*, *natural gas*, *electric vehicles* and *hydrogen fuels*. Some of these substitutes such as electric transportation are currently really trending and have the ability to vastly decrease the demand for oil.

The consumption rate of the market

The consumption rate of the market is closely linked to the *global prosperity*. An increasing *global GDP* and better *living standards* increase the global prosperity which makes it possible for more people to buy a car, travel to distant places and increase their demand for energy and oil. Hence increasing *living standards* are associated with an increase in the *consumption rate of the market*. Although the global prosperity is slowly increasing there are factors as well that decrease the demand for oil. These factors are mainly technological and social based developments. One of the most important factors that decrease the demand for oil besides substitute products is the increase in end-user efficiency. Efficiency gains in the form of fuel efficiency or industry efficiency have a large impact on the demand for oil. Other forms that reduce the consumption rate of the market are an increase in *environmental awareness* through education and information and an increase in *social behavior*. Social behavior has two different forms, one is the more technical based form that is represented by for instance resource-sharing or ride-pooling. The new era of digitalization increases the possibility of ride-pooling and the sharing of for instance decentralized wind turbines or solar panels, the other form of social behavior is again environmental awareness; people will only adopt certain forms of social behavior such as ride-pooling when they have a certain level of environmental awareness.

The production profile of the reserve

The production profile of an oil reserve is determined by the *quantity of oil* that can be produced from the reserve, and the *production rate* with which the oil can be extracted. The absolute quantity of oil that is stored in the ground is of course predetermined, however, the value of the reserve is based on the estimated size of the reserve and the *producible fraction this volume*, which makes the volume dynamic. *The volume of oil* that is stored in the ground might increase since it remains very hard, on geotechnical grounds, to accurately scan and map the volume of the reserve. When additional capital is invested in more accurate measuring systems, then the size of the reserve can be more accurately calculated, which might increase (or in worse case decrease) the size of the reserve as well as the value.

The amount of oil that can be produced effectively from the reserve can also change due to for instance the implementation of new enhanced oil recovery production technologies. When the production technology is enhanced, the quantity of oil that can be effectively produced from the reserve increases and therewith the production fraction increases as well. The growth of a reserve as the result of better geotechnical measurements or the enhancement of oil recovery technologies is called “reserve growth”. Reserve growth is among the main causes of a growing resource base (Maugeri, 2012). In return, the oil that is produced from the reserve diminishes the producible quantity. On the other side, the *production rate* is dependent on the *capacity of the production unit* that is installed and on the *pressure in the reserve*. A larger capacity production capacity means more extraction but a larger capacity is associated with a faster decline in pressure and a decline in pressure in reserve will negatively affected the production rate. The production profile of the reserve is schematically depicted in figure 14.

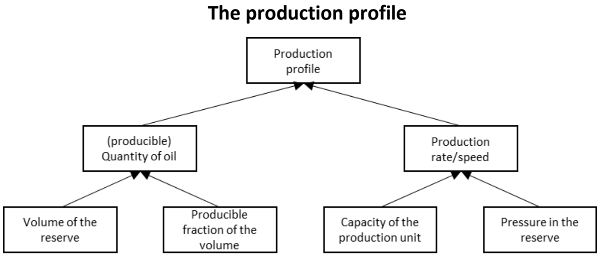


Figure 14 - Production profile

The costs

The costs that are associated with the value of the reserve can be divided into five categories (table 14). First, one of the main costs for oil companies is the *government take*. The government take are mostly *taxes* such as *petroleum revenue tax*, and possibly in the future a *carbon tax* and *royalties* that must be paid. A form of royalties are for instance the oil leases which grants the oil company the right to produce oil from the reserve. Second are the exploration and appraisal costs. These are the costs for the entire exploration and appraisal phase of the oil reserve. These exploration and appraisal costs are to a large extent dependent on technical factors such as the location and depth of the reserve and whether oil is found during the exploration that can be economically extracted. This is reflected in the *exploration risk* and is dependent on the *technical-* and *commercial risk*. Third are the capital costs, which are influenced by the *production design*, and the *construction costs* for building the production facilities, infrastructure etc. In the production design, again the *location of the reserve* and the *size of the reserve* have a high impact on the costs together with the *production technology* which can be onshore, offshore, shale etc. The fourth source of costs is made during the production and is reflected in the *production costs*, which are the costs for physically extracting the oil from the ground. These production costs have as largest sources cost the cost of extraction and the transportation cost. These both processes can be made more efficient by supply chain efficiencies, which may have a large positive effect on the production cost. Downtime caused by conflicts, maintenance or weather conditions can have a large negative effect on the production cost.

The last costs are the abandonment or decommissioning costs. When the oil reserves are fully exploited and further production is not economically viable, then the field gets abandoned and the production facilities removed. The level of cost depends mostly on the technology of the reserve (onshore, offshore, shale, oil sands etc.), which is represented in the *type of the facility* and the size *location of the facility*. In most projects third parties such as contractors are involved, hence their *cost* and their *profit margin* also influence the total cost. In times when oil prices are low, their profit margin is often strongly reduced through new negotiations and contracts. The five main sources of cost are depicted in figure 15.

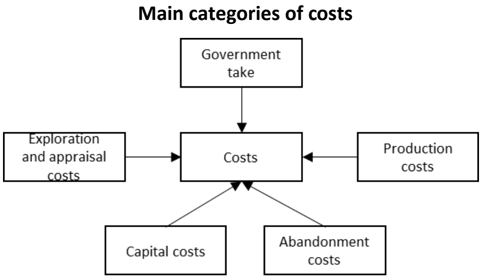


Figure 15 - The five main categories of costs

The timing

The timing of the production (figure 16) influences the value of the reserve due to the time value of money, which implies that a cash flow at this moment is worth more than the same cash flow in the future. This theory is because inflation decreases the value of money over time, and money that is available at this moment can be invested in other projects that will generate a return on the invested capital (Fama & French, 2004a). Hence money or capital has a price itself. This is reflected in the *cost of capital* of the company. The cost of capital is in a simplified version of the system influenced by the *inflation rate*, the *interest rate* the *credit rating* and *risk exposure* of the company. The risk exposure also contains the geopolitical and operational risk. Other factors are important and influence the timing of the reserve as well. These factors are the *exchange rates* of different currencies and the *sentiment of traders*, which can have a significant effect on prices or forward curves and have the ability to increase or decrease the outlook and projections for the entire project.

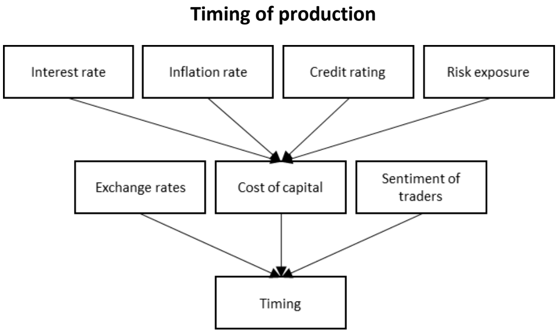


Figure 16 - The timing of production and cash flows

The result from the analytical breakdown

The analytical breakdown in the previous sections has broken down the value of oil reserves in a structured way. The system can be further broken down into more components that influence the value of oil reserves at even lower levels. The system that is created shows how the value of an oil reserve is dependent on a wide range of factors. Among these factors are factors that are shaped by the oil market such as the oil price and supply & demand, and reserve specific factors such as the production profile and the costs. Of the four main factors; oil price, production profile, costs and timing, the oil companies have the least control over the oil price, while the oil price has a significant influence on the value of the reserves. The more factors the system contains the more complex it is to capture the value of the reserves. The next section continues on the valuation of oil reserves and explains the methods that are used to further determine the value of an oil reserve. Figure 17 on the next page summarizes the previous in one schematic overview in which some but not all of the previously explained factors are included. Figure XL on page 41 shows the entire system including current some current events.

Schematic overview of the analytical breakdown of the value of oil reserves

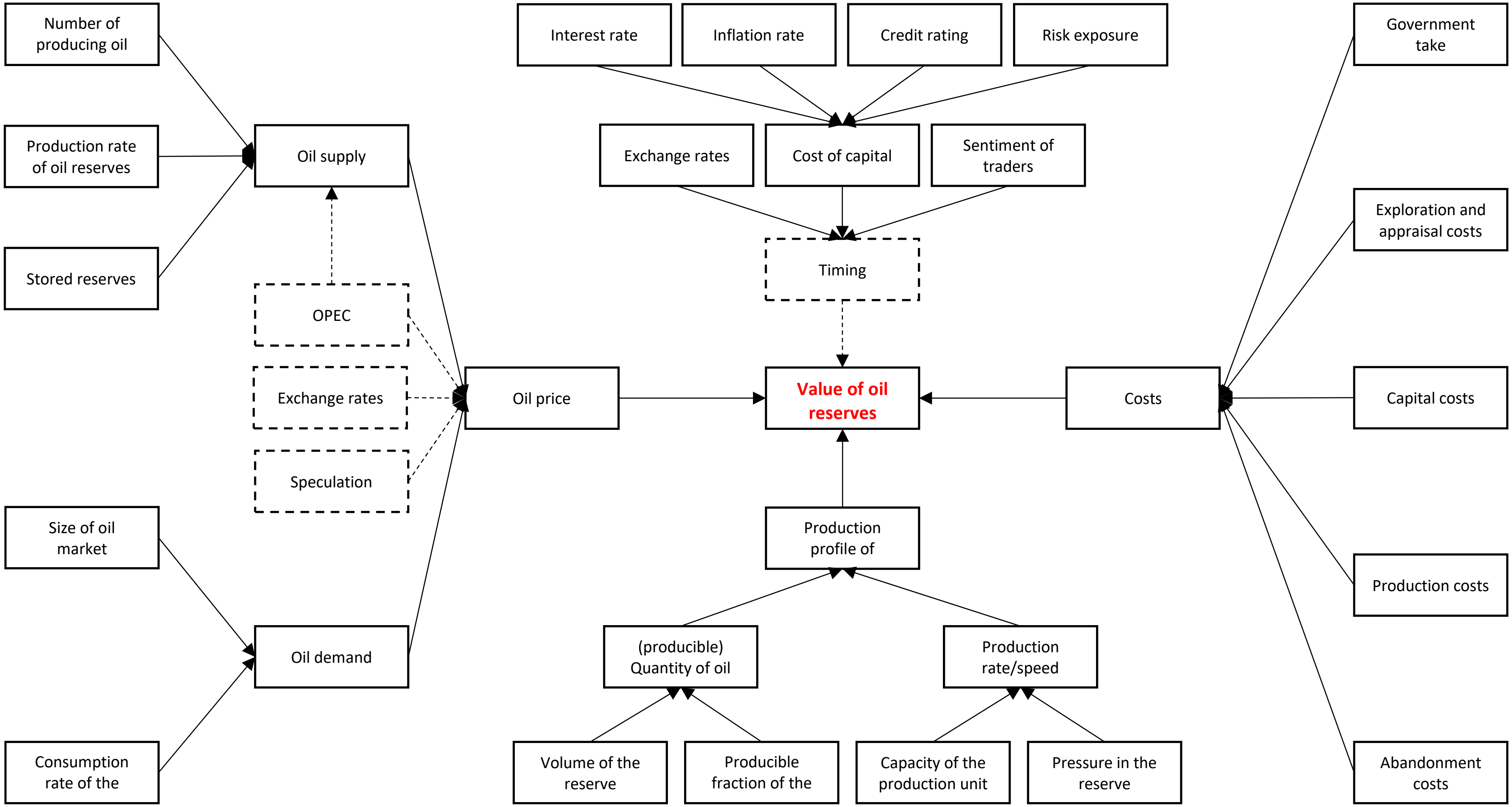


Figure 17 - Schematic overview of factors influencing the value of oil reserves

3.3 The valuation of oil reserves

Many oil projects are characterized by very high upfront capital expenditures and long project lifetimes. These characteristics make it important to closely analyze a potential project before investment decisions can be made. Hence effective capital budgeting is an important aspect when developing large capital oil projects (Preiss, Burcham, & Farrel, 2014). During the process of capital budgeting, managers make decisions regarding the reserves they should exploit, or in which projects they must invest. The managers associated with the capital budgeting have the goal to distribute the capital and cash as efficient as possible among the different projects to generate the highest return on the money invested (van Kessel & Kadre, 2015). The potential returns of the project are calculated as accurate as possible, to be able to determine in which projects they must invest.

The valuation of reserves is slightly different from the valuation of companies. Valuation of companies can occur via three methods; the income approach that estimates the value of future income, the asset approach that establishes the net fair market value of the existing assets, and the market approach which uses data gathered from similar companies and base the value on valuations of these companies. Valuing oil reserves is different from valuing companies because the value of a reserve is primarily based on the underlying oil that can be produced. Hence, the market approach cannot be used since oil reserves differ too much in characteristics such as size, technology, quality of oil, location, fiscal regime etc. And, the asset approach does not suffice since the value of the physical assets such as drilling rigs, pipelines etc. are too small compared to the value of the underlying oil. Therefore, oil reserves are valuated based on the income approach by estimating the future cash flows that go in and out of the project (Bryan, 2012). These cash flows are captured in a value using the Discounted Cash Flow method.

Discounted Cash Flows and Net Present Values

For several decades the most common and traditional way of valuing oil reserves has occurred by means of the Discounted Cash Flows (DCF) and Net Present Values (NPVs) (Dias & Antonio, 2004). The monetary value of the oil reserve is calculated using the projected production of the expected life of the project (Veldhuizen, Graveland, & Bergen, 2009). These cash flows are created by the income and costs associated with the extraction of oil during the expected life of the project (Bailey, Couët, & Bhandari, 2003). The DCF methods discount all future cash flows that go in and out of a project into one present value for all cash flows by using the Net Present Value (NPV) rule. Determining the NPV of an oil reserve, requires the determination of the net cash flows (C) which are generated by the extraction and selling of oil (C_{in}) for each time period (t) of the reserves productive life and the cost associated with the process of extraction and selling (C_{out}). The net cash flows are then discounted using a discount rate (r) which represents the cost of capital and the risk exposure of the project (Knull, Jones, Tyler, & Deutsch, 2007) Using a discount rate implies that the later revenues arrive, the less they are worth today because they are discounted by the discount rate. The formula to calculate the NPV summarizes the above.

$$NPV = \sum_{t=0}^{n} \frac{C_t}{(1-r)^t}$$

The next section will focus on how the size of the cash flows is estimated to be able to fill in the formula. The knowledge from the analytical breakdown of the previous paragraph will assist in providing insight how this process works.

The size of the cash flows

The positive cash flow (income) in an oil project originates from the extraction of oil from the reserve, which is sold in the oil market for the market price. Hence the quantity of oil and the price of oil determine the size of the incoming cash flow. The out going cash flow is the result of the costs associated with the extraction of the oil during the entire life cycle of the project, from exploration till abandonment. This brings the calculation of the net cash flows down to a simple formula:

$$Net\ cash\ flow = \sum C_{in} - \sum C_{out} = (Price * Quantity) - Costs$$

Estimation of the production profile of the reserves (Q)

The size of an oil reserve remains uncertain even with state-of-the-art technologies and during the production phase of the reserve. It has happened numerous times that the oil reserve turns out to be much larger than expected, and vice-versa (Klett, 2015). The estimation of the volume of oil occurs using probability intervals that contain the chance of extracting a certain amount of oil. The intervals contain a P90, P50 and P10 case regarding the volume of the reserve (Garb, 2004). These estimations are based on geotechnical research using seismic measurements of the ground structures and advanced calculations of the chance, volume, quality and the producible fraction of the volume of the reserve (Garb, 2004). The result of these calculations and estimates is a profile of the reserve with its associated volumes and the probability of extracting these volumes. This profile of the reserve has to be converted to a production profile that is able to estimate and forecast the quantity of oil that can be produced from the reserve on an annual basis. The more accurate this profile is estimated the more accurate the valuation will be because the cash flows are dependent on this production of oil according to this profile and thus reflects the quantity of oil that can be produced and sold. One of the most important variables in this conversion is the estimation of the production rate of the reserve. The process of determining the production profile is associated with many uncertainties because it is dependent on the characteristics and behavior of the reserve, which in many cases is uncertain. A simplified example of a production profile can be found in figure 18 below and is adopted from Höök, Davidsson, Johansson, & Tang, (2014). In this production profile, the plateau represents the maximum capacity of oil that can be produced at a certain time period (year). The length of the plateau (and the entire profile) over the time axis is among other variables dependent on the volume in the reserve. There are multiple scenarios possible for the production profile; these scenarios are dependent on the different estimates of the volume based on the probability levels (P90, P50 and P10), the installed production capacity and the pressure in the reserve. An increase in the volume of the reserve will result in a longer or higher plateau or decline (tail), dependent on the maximum installed production capacity and the pressure.

Estimation of the oil price (P)

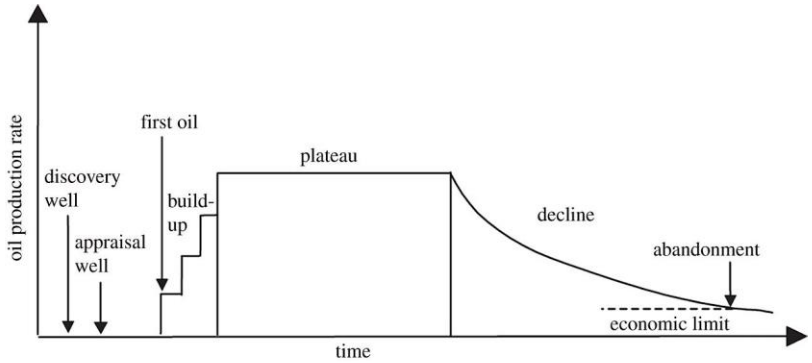


Figure 18 – Simplified production profile of oil reserves (adopted from Höök et al. (2013))

After the production profile of the reserve is estimated, then the incoming cash flow can be calculated by multiplying the annual quantity of oil from the production profile by the oil price. However, the oil price is a complex and dynamic mechanism that is dependent on many uncertain factors as can be seen in figure 17. This characteristic makes it impossible to accurately predict future oil prices. People and companies try to understand the behavior of the oil price and make forecasts of future prices, their predictions turn out to be unreliable and in most cases wrong. This can be reflected in the fact that almost no company or individual saw the current oil price slum coming. Even though the price cannot be accurately predicted, oil companies and financial institutions make forecasts to determine the future cash flows and therewith the value of a reserve. These forecasts are mainly based on factors that have a long-term impact on the oil price such as supply and demand (Eckbo et al., 2016). Supply and demand can be more accurately predicted and the balance between supply and demand is the driving force around the oil price. Focusing solely on supply and demand has as advantage that they exclude short time volatilities inflicted by speculation and other short term drivers (Hamilton, 2009), however, this will make the forecast not representative for daily oil prices but only for long-term prices such as yearly averages. Oil companies and financial institutions make and use these forecasts to publish forward curves of the oil price, which they use to calculate the value of the reserve.

Estimation of the cost associated with the production of oil (C)

The product of the production profile of the reserve and the forward curve of the oil price is an estimate of the positive cash flow (income) of the project. This positive cash flow does not incorporate the costs that are made during the entire lifecycle of the project. The costs have to be subtracted from the income of the project to determine the net cash flow or profit.

During the lifetime of an active reserve there are five phases, as is explained in paragraph 2.1, which an oil company must go through to be able to fully exploit the reserve. Each part of the lifecycle is associated with its own costs. The main sources of costs are explained in the paragraph 3.2. When all the costs associated with the exploitation of the reserves are estimated then the out going cash flow can be determined.

The discount rate

The discount rate is the rate to which cash flows should to be discounted in order to incorporate the risk of the investment and the return that could have been made with alternative risk-free investments. The risk-free investments represent the time preference of money, in which available cash now is more preferred than the same amount of available cash in the future because with the cash that is available now, returns could have been generated which increases the value of the cash in the future. The risk of the investment represented by the risk premium reflects the extra return that investors demand because they want to receive compensation for the additional risk to which they are exposed because there is a chance that the money invested will never be paid back when a risk materializes. Hence, cash flows should be adjusted for the additional risk since the additional risk should be compensated by higher cash flows.

What follows from the previous is that it is financially most attractive to extract the oil as quick as possible from the reserve when considering similar market conditions because it will increase the amount of cash received now instead of the cash received in the future. Moreover, higher levels of risk that are taken with a certain project result in a higher discount rate and decreases the value of the reserve (Alessandri, Ford, Lander, Leggio, & Taylor, 2004).

The limitations of DCF

DCF is the most ideal and accurate method to valuate oil reserves since it is able to quantify all cash flows; therefore it is widely used in accounting and reporting of the monetary value of reserves. However, there are limitations regarding the use of DCF when looking at the future. The main limitation of DCF according to Wang & Halal, (2010) and Bailey et al., (2003) is the fact that DCF assumes that cash flows are predictable and deterministic while in practice it is often difficult to accurately estimate future cash flows due to the uncertainties surrounding these cash flows.

In the phase of investment appraisal for capital projects, many uncertainties exist because the future outcome of the investment decision is uncertain as information is incomplete at the moment the decision is made and information will change during the execution of the project (Verbeeten, 2005). Therefore, Courtney, Kirkland, & Viguerie (1997) suggest that when the uncertainties rise and the investment decision is affected by those uncertainties, then managers are advised to emphasize more on qualitative analysis tools. To strengthen the point of Courtney et al., (1997), Lander & Pinches (1998) found out that quantitative valuation methods such as DCF and Real Options are limited in accurately valuing reserves with many uncertainties. Lander & Pinches, (1998) acknowledge that the quantitative tools should be useful as the basis of the valuation of oil reserves but that they should be enhanced with qualitative analyses. Moreover, in support of Courtney et al., (1997) and Lander & Pinches (1998), Alessandri (2003) found in an empirical study that managers prefer to use more analytical and quantitative approaches, but in situations when the uncertainties increase they tend to emphasize on the use of qualitative tools. Alessandri et al., (2003) suggest that traditional quantitative tools need to be expended or added with qualitative tools under conditions with high uncertainty. In these situations the quantitative method can provide the framework for defining, structuring and analyzing the project under uncertainty and the qualitative methods provide the insights in the situation (Alessandri et al., 2004).

Other valuation methods as an addition to DCF

The previous section suggests that another methods should be used in addition to the DCF method. There are two other renowned methods that are capable of assigning a monetary value to oil reserves. These valuation methods are scenario planning and real options. This section will briefly describe both methods and determine which method suits best to function as an additional tool for the valuation of oil reserves given the developments that are explained in chapter 2.

Scenario planning and impact analysis

Scenario planning or scenario analysis is a valuation approach that has a more qualitative character than DCF. Scenario planning is most often used when variables of a quantitative model are not easily quantifiable and involves the creation of coherent scenarios about possible futures of the variable. The goal of the scenarios is to identify and evaluate the impact, trends and opportunities that are associated with the scenarios (Alessandri et al., 2004). Scenario planning is often used in combination with impact analysis, because the cause of the development of the scenarios is often to determine the impact of the scenarios on a firm (Amer, Daim, & Jetter, 2013). The scenario planning technique was originally developed by Royal Dutch Shell and was utilized within the firm to generate plausible scenarios of the future and to define mitigating strategies to be able to cope with the situation when the scenario materializes (Rounsevell & Metzger, 2013). The process of scenario planning involves the formulation of scenarios of the future, which are based on developments in the market and the environment of the company, and the formulation of alternative strategies that reduce the impact of the scenarios on the company of which the scenarios are made (Postma & Liebl, 2005).

Real options

Through the years an increasing number of scientists and organizations have been experimenting with alternative valuation methods that are better able to cope with uncertainties to overcome the shortcomings of the DCF approach (Suslick, Schiozer, & Rodriguez, 2009). Many scientists where under the opinion that DCFs undervalues projects because DCFs do not take managerial options and policies into account. This has led to the Real Option Analysis (ROA). ROA is a valuation tool that originates from financial options. Financial options give the owner of the option the right but not the obligation to buy the underlying asset at a certain exercise price on a designated date (Wang & Halal, 2010). These financial options made it to the evaluation of real assets, such as oil reserves, hence the name Real Options was imposed.

The real option approach is based on managerial uncertainty for which it evaluates the underlying reserve given some uncertainties and managerial options to comply with the uncertainties (Dias & Antonio, 2004). These managerial options that are imposed by ROA are considered to make the analysis tool more flexible than DCF (Zettl, 2002). The flexibility originates from the fact that managers can intervene in projects in ways that add value over time. DCFs do not take these flexibilities into account and therefore projects analyzed using DCFs under valuate the projects real potential. In DCF models an increase in risk is directly associated with an increasing discount rate resulting in a decreasing valuation, which means that risk decreases the potential of the project (Costa Lima & Suslick, 2006). In ROA the contrary shows that if management is able to control the downside risk of a project, projects with a negative NPV should sometimes be undertaken, given the upside potential embedded in the project (Alessandri et al., 2004).

Although ROA is a good tool to account for some uncertainties, it focuses primarily on the interaction of management decisions on the value of oil reserves instead of the impact of the developments. Hence in the case of the upstream oil sector in a carbon-constrained world, ROA is not the preferred tool to use as an addition to DCF. Scenario planning in the contrary specifically focuses on scenarios in which future developments are analyzed and the impact of the scenarios is determined. Therefore, scenario planning in combination with impact analysis of the scenario may function as an additional tool to DCF, which would be the preferred method to use in in this situation.

Scenario planning and impact analysis as addition to DCF

The method that should be used as an addition to DCF should be able to capture developments in a carbon-constrained world and to determine the consequences and impact of these developments on the value of oil reserves. Since the developments are perceived to have negative effect on the value of oil reserves, the method should be able to determine the resilience of the reserves to the developments and to reduce the possible impact of developments on the reserves. Hence, multiple different scenarios of the developments must be formulated and their impact on the reserves should be determined. Thus, the additional method should be able to consider different scenarios of the developments and determine the impact on the reserve.

Currently, oil companies use scenario planning to explore possible future scenarios. However, the method that is used in this research differs from the standard scenario planning because this method considers multiple possible scenarios and determines the consequences and impact of the different scenarios on the value of oil reserves. Thus, instead of fully analyzing one particular conceptual scenario as is carried out in scenario planning, multiple scenarios are analyzed on their impact. Hence, this method is a mix between scenario planning and impact analysis of different scenarios. Such a mix between scenario planning and impact analysis is referred to by Hiete, Merz, & Schultmann, (2011) and by Seppelt, Lautenbach, & Volk, (2013) as 'scenario-based impact analysis'. Scenario-based impact analysis in this case provides information of the impact of selected scenarios on the value and risk level of oil reserves in a carbon-constrained world. Using scenario-based impact analysis makes it possible to determine the value of oil reserves for different future market conditions. Therewith embracing the uncertainty using a qualitative identification method while at the same time limiting the amount of uncertainty by the formulation of specific scenarios. The goal of the scenario-based impact analysis is to determine the risk for different type of oil reserves in a carbon-constrained world, based on different scenarios of the developments, and to incorporate the impact and risk associated with the carbon-constrained world in the value of oil reserves.

3.4 Integration of the developments and the valuation methods

This last paragraph of the conceptualization phase focuses on the integration of chapter 2 and 3 by reflecting on the findings from both chapters to conclude the conceptualization phase. First, we reflect on the developments that occur in a carbon-constrained world, as explained in chapter 2 and second on the valuation of oil reserves. Thereafter both are integrated and the added value of the research is more clearly defined. Last, the findings from chapter 2 and 3 are presented in one overview that will be used throughout this research.

The developments in a carbon-constrained world

Chapter 2 has shown that changes in the current course of action should be made if the world wants to achieve the goals that are set at the Paris Agreement. These changes will trigger several developments in the oil sector that are the result of governments that will actively address climate change. The developments that will take place in a carbon-constrained world are climate policies and regulation formulated by governments, a declining oil market and demand for oil and increased competition and lower oil price. These developments will play a central role and are considered to be the main developments.

The developments reflect a rational vision of what may happen when climate change is actively addressed. Although the developments are scientifically grounded, the precision of this vision can be argued since it reflects the most likely course of events based on current scientific knowledge and political ambitions. But it does not reflect a scenario that is certain to occur. Hence, in reality there are many more scenarios possible that are derivatives of the developments or entirely different scenarios.

This implies that there are uncertainties surrounding and captured in the developments. These uncertainties cannot easily be captured in the current quantitative valuation models based on discounted cash flows. Hence, the standard quantitative DCF approach should be enhanced with a more qualitative approach to gather insights of the developments and to draw conclusions from the consequences of the developments on the reserves.

The value of oil reserves

When focusing on valuing oil reserves and the methods that can be used to value oil reserves it becomes evident that the valuation of reserves is very complex. Paragraph 3.2 and 3.3 have clarified that there are many factors that influence the value of reserves, and many of these factors depend on the judgment and estimation of the valuator for determining a value. However, since the value of a reserve is by definition a quantified concept these judgments and estimations are important in valuation to come to a quantitative value of a reserve.

There is excessive scientific literature regarding the implementation and use of valuation methods and approaches to determine such an exact, quantitative value for a reserve, but there is not much literature that integrates different methods and approaches to cope with the developments in a carbon-constrained world. Hence, the more uncertainty increases due to the developments in the market the more the current methods and approaches start to fail in accurately assigning a monetary value to reserves. This leads to the situation in which some of the judgments and estimations reach a critical point that they get inaccurate and cannot be quantified anymore, hence solely a quantitative approach does not suffice.

Integration and added value of the research

The developments in a carbon-constrained world are by some scientists perceived to be certain to happen when certain decisions are made and climate change is actively addressed. However, the developments remain conceptual and are surrounded by lots of uncertainty. These developments demand an extension of the current valuation methods with a qualitative approach. But, on the other hand when valuing oil reserves, clear quantified concepts are necessary to determine the value of reserves. These two different perspectives imply a mismatch between the methods that can be used.

The added value is the integration of the future developments in the valuation method to bridge the gap between the uncertainty surrounding the developments in a carbon-constrained world demanding a qualitative approach and the quantitative nature of oil reserve valuation. This integration is carried out using the theories and methods behind the quantitative valuation methods in order to determine the effects of the developments on the value of oil reserves and on the way in which the valuation method should change in a carbon-constrained world. In this approach, the assumption is made that the world will actively address climate change to stay within the 2°C margin for global warming to limit some of the uncertainties.

Integration of the developments and the valuation methods in figure XL

Figure XL on page 41 is the first step in bridging this gap by schematically summarizing the content of chapter 2 and 3. Figure XL is based on the analytical breakdown and the valuation methods, which are carried out in paragraph 3.2 and 3.3. The methods used to compose figure XL are a literature review (references are included in chapter 3.2 and 3.3) and interviews with experts serving the oil and gas industry. Figure XL shows how at the left side market developments and supply & demand affect the oil price. Likewise, the right side of the figure shows how reserve specific factors such as the production profile, the cost and the timing influence the value of an oil reserve.

Reflection of the developments in a carbon-constrained world in figure XL

The developments that are identified in chapter 2 have their consequences for the value of oil reserves. The influence of the developments on the value of oil reserves is important for determining how these developments change the way in which oil reserves should be valued because the influence on the value should be corrected in the valuation method. Therefore the next sections take a first step in determining the effects of the developments on the value of oil reserves using figure XL.

Regulation

When reflecting the regulatory developments of chapter 2.2 on figure XL it shows that increasing regulation can have multiple effects on the value of oil reserves. As chapter 2.2 stated that regulation can be implied on the supply side in the form of a tax and on the demand side in the form of a subsidy. The tax at the supply side has, two implications; first, it increases the costs associated with the exploitation of the reserve by increasing the government take, and second, environmental regulation may decrease the production rate of oil reserves (see figure XL). The decreased production rate may be due to the higher cost or even due to the prohibition of the exploitation of certain reserves depending on the severity of the implied environmental regulation. Regulation at the demand side has other effects, it focuses on stimulating the factors that decarbonize the economy by means of subsidies. These subsidies will aim on increasing the deployment of substitute products for oil, increasing the end-user efficiency and increasing the social behavior in order to decline the oil market. Hence there exist a causality and relation between the 'regulation development' and the 'declining oil market developments' because regulation aims on stimulating the declining oil market according to the goals from the Paris Agreement.

Declining oil market

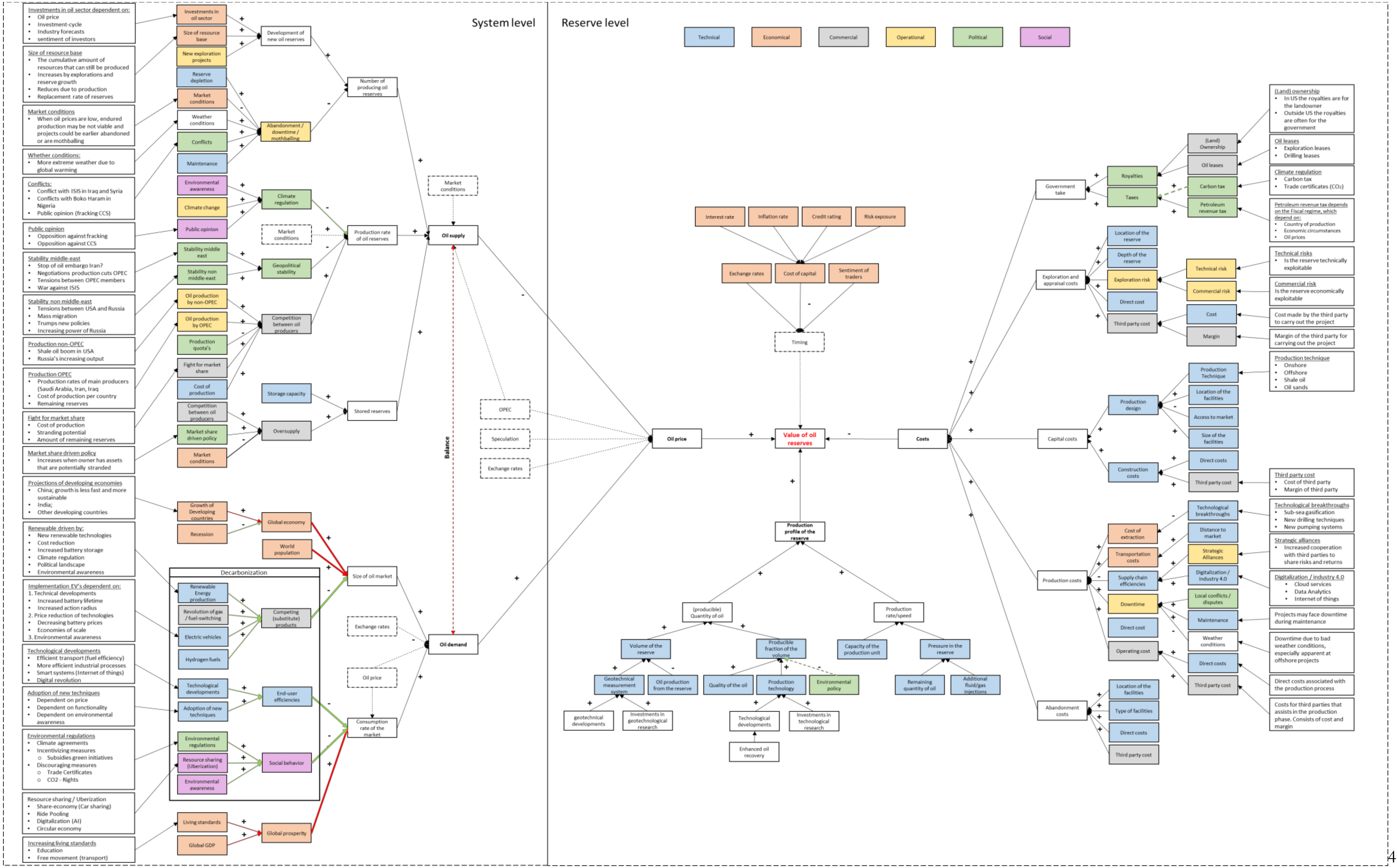
The market and the demand for oil should decline in a carbon-constrained world to be able to meet the goals of the Paris Agreement. Figure XL shows how the decarbonization movement has an impact on the value of oil reserves through a reduction of the demand for oil. Hence, the decarbonization movement contains the factors that have a negative effect on the demand for oil such as substitute products, end-user efficiency and social behavior. If these factors are stimulated and have a higher impact than the demand increasing factors then the demand for oil will start to decline and the market will start to shrink. These demand declining factors that reflect the decarbonization movement have to cope with the demand increasing factors such as the growing world population, a growing global economy and increasing living standards. In a carbon-constrained world, new (clean) technologies that for instance increase the efficiency of fuel combustion engines or make large scale storage of energy possible but also increased environmental awareness should make the demand decreasing factors overpower the demand increasing factors resulting in a declining oil demand and hence in a reduction of the size of the oil market. Figure XL shows the factors that add to the decarbonization movement with green lines and the factors that counteract the decarbonization with red lines.

Increased competition and lower oil prices

The perspective of the carbon-constrained world implies that the market for oil and therewith the oil demand will decline in order to meet the goals formulated in the Paris Agreement. The declining market increases the competition between oil producers. Figure XL shows how competition in the market leads to an oversupply in the market resulting in a negative effect on the price for oil and on the value of the reserve. A low oil price directly influences the value of oil reserves as explained in chapter 3.2 and depicted in figure XL. Moreover, the oil price is dependent on the balance between the supply and the demand in the market; a declining market creates an environment in which the chance increases that oil prices will be lower. Especially when the supply is not adjusted to the perceived demand. Due to the long development times of new oil projects and the increasing importance of maintaining market share, imbalances between demand and supply can be hard to restore. This is also reflected by the current low oil price.

A more extensive analysis of some functions of the system can be found in appendix B. The next chapter, chapter 4, will dive deeper in the developments in a carbon-constrained world and operationalize the different developments.

Figure XL


System level
Reserve level
Technical
Economical
Commercial
Operational
Political
Social
Investments in oil sector dependent on:
Oil price
Investment-cycle
Industry forecasts
sentiment of investors
Size of resource base
The cumulative amount of resources that can still be produced
Increases by explorations and reserve growth
Reduces due to production
Replacement rate of reserves
Market conditions
When oil prices are low, endured production may be not viable and projects could be earlier abandoned or are mothballing
Whether conditions:
More extreme weather due to global warming
Conflicts:
Conflict with ISIS in Iraq and Syria
Conflicts with Boko Haram in Nigeria
Public opinion (fracking CCS)
Public opinion
Opposition against fracking
Opposition against CCS
Stability middle-east
Stop of oil embargo Iran?
Negotiations production cuts OPEC
Tensions between OPEC members
War against ISIS
Stability non middle-east
Tensions between USA and Russia
Mass migration
Trumps new policies
Increasing power of Russia
Production non-OPEC
Shale oil boom in USA
Russia's increasing output
Production OPEC
Production rates of main producers (Saudi Arabia, Iran, Iraq
Cost of production per country
Remaining reserves
Fight for market share
Cost of production
Stranding potential
Amount of remaining reserves
Market share driven policy
Increases when owner has assets that are potentially stranded
Projections of developing economies
China; growth is less fast and more sustainable
India;
Other developing countries
Renewable driven by:
New renewable technologies
Cost reduction
Increased battery storage
Climate regulation
Political landscape
Environmental awareness
Implementation EV's dependent on:
1. Technical developments
Increased battery lifetime
Increased action radius
2. Price reduction of technologies
Decreasing battery prices
Economies of scale
3. Environmental awareness
Technological developments
Efficient transport (fuel efficiency)
More efficient industrial processes
Smart systems (Internet of things)
Digital revolution
Adoption of new techniques
Dependent on price
Dependent on functionality
Dependent on environmental awareness
Environmental regulations
Climate agreements
Incentivizing measures
Subsidies green initiatives
Discouraging measures
Trade Certificates
CO2 - Rights
Resource sharing / Uberization
Share-economy (Car sharing)
Ride Pooling
Digitalization (AI)
Circular economy
Increasing living standards
Education
Free movement (transport)
Investments in oil sector
Size of resource base
New exploration projects
Reserve depletion
Market conditions
Weather conditions
Conflicts
Maintenance
Environmental awareness
Climate change
Public opinion
Stability middle east
Stability non middle-east
Oil production by non-OPEC
Oil production by OPEC
Production quota's
Fight for market share
Cost of production
Competition between oil producers
Market share driven policy
Market conditions
Growth of Developing countries
Recession
Decarbonization
Renewable Energy production
Revolution of gas / fuel-switching
Electric vehicles
Hydrogen fuels
Technological developments
Adoption of new techniques
Environmental regulations
Resource sharing (Uberization)
Environmental awareness
Living standards
Global GDP
Development of new oil reserves
Abandonment / downtime / mothballing
Climate regulation
Market conditions
Geopolitical stability
Competition between oil producers
Storage capacity
Oversupply
Global economy
World population
Competing (substitute) products
End-user efficiencies
Social behavior
Global prosperity
Number of producing oil reserves
Production rate of oil reserves
Stored reserves
Size of oil market
Exchange rates
Oil price
Consumption rate of the market
Market conditions
Oil supply
Balance
Oil demand
OPEC
Speculation
Exchange rates
Oil price
Interest rate
Inflation rate
Credit rating
Risk exposure
Exchange rates
Cost of capital
Sentiment of traders
Timing
Value of oil reserves
Costs
Production profile of the reserve
(producible) Quantity of oil
Production rate/speed
Volume of the reserve
Producible fraction of the volume
Capacity of the production unit
Pressure in the reserve
Geotechnical measurement system
Oil production from the reserve
Quality of the oil
Production technology
Environmental policy
Remaining quantity of oil
Additional fluid/gas injections
geotechnical developments
Investments in geotechnological research
Technological developments
Investments in technological research
Enhanced oil recovery
Government take
Royalties
Taxes
(Land) Ownership
Oil leases
Carbon tax
Petroleum revenue tax
Exploration and appraisal costs
Location of the reserve
Depth of the reserve
Exploration risk
Direct cost
Third party cost
Technical risk
Commercial risk
Cost
Margin
Capital costs
Production design
Production Technique
Location of the facilities
Access to market
Size of the facilities
Construction costs
Direct costs
Third party cost
Production costs
Cost of extraction
Transportation costs
Supply chain efficiencies
Downtime
Direct cost
Operating cost
Technological breakthroughs
Distance to market
Strategic Alliances
Digitalization / industry 4.0
Local conflicts / disputes
Maintenance
Weather conditions
Direct costs
Third party cost
Abandonment costs
Location of the facilities
Type of facilities
Direct costs
Third party cost
(Land) ownership
In US the royalties are for the landowner
Outside US the royalties are often for the government
Oil leases
Exploration leases
Drilling leases
Climate regulation
Carbon tax
Trade certificates (CO₂)
Petroleum revenue tax depends on the Fiscal regime, which depend on:
Country of production
Economic circumstances
Oil prices
Technical risks
Is the reserve technically exploitable
Commercial risk
Is the reserve economically exploitable
Cost made by the third party to carry out the project
Margin of the third party for carrying out the project
Production technique
Onshore
Offshore
Shale oil
Oil sands
Third party cost
Cost of third party
Margin of third party
Technological breakthroughs
Sub-sea gasification
New drilling techniques
New pumping systems
Strategic alliances
Increased cooperation with third parties to share risks and returns
Digitalization / industry 4.0
Cloud services
Data Analytics
Internet of things
Projects may face downtime during maintenance
Downtime due to bad weather conditions, especially apparent at offshore projects
Direct costs associated with the production process
Costs for third parties that assists in the production phase. Consists of cost and margin

PART III – Operationalization

‘The Stone Age did not end because of a lack of stones, so will the oil age end long before there is a lack of oil’

Sheikh Zaki Yamani (2000)
former minister of oil of Saudi Arabia

Introduction part III
The third part of this research, the operationalization consists of two chapters, chapter 4 and chapter 5. In chapter 4, the developments that are introduced in chapter 2 are further operationalized and the consequences of the developments are determined. The operationalization of the developments occurs by means of a desk research in which existing data and information is used as well as the interviews from part II. In chapter 5, the developments are incorporated in the value of oil reserves. The incorporation occurs through the translation of the three developments in characteristics of the reserves to be able to monitor the changes of the developments for the reserves (paragraph 5.1). Next, the scenario-based impact analysis is conducted using the characteristics and multiple scenarios of the developments to determine the impact of the developments on the reserves (paragraph 5.2). With the impact and the translation of the developments in characteristics the developments can be accounted for to determine the method of accounting for the developments in the value of oil reserves (paragraph 5.3).

4. Operationalization and consequences of the developments in a carbon-constrained world

This chapter, chapter 4, further operationalizes the developments that are identified in chapter 2. The operationalization of the developments is aimed on determining the consequences of the developments on the value of oil reserves. The insights regarding the valuation of oil reserves provided by chapter 3 and figure XL are used to determine the consequences of the developments. The methods that are used throughout this chapter are desk research based on data and literature regarding the oil sector as well insights gathered from the interviews. The focal question that is formulated and which will be addressed in this chapter is as follows:

'What are the consequences of the developments in a carbon-constrained world and how do they affect the value of oil reserves?'

Chapter 4 consists of 2 paragraphs. Paragraph 4.1 is divided in three sections that each operationalizes one of the three main developments that are identified in chapter 2. Paragraph 4.2 will emphasize on the consequences of the developments on the value of oil reserves. The developments that are identified in chapter 2 and will be used throughout this chapter are the following:

- Increasing environmental regulation
- Declining oil demand
- Increasing competition and lower oil prices

4.1 Operationalization of the developments in a Carbon-Constrained World

Environmental regulation

One fact that follows from the Paris Agreements is that governments will aim on staying within the carbon budget. But, companies are economically not incentivized to reduce their emissions and to implement sustainable production facilities and production techniques, without effective policies implemented to reduce the emission of GHGs. Therefore, the transition towards an economy that is in line with the 2°C pathway and the distribution of the costs associated with the transition requires some form of intervention by government policies.

Because climate change is a global problem, all governments should be involved in reducing GHG emissions by implementing a carbon-pricing mechanism. When not all countries cooperate, carbon emission may "leak" to countries that do not have a pricing system. Hence regulations are most effective when implemented on global scale (Jenkins, 2014). The Paris Agreements is a first sign that the implementation of a global carbon pricing system may become possible. This strengthens the bargaining power for a global carbon pricing mechanism. It remains uncertain how the Paris Agreements will work out for companies until new policies are implemented that are able to keep the emission of GHG on target for the 2°C pathway. Oil companies are large emitters of GHGs and their strategy will be affected by future climate policies. The uncertainty in the market has as a consequence that oil companies are reluctant to invest. This uncertainty even result in the fact that major oil companies such as Shell, BP, Exxon and Total are in favor of the implementation of a carbon tax to end the uncertainty in order to know what they are up against. If some form of carbon pricing is implemented it increases the costs of a reserve through an additional tax that has to be paid to the government (see Figure XL). The next sections emphasize on the different type of carbon pricing mechanisms and the consequences of these mechanisms on the value of oil reserves.

Carbon pricing mechanisms

There are multiple possible pricing mechanisms which government may use. However, governments should ensure and facilitate the efficient allocation of subsidies and taxes across the economy by using price mechanisms. These price mechanisms should be aimed to pursue three goals (Shell, 2016).

- To incentivize low-carbon technologies and energy sources or technologies that reduce the emission of GHG.
- To reduce the emissions from carbon-intensive fuels by reducing the incentives of producing these emissions.
- To enhance a change in the behavior throughout the economy that triggers people to use energy in a smarter way and to adopt and implement low-carbon technologies.

Mechanisms that support these three goals are implicit and explicit carbon pricing. Explicit carbon pricing directly taxes the emission of carbons, while implicit carbon pricing works through the implementation of policies or instruments that price the carbon. Other ways to distinguish between explicit- and implicit pricing mechanisms are direct pricing mechanisms (explicit) and indirect pricing mechanism (implicit). An example of explicit carbon pricing is an economy-wide carbon tax on the emission of CO_2. An example of an implicit carbon tax is a target regarding the future energy mix of a country. Additional information regarding explicit and implicit pricing can be found in appendix C.

The advantages of explicit carbon pricing

Explicit carbon pricing is seen as more effective than implicit carbon pricing because it produces the preferred incentives by directly taxing the negative unwanted effects (Baranzini et al., 2015). Of the explicit carbon pricing methods a carbon tax is currently considered to be the most effective and has the highest chance to be implemented accroding to research conducted by Shell (2016). Below are the three most important advantages of explicit carbon pricing.

- Carbon pricing leads to a new cost ranking of goods and services according to the Polluter Pays principle. This should lead to higher costs for dirty, polluting goods and services, and lower cost for the cleaner and sustainable goods and services (Baranzini et al., 2015).
- Carbon pricing contributes to dynamic efficiency, because it incentivizes research & development and the adoption of low carbon technologies due to the financial benefits. This enhances the business case of new, cleaner technologies that would not have made sense without a pricing mechanism. Thus without environmentally corrected prices, effective and well-oriented innovation cannot be expected (Shell, 2016).
- Carbon pricing allows emitters to operate fully autonomous and flexible because they have the possibility to change their behavior and reduce emissions and therewith their costs (Jenkins, 2014).

Revenues from carbon pricing

The income that is generated by the carbon pricing mechanism should be used to invest in clean technologies that reduce the demand for oil. When looking at figure XL, a reduction in oil is possible by stimulating substitute products such as electric vehicles and renewable energy. Another demand reducing method is to invest in technologies that increase end-user efficiency and stimulate social behavior. If the revenues from the carbon pricing mechanism are directly invested at the demand side, then the mechanism has double the impact.

The impact of environmental regulation on the oil sector

The goal of climate regulation is to reduce the emission of GHGs. Hence the implementation of a carbon pricing mechanisms will make the emissions associated with the production of oil important for the oil companies. The type of oil reserves that produce more GHG will be more heavily priced, and will add to the production cost of the reserve. Cleaner type of oil reserves will get economically more attractive, which will change the relative prices of products resulting in a new cost ranking of reserves. This new cost ranking of oil reserves, based on their emission footprint, incentivizes oil companies to switch from dirty oil reserves to cleaner oil reserves, and, it incentivizes companies to invest in technologies that reduce the emissions from the reserves such as carbon capture and storage. These incentives for reducing the emission from the production of oil are currently absent or only on small scale due to the lack of thorough environmental policies. The next section goes into further detail regarding the environmental footprints of certain type of oil reserves, to determine which reserves will be mostly hit when regulation is implemented.

The environmental footprint of oil reserves

Gordon et al., (2015) from the Carnegie Institute have committed research to make an index for the quality of oil projects to distinguish between dirty and clean oil projects. The index is used in this section to analyze the environmental footprint of different oil reserves and to determine which reserves will be most affected by climate regulation.

The footprint of an oil reserve on the environment depends on the design of the entire supply chain; from the way that the oil is extracted from the reserve, to the necessary transportation and refining of the oil. There are a few elements that influence the footprint of the reserve. According to Gordon et al., (2015) upstream emissions are dependent on the production process. Hence, the technology that is used to extract the oil from the ground is the main emission driver for upstream oil companies. Downstream emissions are dependent on the quality and the composition of the oil. Oil with a lower quality needs more intensive refining and produces a higher amount of emissions. Midstream emissions, caused by transportation, are in most cases only a small fraction of the upstream and downstream emissions. For IOCs and NOCs that operate both up- and downstream, all three elements are important, but for companies that solely operate upstream only the production process determines their emissions and the associated taxes when environmental regulation is implemented. Companies can influence these emissions and the level of taxes through enhancing their production technique and the state of technology of their production facilities. Gordon et al., (2015) argue that a large share of the upstream emissions can be prevented if newer facilities are installed or updated which are cleaner in general and which do not flare but capture associated gasses. Different types of reserves require different production processes due to their location or the type of oil. These different production processes have different levels of emissions. Reserves with higher emissions are primarily the unconventional oil reserves or reserves. Table 4 shows the footprint of different type of reserves based on averages of the oil sector.

Main upstream emission drivers according to Gordon et al., (2015)

- Flaring and fugitives (production technique); flaring of gas and gas that escapes while producing oil is often burned/flared or released. This flaring as well as the fugitive gasses generates a lot of CO_2, methane and other GHGs that go directly into the atmosphere; thus, highly gaseous reserves have a relatively high footprint.
- Watery/depleted oil reserves (composition of oil); produce significant amounts of water along with the oil. Bringing this water to the surface, to process it and to re-inject or dispose it uses a lot of energy. These watery oils can have a footprint of 60% larger than normal oil reserves
- Land use (production technique); the extraction of heavy and extra-heavy oils such as tar sands has a high impact on the landscape resulting in destruction and contamination of the surrounding environment, which leads to opposition from the public and environmental organizations.
- Reserves at extreme locations (production technique) are difficult to access and may have a disrupting effect on nature, such as artic oils, oil reserves in the middle of a rainforest, or oil reserves on continental shelves such as the ultra-deep Chayvo oil field in Russia's Sakhalin shelf. Hence these projects are mostly contested by the public and environmental organizations and may face the chance of getting subject to additional regulation (Gordon et al., 2015).

Downstream emission driver

- Oil type; (extra-) heavy oils (low quality) and contaminated oils need more refining and upgrading than light oils. The difference in GHG footprint can be twice as much as light sweet crude oil.

Overview of environmental footprint and additional cost with carbon pricing

The table below shows the results from Gordon et al., (2015) regarding the environmental footprint of oil reserves, the emission driver of the reserve, the density of the oil and the associated additional costs when carbon-pricing is introduced. The costs are an estimate based on the data provided by the Carnegie Institute.

Type	Location reserve [Abbreviation]	Density of oil	Emission footprint	Emission driver	Add. Cost* [$/barrel oil]
Conventional					-
Onshore		Light to medium	Small	-	9
Offshore		Light to medium	Small to medium	Flaring and venting	-
• Deep	MEX, BRA, NOR, UK	Light to medium	Small to medium	Flaring and venting	11
• Ultra-deep	MEX, BRA, NGA	Light to medium	Small to medium	Flaring and venting	11
• Arctic	ATA, ALA	Light to medium	Medium to large	Location, land use (disrupting nature),	12
• Shelf	RUS, CAN, USA	Light to medium	Medium	Extreme conditions, flaring	12
Unconventional					
Shale oil / tight oil	USA	Medium	Medium	Flaring, land use**	10
Oil shale/ extra-heavy	USA	Extra-heavy	Large	Oil type, land use**	15
Tar sands / oil sands	CAN, CHN, VEN	Extra-heavy	Large	Oil type, land use**	15

* Based on a $20 carbon tax

**Land use as the result of pollution and devastation is included in the footprint but is not included in the additional cost per barrel of oil

Table 4 - Different type of oil reserves with their characteristics

Decarbonization and shrinking demand

The Paris Agreement in the end comes down to limit the GHG emissions by phasing out fossil fuels before the carbon budget is exceeded. This means that a decline in the use and production of oil is necessary to meet the goals from the Paris Agreement. This section will determine to what extend emissions need to be reduced and whether oil companies account for this reduction in emissions.

The carbon budget

Past decade research has gone out to determine the exact maximum amount of GHG emissions. Several researchers (Heede, 2014; IPCC, 2014; Meinshausen et al., 2009; Rozenberg, Davis, Narloch, & Hallegatte, 2015) have quantified such a maximum limit, which is better known as the 'carbon budget'. Of these studies the report by the International Panel for Climate Change (IPCC), which is based on Meinshausen et al., (2009) is the most prominent publication regarding the carbon budget. The IPCC and Meinshausen et al., (2009) have calculated this carbon budget to be a cumulative amount that lays around 2900 GtonCO$_2$. During the period of 1870 till 2015 society has already used an amount of 2000GtCO$_2$. This leaves a remaining budget of approximately 900 GtCO$_2$ with an assurance of 66% to stay below 2°C for global warming (figure 19). This total budget of 900GtCO$_2$ must be distributed over coal, oil and gas. With current annual emissions of 33GtCO2 per year the remaining carbon budget would be exceeded within 30 years. The current share of oil in the addition to the total amount of CO$_2$ emissions is approximately 36% according to the U.S. Energy Information Administration (2016). The share of gas is 22% and the share of coal is 42%. Using the current distribution of fuel usage of oil brings the remaining budget for oil at approximately 324GtCO$_2$ for gas at 198GtCO$_2$ and for coal at 378GtCO$_2$.

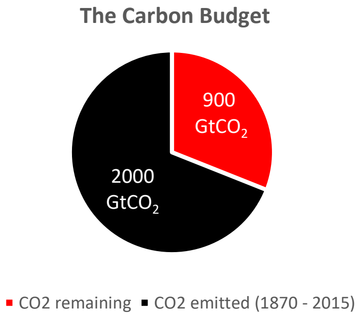


Figure 39 – The remaining carbon budget

The amount of fossil fuel reserves and reserve growth

According to the BP Statistical Review (2016) and US geological survey (USGS) the remaining oil resources, better known as the 'resource base' or the 'Original Oil in Place' (OOP) is around 8 to 9 trillion barrels. Of these 8 to 9 trillion barrels approximately 1700 billion are still economically viable to extract using the current state of technology. Other institutions (Carnegie institute and Rystad Energy) estimate this amount to be even larger (2 to 6,5 trillion) due to the increasing possibilities regarding unconventionals. However, in this research a conservative view regarding the proven reserves will be adopted. These 1700 billion barrels of oil are equivalent to a CO$_2$ emission of around 730 GtCO2. The same estimations for natural gas and coal, using the BP Statistical Review, (2016) result in an equivalence of 360GtCO$_2$ for natural gas and 1710GtCO$_2$ for coal.

Figure 14 shows the rapidly growing amount of technically recoverable oil reserves by comparing the amount of proven reserves in 2015 and 1995. This indicates that the amount of oil (and gas and coal) reserves is still growing and larger than ever before. This is due to:

1. New discoveries through geological research and exploration projects.
2. The increasing opportunities and technological development regarding unconventional oil techniques.
3. The increase in volume of existing oil fields due to discovered accumulations trough extension, revision, improved recovery efficiency and addition of new pools or reservoirs in current reserves (Maugeri, 2012) which makes it possible to recover more oil from existing reserves (Klett, 2015). This phenomenon is known as "reserve growth" (Maugeri, 2012).

The abundance of oil

What becomes clear from figure 20 is that the amount of CO$_2$ stored in the proven fossil fuel reserves is more than three times the size of the carbon budget. This implies that in order to remain within the carbon budget approximately 70% of the current reserves have to remain in the ground. Additional discoveries or reserve growth add to this amount. The carbon budget that is left for oil is approximated at 360GtCO$_2$ and depends on the share of oil in the fuel mix. With the current fuel mix, not even half of the oil reserves can be used. This strongly implies that a decline in the use of oil is necessary and, even more importantly, that oil is abundant in a carbon-constrained world where climate change is actively addressed.

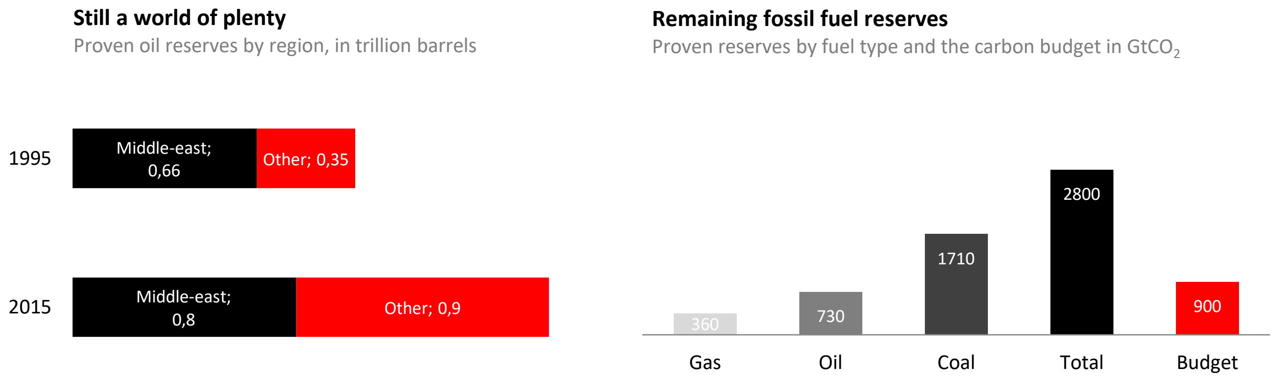
Consequence of the abundance of oil for the market

The abundance of oil implies that in the end, oil should remain in the ground without further purpose. This situation can only be achieved if the demand declines, otherwise oil would not get abundant. When the demand declines, the supply has two possibilities, one, stay on the same level, this will inflate the oil price and may lead to bottom prices, and two, the supply declines with the demand to balance the oil price but this will result in reserves getting obsolete and in other words, stranded. Figure XL shows the relations between demand, supply and the oil price.

In a world where oil is abundant and where the market operates completely efficient the cheapest oil reserves will be extracted until the budget is filled. However, companies owning reserves that are at the expensive side of the cost curve will try to produce as much as oil as possible before the reserves become stranded. This form of competition may trigger a market share driven policy of oil producers to sell as much as oil as possible while it still has a value. Because when oil reserves are stranded, their value will be significantly reduced. Thus, a declining demand for oil will influence the value of oil reserves, especially the reserves that will become stranded.

Demand driven oil reduction

Many reserves have to remain in the ground for environmental reasons, but how is it possible to realize such a reduction in the use of oil and what is necessary to achieve this? A declining oil market can be achieved through reducing the supply in the market, but this will create shortages and high oil prices. These high prices make people reluctant to use more oil and will reduce some of the demand for oil or force people to switch to substitutes such as electric transportation and renewable energies (Puik, 2016). However, a declining market through reducing supply is not a sustainable way of letting the market shrink and oil companies will not be very enthusiastic and hard to convince to reduce their output as can be seen during the current oil price slum where all companies and governments have used a market share driven policy. A more sustainable way of reducing the use of oil is through a decreasing demand for oil from the market (Nelson et al., 2014).



Still a world of plenty

Proven oil reserves by region, in trillion barrels

Remaining fossil fuel reserves

Proven reserves by fuel type and the carbon budget in $GtCO_2$

Source: BP Statistical review (2016)

Sources: BP Statistical review (2016) and US geological survey (2015)

Figure 20 - Proven fossil fuel reserves (based on data from BP statistical review (2016) and the US Geological Survey (2015))

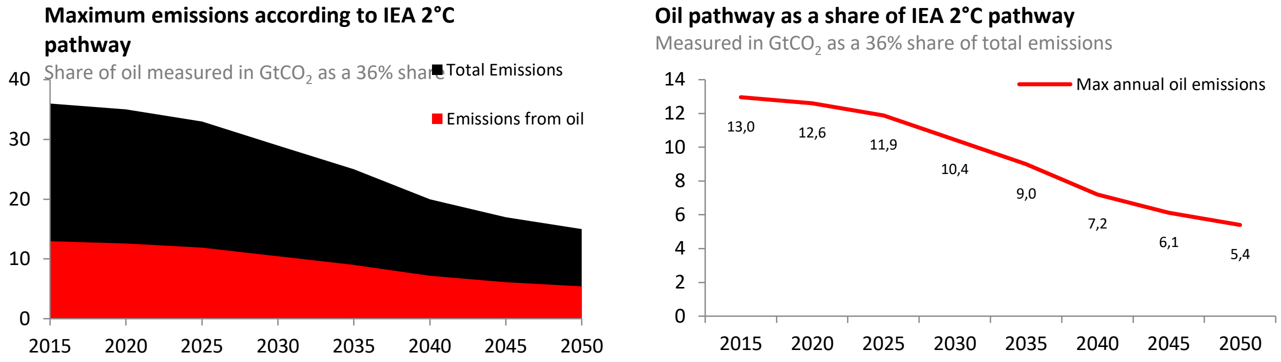
The drivers of demand reduction

The oil demand is in the long term dependent on two main factors, which are the size of the market and the consumption rate of the market, which is also reflected in Figure XL. A reduction in the size of the market can be achieved through the implementation of substitute products such as renewable energy technologies, electric vehicles and in the long run hydrogen fuels. These substitute products have to outcompete the growing population and global economic growth in order to result in a declining market. The consumption rate of the market can be reduced through increased end-user efficiency by developing and adopting new technologies for the mass market or for industrial processes. Especially energy efficiency of vehicles such as light and heavy transport plays a major role in reducing the use of oil because 55% of oil is used for transportation (figure 5). Another way of reducing the consumption rate of the market is through increasing social behavior by increased environmental awareness and sharing of resources such as cars (carpooling), which will become much easier through the digitalization and artificial intelligence.

Pathways

In 2015 there was an annual amount of $36GtCO_2$ of CO_2 emissions of which 36% originated from the use of oil (U.S. Energy Information Administration, 2016). This brings the oil related energy usage to $13GtCO_2$ annually. Solely the emissions from oil would exceed the carbon budget within 70 years if no other fossil fuels would be used and produced.

When the 2°C emission pathway from the IEA is considered and the share of oil compared to the total amount is kept constant at 36% then the emissions of oil should be reduced from 13Gt in 2015 to 5,4Gt in 2050. Hence in a 35 years period from 2015 till 2050 the emission should be reduced with 7,6Gt, which means an annual reduction of 0,22Gt, which is equal to an annual decrease of 1,7% based on the current state of technology (figure 21). When the world wants to comply with the 2°C pathway its evident that the market for oil should shrink because there is currently no feasible technology that is able to capture a vast amount of emissions associated with the production of oil because most emissions from oil originate from transportation. The 2°C pathway is the preferred pathway in a carbon-constrained world and is composed by the IEA. Oil companies at the other hand make their own projections based on their expectations of the market.



Maximum emissions according to IEA 2°C pathway

Share of oil measured in $GtCO_2$ as a 36% share

Oil pathway as a share of IEA 2°C pathway

Measured in $GtCO_2$ as a 36% share of total emissions

Data source: IEA analytics

Data source: IEA analytics

Figure 21 - The share of oil in the emission pathway

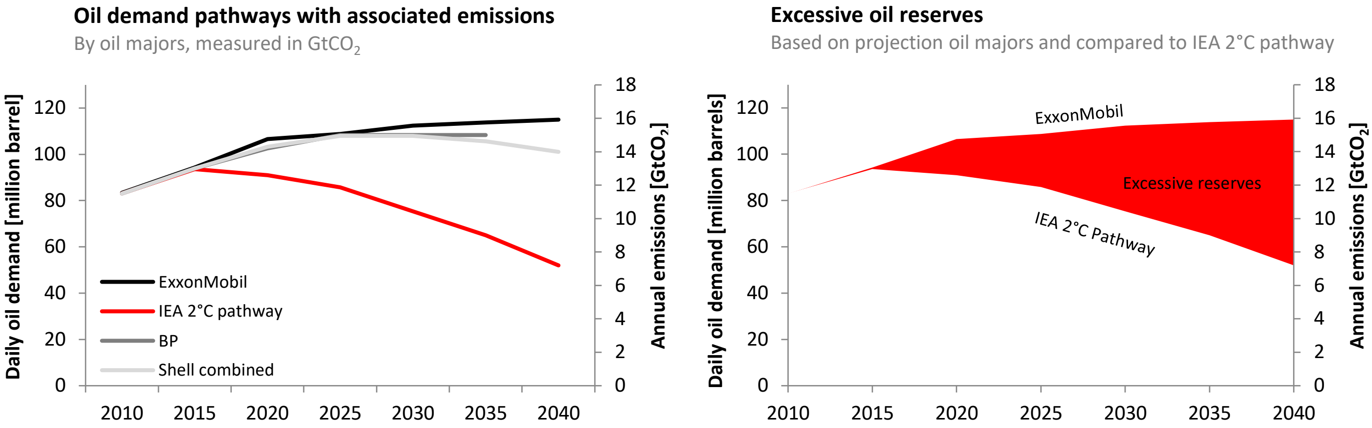
The projections of the oil majors

Every year, the oil majors publish a statement with projections regarding the global energy demand and supply etc. for at least the next 20 years. They base these statements on their own market research and data gathered in the market. These outlooks are in the industry seen as reliable projections because the majors have the best knowledge and resources available to calculate different scenarios and to make accurate projections. The following table shows the projections from the oil majors.

BP (2017)	BP projects the output of CO_2 to grow during the period from 2015 to 2030. However they growth foresee a decline in the growth rate from 2,1% to 0,9%. This will result in a total increase of 20% over the period from 2015 to 2035. In this same period they predict that the demand for oil will peak and increase with 0,6% annually. BP state in its outlook that only when global emission taxes are implemented then the emission will be reduced.
Exxon Mobil (2017)	Exxon Mobil projects that the global emissions will continue to grow through 2040 to 10% above the current emission rate. The demand for oil is forecasted by Exxon Mobil to grow with 20% till 2040, with the largest growth in commercial transportation and in chemicals.
Shell (2016)	The "Shell combined" pathway is a combination of the Oceans and Mountains scenarios. This pathway projects oil demand to grow until 2025 in which it peaks and plateaus until 2030 and from 2030 Shell forecast the demand for oil to decline.

Results from projections of oil majors

All oil majors forecast emission pathways that do not stay within the emission limits and do not comply with the Paris Agreements. In other words, the oil major companies do not account for the oil market to shrink, and they all project the demand for oil to grow instead of to fall as the IEA 2°C pathway prescribes. However, in a carbon-constrained world, society is bound to stay on track to comply with the 2°C pathway due to their commitment to the Paris agreement. Hence in a carbon-constrained world, these major oil companies will probably face problems because they do not plan for a declining oil market, but for a market that increases in size as figure 22 shows. The surface in the figure between the 2°C pathway and the pathways projected by the oil majors are the excessive reserves when the 2°C pathway is followed. In a carbon-constrained world, these are the reserves that potentially lose some or all of their value because they cannot be produced as the result of a declining oil market. Hence IOCs and NOCs will be left with an excessive amount of reserve due to the abundance of oil. If oil companies do not plan for the demand to decrease and they base their investments on their projections of the oil market, then they will add to the potential oversupply in the market and increase the amount of reserves that will end up useless. Hence, the projections of the oil majors enforce the outlook that in a carbon-constrained world, oil is abundant.



Oil demand pathways with associated emissions

By oil majors, measured in $GtCO_2$

Excessive oil reserves

Based on projection oil majors and compared to IEA 2°C pathway

Figure 22 - Demand pathways and excessive oil reserves

Increased competition and oil price volatility

The carbon budget and the associated 2°C pathway to which the world has dedicated with the ratification of the Paris Agreements, will and must have their effect on climate policies, regulations and the global demand for oil. Since the Paris Agreement in the end boils down to the commitment to reduce the size of the oil market and to phase out fossil fuels (Van de Graaf, 2016). Another mechanism on which the Paris Agreements will have an impact is the oil price. The oil price has seen a vast decline that started in 2014 and is still not recovered to pre-oil-crisis levels. This section emphasizes on the effect of the Paris Agreements on the oil price by analyzing the main drivers of the oil price and the insights provided by the current oil price crisis.

The main drivers of the oil price

The main long-term driver of the oil price is the balance between the supply and the demand of oil in the market, as explained in paragraph 3.2. Other factors that influence the oil price with a more short-term character are speculation in (financial) markets and exchange rates and can be found in figure XL. The sort-term drivers of the oil price are left out of the scope in this chapter because the emphasis lies on long-term price effects, hence on supply and demand.

The current oil price crisis

Among the main causes of the current oil price crisis are the projections of the future oil demand that show a falling trend compared to previous projections due to the slowing growth of the Chinese economy while at the same time the supply of oil increased because of the vast increase in the production of US shale oil according to Arezki & Blanchard (2014), Baumeister & Kilian (2016a, 2016b) and Hamilton, (2009). The increasing supply and the decreasing demand has led to an oversupply in the market resulting in declining oil prices. Oil producers could have offset this oversupply by reducing their output. However, producers that are concerned with their revenues when the oil price is low have an incentive to increase their production to make up for some of the lost revenues (Hamilton, 2009). Hence a reduction in output would result in both a financial as well as a competitive disadvantage for these producers because they would lose market share to their competitors. Only organized reductions in output by all main oil producers is a possible solution.

The role of Saudi Arabia during the oil price crisis

Before the oil price crisis, Saudi Arabia as the largest and lowest cost oil producer was considered to be the global swing producer that was able and willing to absorb fluctuation in oil production by adjusting their oil output. But during the oil price crisis Saudi Arabia maintained a market share driven policy in the hope to outcompete their competitors such as US shale oil producers, that were vastly increasing oil output, and their political rival Iran. This market share driven policy and the maintained levels of oil production resulted in oversupply and in the low oil prices.

Reducing demand as the result of decarbonization

The current oil price crisis shows that the balance between the supply and demand drives the oil price and the oil price will remain depressed until the supply is matched with the demand. In a carbon-constrained world based on the Paris Agreement, the world must reduce the demand for oil to meet the goals from the agreement. Thus the global movement and urge for decarbonization incentivized by governments will structurally decline the demand for oil in the coming years. This structural decline in the demand will influence the oil price. If the decline in oil demand occurs according to the 2°C pathway of the IEA, then the demand is set to increase until 2020 to 93,7 million barrels per day and from 2020 until 2040 decline to 74,1 million barrels per day (Myers Jaffe & Van der Veer, 2016). This would mean an annual reduction of almost 1 million barrels per day starting in 2020 (without taking into account that the current oil demand is set by the IEA at 96,7 million barrels and therefore already exceeds the 93,7 million barrels which implies that a larger reduction should be achieved). This annual reduction will result in an equal price depression if the supply of oil is not reduced as well. Hence, in a carbon-constrained world, OPEC and other large oil producers face a period in which the oil demand strongly declines and in which all producers should; or cooperate and reduce their output with an equal share, or compete in production to maintain market share, which may have severe consequences.

Increased competition and market share driven policy

The prospects of the oil sector being an ex-growth and declining sector, will change the perspective from peak oil supply to peak oil demand as is described in paragraph 2.2. The peak oil demand perspective is associated with the urge to sell as much oil as possible because unproduced oil will be worthless when there is no demand for oil left. Hence, when the demand for oil starts to decline, oil producers will be triggered to engage in the competition for market share to generate as much revenue as possible from their remaining oil reserves (Verbruggen & Van De Graaf, 2015). The policy handled by Saudi Arabia during the oil price crisis resembles the urge in the market to maintain market share. This indicates a shift from revenue driven policy to market share driven policy, which is also supported by the tough negotiations between OPEC members regarding production quotas which failed several times to reach an agreement because they did not want to reduce their output.

The consequences of market share driven policy

An oil market in which oil producers compete over market share probably result in low oil prices due to an oversupply that is generated to be able to compete in the competition. This vision is supported by the analysis of the current oil price crisis and by Baumeister & Kilian (2016b), van de Graaf (2016), and Verbruggen & Van De Graaf (2015). Because the competition for market share is followed by these low oil prices, the companies or countries with low production cost or those that are supported by a high amount of capital are able to endure a prolonged competition for market share. Since there are large differences in production costs, parties have a different stake in this competition and may not be able to endure as long as others.

Consequences of a low oil price

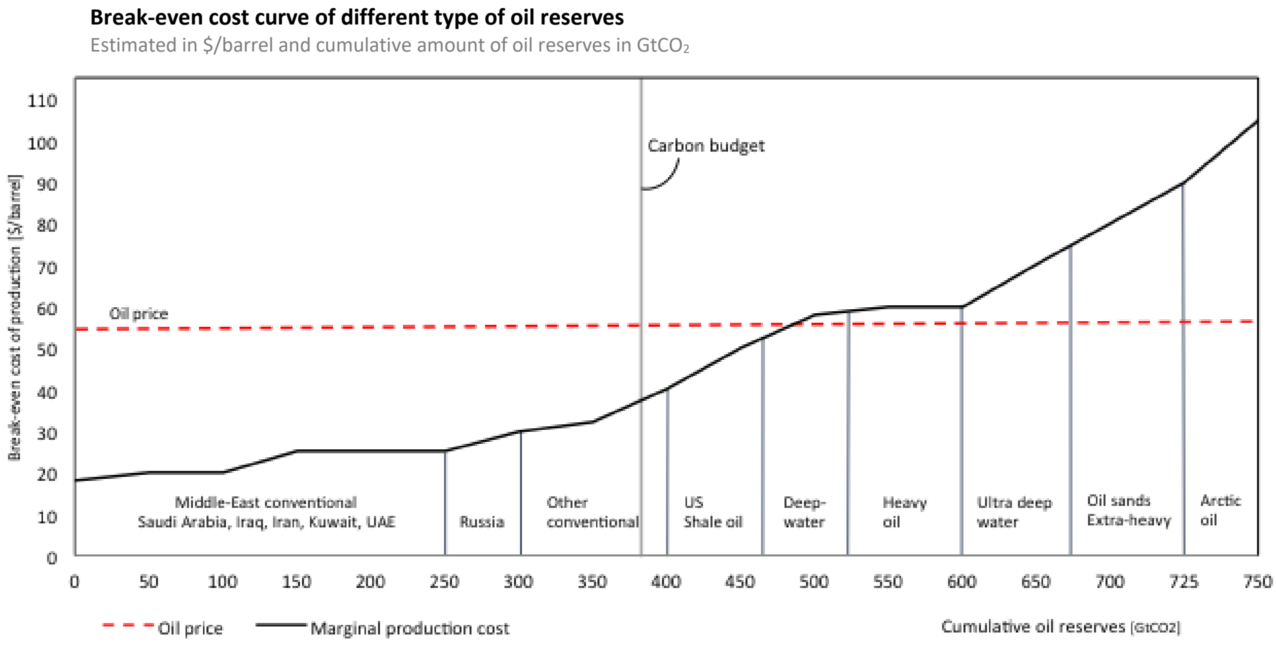
If the oil price falls below the breakeven cost of production, then the costs of producing oil are higher than the income from the oil. When the oil price remains at the level below the breakeven cost of production and when the companies or countries sustain the same production rate, then, the companies and countries must dig in on their capital or take additional loans. These companies or countries are able to continue competing until their capital is spend or until the banks stop providing additional loans. Hence, companies and countries that possess more capital, and have a lower breakeven cost of production are able to compete longer during low oil prices. Companies or countries that do not want to compete or no longer have the financial means to compete in low price scenarios are forced to stop or reduce their production and therewith lower their oil supply. The more companies that lower their output, the more the oil supply will shrink. This may result in an increasing oil price, unless the parties that are still competing fill in the lost supply by increasing their output. The companies that are still competing are incentivized to maximize their output because it compensates some of the lost revenues (Hamilton, 2009) which will increase their market share. When the parties that have stopped producing increase their output again it will have a negative influence on the oil price because the supply increases.

Sustaining low oil prices

When companies are producing below their breakeven cost of production or have stopped producing due to the low oil price their reserves are not economically viable. For a short period this may not be very problematic, but it may have severe consequences when low oil prices sustain. The reserves with breakeven cost above the oil price are not economically viable to exploit and should according to the classification of resources be labeled as resources instead of reserves. This also implies a downgrade of their value in the financial statements with possibly a reduction in the value of the company. When these low prices sustain for a longer term, then the expensive reserves may in the end be not able to produce at all if no cost reductions can be achieved. Hence, a sustaining low oil price may have as a result that the oil reserves at the expensive side of the breakeven cost curve have to be devaluated or get stranded. Figure 23 shows the estimated breakeven cost curve and the current oil price ($55/barrel). It shows that the reserves at the expensive side (right) are not economically viable for the current price. When the price remains this low, the expensive reserves may not get exploited at all and get stranded.

Competitive advantage of low cost producers

If the global movement for decarbonization causes a race to sell oil resulting in oversupply and a low oil price, then companies that have low break-even cost have a competitive advantage over companies with higher break-even prices. The BP Group, (2017) has forecasted that these low cost producers will increase their market share in the period from 2020 to 2035. Which is the same period in which the demand for oil must decline, according to the IEA. This will make the position of the Middle-East oil producers even stronger than it currently is and they may even have the ability to force other producers out of business. Market share driven policy may even result in geopolitical conflicts and even war according to Verbruggen & Van de Graaf, (2013) because some countries are highly dependent on the profits generated by the production of oil.



Break-even cost curve of different type of oil reserves

Estimated in $/barrel and cumulative amount of oil reserves in GtCO₂

Figure 23 – Break-even cost curve per type of oil reserves

Business cycles

In times of lower oil prices and market share driven policy, investments in new oil projects are often postponed, with the result that the amount of oil available gets below the demand for oil due to the high output. This may cause the oil price to increase due to the temporary scarcity. This effect may break the market share driven policy and cause price spikes until additional production capacity is installed. Companies that have invested in time may profit a lot from these price spikes. However, when the production capacity is increasing again the same oil producers may maintain their market share driven policy resulting in lower oil prices. These business cycles may cause huge volatility in the oil price over the longer term and repeat itself. The problem in the oil sector that make companies unable to quickly adjust to these business cycles are the long lead times associated with oil projects; installing additional production capacity may take several years. A large base of available resources can endure the duration of these business cycles. During times when market share driven policy is conducted, a larger resource base will make it possible to have a higher supply for longer, with low prices as the result.

The role of OPEC

OPEC is to some extend able to influence the market price for oil, as they did last December. OPEC influences the price through negotiating production quotas among OPEC members. These production quotas reduce the oil output of the OPEC members and therewith reduce the total oil supply, which has a price increasing effect when the demand remains equal. However OPEC has a long history of neglecting the production quotas that are agreed upon. Reason for neglecting the agreements is that they are caught in a prisoner's dilemma in which they can meet the highest profits when the OPEC members do not adhere to the agreement. Hence they are incentivized to maximize their oil output.

Intermediate conclusion

Climate regulation is necessary to set the right incentives to limit the emission of GHG and to increase the adoption of low- and no-carbon technologies. Climate regulation must be implemented on global scale to prevent competitive advantages and carbon leakage from taking place and disrupting the preferred outcome. The type of regulation that sets the most adequate incentives is explicit regulation in the form of a carbon tax or a cap and trade system. Effective regulation has the ability to kick-start the world to comply with the 2°C pathway of the IEA and to limit the emission of GHG from the dirty oil fields. However, the implementation of climate regulation may result in dirty oil reserves to get less profitable than clean reserves. The income from the carbon tax must be invested to reduce the oil consumption of the market by means of increasing efficiency and substitute products of oil.

There is an abundance of oil according to data from the IEA, the USGS and BP, especially in a carbon-constraint world. The demand for oil and therewith the size of the oil market should be significantly declined over the years to be able to stay within the carbon budget and on track to meet the 2°C pathway. This decline in demand has the potential to inflate prices or to devaluate reserves. The major oil companies do not account for this reduction to happen which may lead to higher risk of a significant amount of oil reserves that may get stranded and should be devaluated. The drivers that cause the reduction in the demand for oil are the penetration of low- and no-carbon technologies such as renewable energy and electric vehicles, together with increased end-user efficiency and social behavior.

The movement for decarbonization of the economy together with the fact that not all proven reserves can be exploited due to the abundance of oil may result in a race to sell oil and market share driven policy of large oil producers. This may result in an oversupply and low oil prices. In such situation, companies that are at the lower end of the breakeven cost of supply curve have a competitive advantage compared to companies with higher breakeven cost. A larger resource base will prolong the duration of the business cycle with low oil prices as the result of market share driven policy due to a high amount of available resources.

4.2 The consequences of the developments

The three main developments and the drivers of the developments are in this paragraph further analyzed and operationalized by focusing on the consequences and effects of the developments on the value of oil reserves. Figure XL is used to conduct this analysis since it gives a good overview of how the upstream oil sector functions and how the value of oil reserves are influenced by different factors in the system.

The three main developments in a carbon-constrained world as identified in paragraph 2.2 and further operationalized in paragraph 4.1 are the following:

- Regulation The implementation of environmental regulation is aimed to set the right incentives to limit the emission of GHG in order to meet the environmental targets from the Paris Agreements.
- Demand The demand for oil should decrease to be able to meet the goals of the Paris Agreements and limit the amount of GHG emissions.
- Price There will be a high chance for long-term low oil prices as the result of increased competition and oversupply in the market to sell as much reserves as possible.

The three developments in a carbon-constrained world have implications for the value of oil reserves and may pose a threat for the economic viability of some of the reserves. These implications are caused by the risk that certain oil reserves may face devaluations or get stranded under certain scenarios imposed by the investigated developments in a carbon-constrained world. The table 7 on page 54 gives an overview of the consequences and the effects of the developments on the value of oil reserves. The next sections are based on this overview. A more in-depth explanation of the factors that influence the value is given in appendix D and the consequences that build up to the overview are further explained in appendix E.

Consequences of the developments

Environmental regulation in the form of a carbon tax at the supply side make dirty reserves more expensive than clean reserves due to the additional tax based on the emissions from the reserves. Therewith increasing the relative value of clean reserves compared with dirty reserves. Regulation imposed at the demand side (subsidies) increases the decarbonization of the economy by stimulating substitute products, end-user efficiency and social behavior. Stimulation of the decarbonization movement will cause a reduction in the use of and the demand for oil, which will result in a declining oil market. Hence, the additional effect of a demand side subsidy is a declining oil market. Environmental regulation may result in dirty oil reserves to get stranded and the demand for oil to decline.

The penetration of low and no-carbon technologies together with increases in end-user efficiency and social behavior have as an effect that the demand and the market for oil will start to decline. A declining demand for oil will result in the abundance of oil and reserves with long lifetimes to get stranded. The faster the decrease in demand occurs, the more reserves will be stranded. Currently oil companies are under the perception that their competitive reserves will remain producing till the reserves are fully exploited. However, a declining market may result in oil reserves to get out of business before the entire reserve is exploited. This may have a severe impact on the valuation method of oil reserves. Hence, lower demand combined with the abundance of oil result in reserves to get stranded and devaluated.

The increased competition and the oversupply will cause lower long-term oil prices, which will result in expensive oil reserves to get stranded. Hence reserves with high break-even costs are gaining a competitive disadvantage, resulting in oil companies and investors to decrease their investments in these types of oil reserves. The lower prices result in devaluations of the value of oil reserves while the disadvantage of reserves with high breakeven cost may result in expensive reserves to get stranded due to the lower oil prices. Figure 24 summarizes the consequences of the three developments that are comprehensively explained in table 7 on the next page. Both give an answer to the research question that is formulated at the introduction of this chapter.

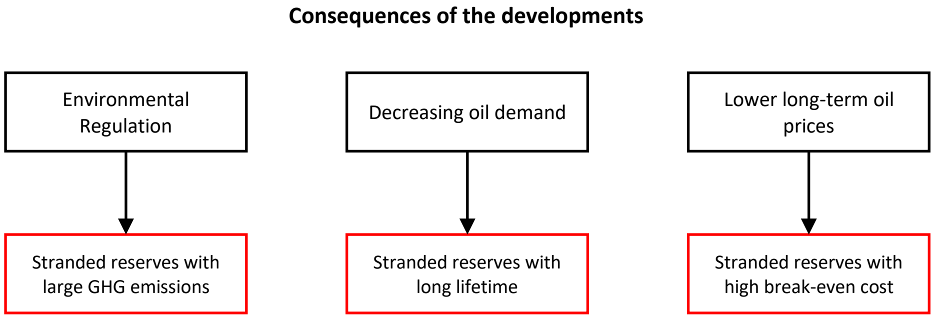


Figure 24 – Main consequences of developments

Conclusion regarding the developments

The three developments are potential stranding causes for oil reserves that are vulnerable to one or more of the developments. The impact of the developments on oil reserves should be more closely examined because the threat for oil reserves to get stranded will have a large impact on the value of oil reserves. Therefore, valuation methods should be able to account for these consequences in order to reflect an accurate value and incorporate the consequences.

The oil sector has always been growing and oil prices have been increasing. Stranded reserves were not even considered under the perception that oil will be scarce. Hence, the current valuation methods do not yet effectively incorporate the risk of reserves to get stranded in the value of the reserve because the oil companies do not yet fully consider the developments that make them strand to occur. But due to the long lifetimes of oil projects, the developments that are perceived to influence the value of the reserves in about 10 to 20 years should already be included in the valuation of the reserves. Otherwise oil reserves turn out to be unprofitable or may even get stranded. Moreover, the projected pathways of the oil companies show that the oil majors do not account for the developments in a carbon-constrained world to take place. This leaves their reserves vulnerable to get stranded when the developments materialize.

The next chapter takes a closer look at the different type of oil reserves and the impact of different scenarios of the developments on the value of oil reserves. This way reserves with a high stranding potential can be identified and measures to account for the stranded reserves can be composed.

Effect and consequences of the developments

Develo pment	Factor	Direct effect	Secondary effect	Effect on reserve value	Δ	Combined effect	Δ
Environmental regulation	• **Tax on supply side** (carbon tax, CO_2 certificates)	1. Increases the cost of exploiting reserves. Dirty reserves relatively more than clean reserves	1. Decreases the supply of oil especially the supply of dirty reserves	Higher cost reduces the value of the reserve. The value of dirty reserves are more reduced than clean reserves	↓	The supply side tax has a negative effect on the value of reserves, especially for the dirty reserves. This may result in dirty reserves getting stranded due to higher cost. A demand side subsidy for substitutes reduces the demand for oil. Both forms of tax have the goal of reducing the supply and demand for oil. When both the demand and supply decrease, the entire market gets smaller which will in the end devaluate oil reserves that cannot be produced (stranded).	↓
		2. Reduces the total supply of oil because fewer projects are profitable with the extra cost.	2. Slightly increases the oil price due to lower supply as a result of higher cost (short term effect)	Higher oil price increases the value of the reserve *	↑		
	• **Incentive on demand side** (subsidy)	Stimulates the adoption of substitute products which decrease the demand for oil such as (EVs, renewable, efficiency)	Permanently reduces the demand for oil, and therewith reduces the cumulative amount of reserves that must be produced in the future.	May devaluate assets that are not produced in time due to lower aggregate demand because of a declining oil market.	↓		
Declining demand	**Substitute products**	Permanently** reduce the oil demand due to adoption of substitutes	Decreases the oil price for a longer period *	Reduce the demand for oil leading to devaluations and stranded reserves	↓	The combined long-term effect of demand reducing factors result in a declining global oil market. This declining oil market limits the amount of oil that can still be produced. Which may result in stranded oil assets and severe devaluation of the reserves that cannot be produced within time.	↓
	End-user efficiencies	Permanently** reduce the oil demand due to efficiency gains	Decreases the oil price for a longer period *	Reduce the demand for oil leading to devaluations and stranded reserves	↓		
	Social behavior						
	• **Resource sharing / Uberization**	Permanently** reduce the oil demand due to sharing of resources	Decreases the oil price for a longer period *	Reduce the demand for oil leading to devaluations and stranded reserves	↓		
	• **Environmental awareness**	Permanently** reduces the oil demand	Decreases the oil price for a longer period *	Reduce the demand for oil leading to devaluations and stranded reserves	↓		
Price	**OPEC**	May adopt production quota's	Increases and stabilizes the price	Increase the value of reserves due to higher prices	↑		
	Resource base	Growing resource base increases the potential supply of oil	May lead to overproduction resulting in low oil prices. Increase the amount of stranded reserves	Low oil prices result in devaluation of oil reserves.	↓	May add to the amount of stranded reserves in combination with a declining oil market. Because more reserves are available while the market declines.	↓

* When supply remains the same or is not reduced as much as the demand or vice versa, when demand remains the same or is not reduced as much as the supply

** When assumed that the new technologies keep developing away from the use of fossil fuels

Table 5 - Effect and consequences of the developments

5. Incorporation of the developments in the valuation method

Chapter 3 has emphasized on the factors and methods that determine the value of an oil reserve and the methods that should be used to come to such a value. This has resulted in the fact that the current quantitative method of discounted cash flow methods should be extended with a more qualitative method that is able to determine the consequences of the developments in a carbon-constrained world. The previous chapter, chapter 4, has operationalized the developments and the consequences of the developments that will evolve in a carbon-constrained world. The result of the operationalization stated that the developments pose a threat for the value of oil reserves and that some reserves may end stranded when no measures are taken that incorporate the developments when valuing a reserve. This chapter, chapter 5 dives deeper into the concept of stranded reserves and the impact and consequences of the developments in a carbon-constrained world. Moreover, in this chapter the specific type of reserves that have the highest chance of getting stranded are identified and methods to account for these stranded reserves in their valuation are introduced. The research question that is associated with this chapter is as follows:

> 'Which types of reserves will experience the highest impact from the developments and how to account for these reserves in the valuation method?'

The building blocks used in this chapter

The insights, provided by chapter 2, 3 and 4, function as building blocks to answer the above research question. The building blocks from chapter 3 are the valuation methods that are currently used and are based on Discounted Cash Flows and Net Present Values as explained in paragraph 3.2 and 3.3. The building blocks from chapter 2 and 4 are the developments and the consequences of the developments on the value of oil reserves in a carbon-constrained world. These building blocks will be used to formulate a method that makes it possible to account for the developments in the valuation of the reserves. This method is formulated throughout paragraph 5.1 to paragraph 5.3.

In paragraph 5.1 the translation of the developments into characteristics of oil reserves is carried out in order to determine which characteristics of the reserves are influenced by the developments. This paragraph is based on the operationalized developments from chapter 4 and on the knowledge of oil reserves as stated in chapter 3. The characteristics represent the development and cause the chance of getting stranded. Hence, these characteristics represent the vulnerability of reserves to one of the developments.

In paragraph 5.2 the scenario-based impact analysis is conducted which determines the vulnerability of certain type of reserves to the developments in a carbon-constrained world. The scenario-based impact analysis is based on multiple possible scenarios of the developments. The scenarios are formulated based on the developments and the characteristics of the reserves as explained in paragraph 5.1. After the scenarios are formulated the analysis with the scenarios is carried out that will result in an overview of different type of reserves, their competitiveness and their chance to get stranded when considering the different scenarios. The overview that is created is further used in chapter 6 to define strategies to cope with the developments.

Paragraph 5.3 will emphasize on defining the methods of accounting for the developments in the value of the reserve. The methods are formulated using the knowledge and methods of valuing oil reserves provided by chapter 3 and the outcomes of the scenario-based impact analysis of paragraph 5.2. The formulation of the method of accounting for the developments is an extension of the currently used DCF method that functions as a building block in which the developments are integrated.

5.1 Translation of the developments in characteristics of oil reserves

The translation of the developments

The analysis of the carbon-constrained world of chapter 2 and 4 has resulted in three main developments that bare the risk of reserves to get stranded under the future developments associated with the carbon-constrained world. The three risks (regulation, demand, price) that can make reserves stranded should be included in the value as potential risks when valuing oil reserves. However, not every reserve is as vulnerable to the stranding risks, some reserves may not be influenced at all or even increase in value, while other reserves may be left stranded. Hence, the reserves should be assessed based on the characteristics that may cause the reserves to get stranded. Therefore, the developments must be translated into characteristics that make it possible to identify the reserves with the highest exposure to get stranded.

Reserves that have a high stranding potential are reserves that have a high rate for one of the three causes for getting stranded. Hence reserves are vulnerable to get stranded in a scenario with a high level of regulation, low demand or low oil prices. The three stranding risks need to be translated to characteristics of oil reserves to be able to identify which reserves have a high exposure for the stranding risks and have a chance to get stranded. The reserves can be divided in groups based on the characteristics that represent the risk and their score on that characteristic. This way its possible to express the vulnerability of different type of oil reserves to the developments in the carbon-constrained world. Starting of with the regulatory risk of getting stranded.

Stranding risk due to technology and regulation

The adoption of environmental regulation may have significant effect on the value of oil reserves as explained in chapter 4. The implementation of a carbon pricing mechanism, which bases the price on the size of the emissions, will result in different additional cost per type of reserve. More polluting reserves, based on upstream emissions, will experience higher costs than less polluting reserves. The rate of emissions is primarily determined by the *technology* that is used to extract the oil from the reserve. These different technologies and the associated emissions are described in the table with different emission per technology in table 4 on page 45. The characteristic technology is introduced because it closely resembles the environmental footprint since it reflects the upstream emissions that are made. The production technique of a reserve tells a lot about the physical Characteristics of the production process and the associated emissions to extract the oil. The reason that technology (measured in an equivalence of $kgCO_2$) is chosen instead of GHG emissions is because the technology also includes the methods of extracting the oil and for instance the devastation of the local environment. When only the emissions are included then the land use and other non-emission type of pollution are excluded while these are also vulnerable for future regulation.

The technologies are further divided based on the production technique, conventional being: onshore, offshore and artic. And, unconventional being: shale oil, tar sands and extra heavy oil. Dirty types of oil are for instance the heavy oils, oil sands and tar sands, which have a much higher footprint on the environment (both upstream and downstream). But there are also highly contested type of reserves such as arctic oil, due to its controversial interference in nature and disastrous effects of oil spills. Table 8 reflects the division of different type of reserves based on their upstream emissions and ecological footprint. Table 8 is mainly based on the findings of primarily Gordon et al., (2015) but also on Karras, 2011; Mui, Tonachel, Mcenaney, & Shope, 2010; and the Science Advisory Council (2016).

The scope of this research is set on upstream; hence the quality of the oil is less important because the emissions caused by lower qualities of oil are made downstream. But as Gordon et al., (2015) indicate, reserves that have higher emissions upstream also have more emissions downstream, because the emissions upstream are higher for the more unconventional types of oil, which in general produce more emissions downstream due to the heavier and dirtier type op oil. Therefore the outcomes including downstream would approximately result in the same label (clean, medium, dirty) for the different type of reserves but with a different scale for their environmental footprint.

Technology	Environmental footprint*		Type of oil reserves
Clean	0 - 50	$kgCO_2$ eq./barrel	Onshore conventional oil, shallow water, deep-water
Medium	50 - 100	$kgCO_2$ eq./barrel	Shale oil, ultra-deep water
Dirty	100+	$kgCO_2$ eq./barrel	Tar sands, (extra)-heavy oil, arctic oil

*Based on upstream environmental footprint

Table 6 - Technology and environmental footprint of oil reserves

Stranding risk due to lifetime and a declining market

In a carbon-constrained world, the lifetime of a reserve is important because when the demand for oil falls and the market for oil gradually declines, then fewer reserves will be needed in the future. Current producing reserves will, when competitive, remain producing till they are depleted, but reserves that are not yet developed or have a very long lifetime will suffer from the declining demand and may end stranded or get devaluated. Under the perception of the scarcity of oil, all reserves were considered to remain productive till they are fully depleted, but due to the abundance of oil and the perception of the declining oil market, their full exploitation gets less certain which change the valuation method of oil reserves.

The characteristic of reserves that is associated with the declining demand constrained and the reduction in the demand for oil is the *lifetime* of the reserves. The lifetime is based on the R/P ratio. R/P ratio stands for the duration in years that the reserve can maintain its current production capacity until the reserve is depleted. The characteristic 'lifetime' takes the R/P ration into account for reserves that are already producing but also adds the time till the start of the production for reserves that are not yet developed. Thus, the characteristic 'lifetime' is the total time till the end of production. Hence, reserves with a longer lifetime have a higher chance of getting stranded due to the decreasing demand for oil and the gradually declining oil market as a result of the carbon-constrained world.

The reserves are divided into three groups, these groups are; short, medium and long. The three groups are based on averages from the BP Statistical Review (2016) and on the declining oil demand. The reserves that have a short lifetime (0-25 years) have the highest chance of getting fully produced, according to the demand derived from the goals of the Paris Agreements. The reserves with a medium lifetime (25-50 years) have a significant chance of getting affected by the declining demand. And the reserves with a long lifetime (50+ years) have a very high chance of getting devaluated or even stranded, assuming that the demand for oil will be significantly reduced by 2067. Hence, reserves with a long lifetime (Saudi Arabia, Iraq, Iran, Canada and Venezuela) have potential to get affected by the declining demand in terms of devaluation or stranding. The lifetime of the reserves of IOCs have much smaller chances of getting stranded because their reserves have often much shorter lifetimes.

Lifetime	Range	Unit	Ownership of reserves
Short	0 – 25	Years till end of production	Brazil, Mexico, China, (IOCs), etc.
Mid	25 – 50	Years till end of production	US, Qatar, Nigeria, Libya, Russia, Kazakhstan, etc
Long	50 - 100	Years till end of production	SA, Iran, Iraq, Canada, Venezuela, Kuwait, UAE

Table 7 - Lifetime of oil reserves

Stranding risk due to breakeven cost and lower prices

Another important characteristic of reserves that determines the level of risk for a reserve is the *breakeven cost of production*. The breakeven cost of production is measured in dollars per barrel of oil and reflects the price from which the production of the oil will start to generate profit, when the market price is above the breakeven cost, or loss, when the market price falls below the breakeven cost. A reserve with low breakeven cost is more competitive and is better able to withstand periods with low oil prices. Hence reserves with low breakeven cost have a lower stranding potential when competition result in to lower oil prices.

The range of the breakeven cost that distinguishes between low-mid and mid-high are based on the current breakeven cost of oil reserves in the market (data from Rystad Energy, 2015) and the amount of reserves with certain characteristics in the market. The most cost efficient reserves are the onshore conventional reserves, especially the ones in the Middle East. The breakeven cost of these reserves range from 10 to 40 dollars per barrel. The medium expensive reserves range from 40 to 75 dollars per barrel and the most expensive reserves at the cost curve can be seen in figure 23 and range from 75 to 100 dollars per barrel. These numbers are based on data from Rystad Energy, 2015. The expensive reserves have the highest stranding potential these are projects and reserves such as (extra) heavy oil, artic oil and tar sands.

Breakeven cost	Range	Unit	Type of oil reserves
Low	0 – 40	Dollars per barrel	Conventional onshore
Mid	40 – 75	Dollars per barrel	Shale, deep water, heavy oil, ultra deep
High	75 - 100	Dollars per barrel	Tar sands, (extra) heavy oil, arctic oil

Table 8 - Breakeven cost of oil reserves

Table 11 summarizes the three characterizations from table 8, 9 and 10.

Type of reserves	Technology [kgCO_2 eq./barrel]		Lifetime [years]		Price [$/barrel]	
Conventional	Type	Emission range	Type	R/P range	Type	Price range
Onshore	Clean	0 – 50	Short - long	0 – 100	Low	0 – 40
Deep water	Clean - mid	0 – 100	Short - mid	0 – 50	Mid	40 – 75
Ultra deep water	Clean - mid	0 – 100	Short - mid	0 – 50	Mid - high	40 – 100
Arctic oil	Dirty	100+	Short - long	0 – 100	High	75 – 100
Unconventional						
Shale oil	Mid	50 – 100	Short	0 – 25	Mid	40 – 75
Heavy oil	Dirty	100+	Mid - long	25 – 100	Mid - high	40 – 100
Extra heavy oil	Dirty	100+	Short - long	0 – 100	High	75 – 100
Tar sands	Dirty	100+	Mid - long	25 – 100	High	75 – 100

Table 9 - Overview of characteristics per type of reserve

5.2 The scenario-based impact analysis

In the previous paragraph the reserves are divided in groups based on their characteristics that may cause the reserve to get stranded by the developments. Reserves that are more vulnerable to one of these developments have a higher chance of getting stranded in a carbon-constrained world. The different groups of reserves are in this paragraph exposed to different scenarios. These scenarios are based on the developments from chapter 2 and 4. This will provide insight in the impact of the developments and the vulnerability of the reserves in the different scenarios, making it possible to determine the stranding potential and the competitiveness of oil reserves. Hence the goal of the scenario-based impact analysis is to determine the impact of the developments in a carbon-constrained world on the value of oil reserves.

In this paragraph the future market conditions are formulated in multiple scenarios and an impact analysis of the different scenarios is carried out. Literature from the scenario analysis discipline is used for composing the scenario-based impact analysis because the impacts in this impact analysis are based on different scenarios and because impact analysis is one of the most important components of scenario analysis (Amer et al., 2013). The formulation of the scenarios and the impact analysis is carried out using the 'stages in scenario development' from Rounsevell & Metzger (2013), which are identical to the phases of scenario planning as described in Alessandri et al., (2004) and Swart, Raskin, & Robinson (2004).

The difference between impact analysis and scenario analysis is that in scenario analysis some very specific scenarios are analyzed and often quantified. The scenario to further analyze is mostly chosen based upon the outcome of the impact analysis. Hence, impact analysis is often seen as the basis of scenario analysis (Amer et al., 2013). The reason why the focus lays on impact analysis instead of scenario analysis is because the goal of the analysis is to identify the impact of the different scenarios and not exploring one entire scenario. Thus, completely identifying what happens in certain specific scenarios is not necessary to meet the goal.

The stages of scenario- and impact analysis

The first stage is to identify the focal question of the impact analysis regarding the reason that the analysis is carried out. In this case the focal question is aimed on determining which reserves have the highest risk to get stranded regarding the perceived market developments. Hence the focal question is formulated as follows: 'which type of reserves will experience the highest impact from the developments in a carbon-constrained world?'

The second stage, according to Rounsevell & Metzger (2013), is to identify the key drivers that affect the focal question. These key drivers are the developments associated in the carbon-constrained world that will influence the value of the reserves which come down to regulation, the oil demand and the oil price as identified and analyzed in chapter 2 and 4.

The third and fourth stages are to determine the scenario logic and describing the assumptions. In this scenario based impact analysis the logic lays in submitting the different type of reserves to the different market conditions (scenarios). The market conditions are based on scenarios of the key drivers that affect the value of the reserves and hold assumptions how the developments will turn out in the future. Hence the scenario logic aims on defining different scenarios for the different market conditions and the description of the assumption on supporting the choices that are made in the definition of the scenarios. The scenarios that determine the impact on the reserves are based on the relations and causalities between different characteristics of reserves. Based on the definition of the scenarios and their causalities and relations to the characteristics of the reserves the impact analysis can be carried out.

The fifth and last stage is the analysis of the scenarios by making an assessment of the outcomes of the scenarios and their impact deducting the results and conclusions from the outcomes of the scenarios and their impact (Rounsevell & Metzger, 2013). The fifth stage not solely focuses on the outcomes and conclusion but also on the implications that occur during the scenarios and the effects of the relations and causalities between the scenarios (Swart et al., 2004).

Because the key drivers are already identified and analyzed in chapter 2 and 4, the next section continues with the scenario logic and the assumptions made when defining the scenarios. Hence with stage three and four of the scenario development.

The logic behind the impact analysis and the scenarios

This section focuses on the definition of the logic behind the impact analysis and the scenarios for which the impact is determined that are the basis of the impact analysis analyses should be carried out. To be able to measure the impact of different scenario the following steps are to be taken:

- Definition of the scenarios
- Determination of the causalities and dominance of scenarios and characteristics
- Conduct the impact analysis
- Conduct the scenario-based impact analysis

The scenarios

The key drivers that affect the value of oil reserves in a carbon-constrained world are determined to be increasing environmental regulation, declining oil demand and low and more volatile oil prices. Hence the scenarios should be designed surrounding these three key drivers. Paragraph 5.1 emphasized on the characterization of different reserves into groups to be able to distinguish between the different types of reserves. For every characteristic three groups are designed that divides the group. These characteristics are submitted to different scenarios to determine what the impacts of the scenarios are on the stranding potential of the reserves. Three scenarios per driver are composed that distinguish between a low case, a medium case and a high case for the key drivers in a carbon-constrained world, resulting in a total of 9 different scenarios (3x3).

The regulatory scenarios

Different levels of regulation will imply different levels of additional costs for the reserves with a higher environmental footprint. The lowest level of cost is reached in the low regulation scenario whereas the highest level of additional costs and consequences are apparent in the high regulation scenario. The mid scenario lies between the low and high case. The low regulation scenario matches the business-as-usual scenario (BAU) in which no additional regulation is implied to address climate change.

Low regulation (BAU)	The low case regulatory scenario implies the situation without the adoption of significant forms of environmental regulation based on carbon pricing. This means that there are no changes compared to the current situation and there is no competitive advantage for cleaner reserves based on their emissions.
Mid regulation	Carbon pricing imposes additional cost for the emission of GHG relatively to the size of emissions. Hence dirty reserves have to pay higher cost than clean reserves, which result in an advantage of clean reserves over dirty reserves. The business case for dirty reserves is affected which increases their chance of getting stranded. The additional effect of the mid regulation scenario is that the demand for oil will decrease due to the carbon pricing mechanisms and subsidies for substitute products. The decreasing demand will result in increasing competition among oil producers, resulting in oversupply and a lower oil price. This effect is less strong than in the high regulation scenario.
High regulation	The emission of GHG is highly priced and contested oil reserves such as arctic oils are even prohibited. Dirty oils are really affected by the regulations and their competitiveness is further reduced which has as a result that most of the dirty oil reserves are highly impacted by the high forms of regulation and severely increases their chance of getting stranded. The additional effect of the high regulation scenario is a decreasing oil demand as the result of carbon pricing mechanisms and subsidies for substitute products. This decreasing demand for oil results in increasing competition among oil producers resulting in oversupply and hence lower oil price. The additional effects further affect the competitiveness of dirty oil reserves due to their influence on the demand and the price.

The demand scenarios

The demand scenarios reflect the different pathways in the demand for oil. The low demand pathway resembles a severe reduction in the demand for oil which is according to the IEA 2°C pathway. The high demand scenario is the business-as-usual scenario in which the demand for oil does not decline and the goals from the Paris Agreements are not met. The mid demand scenario lies between the low and high demand scenario.

Low demand	The demand follows the IEA 2°C pathway as described earlier on in this research. The IEA 2°C pathway forecast a growing demand for oil until 2020 and thereafter keeps decreasing until the use of oil is negligible. Reserves with a long lifetime are getting stranded due to the rapid

	declining market for oil and even some reserves with a medium lifetime have a significant chance of getting stranded. An additional effect of the low demand scenario is that it triggers oversupply due to the increased competition among oil producers, resulting in low oil prices. The low oil prices negatively affect the business case of reserves with high breakeven cost and result in a high chance of getting stranded. In the low demand scenario profit optimization becomes important before oil ends up worthless, thus the most competitive reserves get increasingly valuable.
Mid demand	The mid demand resembles the demand that is in between business as usual and 2°C pathway. Only reserves with a long lifetime have a chance of getting stranded.
High demand (BAU)	The demand goes as business as usual, no real decline is apparent and the world is heading towards a rate of climate change around 4°C. Even the reserves with a long lifetime are needed to fulfill the global oil demand. The high demand will also increase the oil price and it will result in the adoption of regulation, however the regulation does not have effect because all reserves are needed to fulfill the world's oil demand.

The price scenarios

The price scenarios have a close relation to the breakeven cost of oil reserves. Expensive reserves are less competitive than the reserves with low breakeven cost and are therefore also more vulnerable to get stranded. In situations with low prices, reserves with high breakeven cost may encounter problems because their costs are higher than their income.

Low price	Low price will result in reserves with high breakeven cost to end up stranded. The low price scenario resembles the situation in which the fight for market share due to increasing competition materializes. This will have significant influence on the oil price resulting in a low average oil price over the entire period. The average oil price in the oil price scenario lays around $40 per barrel. The additional effect of a low oil price is that it increases the demand for oil due to its low price.
Mid price	The mid price scenario is the scenario in which there will be middle range prices. The competition for market share does not really materializes resulting in prices around the $60 per barrel. The effect of a mid price is that reserves with high breakeven cost have an increased chance of getting stranded.
High price	In the high price scenario the perspective of scarce oil dominates resulting in high oil prices. This result in high average oil prices over the entire period of at least $80 per barrel, with which all reserves are feasible. The additional effect of the high price scenario is a quicker adoption of substitute products, resulting in reserves with a long lifetime to have a higher chance of getting stranded.

Causalities of the scenarios

Some of the scenarios have additional effects that are implied by the causal relations of the characteristics in certain scenarios. These causal relations result in the reaction of a reserve with a certain characteristic to influence another characteristic in that same scenario. An example of this causal effect, is that in a high regulation scenario not only the characteristic with a direct link (technology) to regulation has a chance of getting stranded but it result in reserves with long lifetimes to have an increased chance of getting stranded, as well as reserves with high breakeven cost. These causal relations are described as the additional effects in the previous section. Although the focus lays on the downward potential that cause risks to get stranded, there is also upward potential that increases the value of reserves. An example is a low oil price, which increases the demand for oil. In the following sections the upward potential result in a lower impact on reserves. However, a low impact remains a low impact even with additional upside potential, hence the upside potential is visible in the table but it is taken into account. Figure 25 shows the causalities of the scenarios.

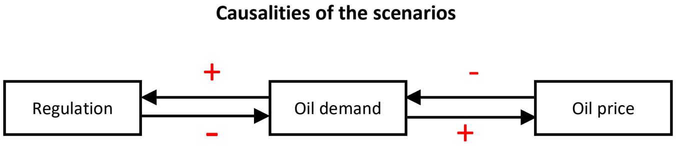


Figure 25 - Causalities of the scenarios

Impact analysis of the scenarios on the reserves

The impact analysis is a technique used in scenario analysis to identify and present the impact of certain scenarios for different characteristics (Amer et al., 2013). Impact analysis is based on the underlying causal linkages among the different scenarios, which makes it possible to identify the scenarios and characteristics with the highest impact (Schnaars, 1987). The impact analysis in this case identifies the effects of a certain scenario on a single characteristic. Thereby determining the consequences for the value of the reserve and the possibility for the reserve to get stranded.

The characterizations of the reserves, the scenarios and the causalities determine the outcome of the impact analysis. Hence, choosing different scenarios and redefining the characteristics will also change the outcome of the analysis, which makes it important to clearly define the chosen scenarios and characteristics. When the impact analysis is carried out, it is possible to identify the effects of the regulatory-, demand-, and price scenarios on the stranding potential of the different type of oil reserves. Reserves that experience a high impact from the scenarios also have a high chance of getting stranded. The impact and effect of each scenario on the different characteristics are illustrated by the different colors in table 12.

Characteristic:		Technology			Lifetime			Breakeven cost		
Scenario	Type	Clean	Mid	Dirty	Short	Mid	Long	Low	Mid	High
Regulation scenarios	Low	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Mid	🟩	🟩	🟨	🟩	🟩	🟨	🟩	🟩	🟨
	High	🟩	🟨	🟧	🟩	🟨	🟧	🟩	🟨	🟧
Demand scenarios	Low	🟩	🟩	🟩	🟩	🟨	🟧	🟩	🟨	🟧
	Mid	🟩	🟩	🟨	🟩	🟩	🟨	🟩	🟩	🟨
	High	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Price scenarios	Low	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟧
	Mid	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨
	High	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩

🟩 Low impact 🟨 Medium impact 🟧 High impact

Table 10 - Impact of scenarios for different characteristics of oil reserves

Results and characteristics

The impact analysis shows that the high regulation scenario and the low demand scenario have the highest impact on the value of oil reserves. Dirty- and medium clean reserves, reserves with a long- and medium long lifetime and reserves with high- and medium breakeven cost experience a high or medium high impact from the high regulation scenario. The low demand scenario results in reserves with a mid lifetime and mid breakeven cost to have a high chance to get stranded and reserves with a long lifetime and reserves with high breakeven cost to get stranded. When looking at the different characteristics of the reserve, the reserves with high breakeven cost show the largest vulnerability to get stranded. In 6 of the 9 scenarios they have a significant chance of getting stranded. Of these 6 scenarios the reserves with high breakeven cost get stranded in the mid and high regulation case and the low price case. In the other 3 scenarios, the reserves have a high chance of getting stranded. The reserves that have the second largest chance of getting stranded are the reserves with a long lifetime, from the 9 scenarios they end up stranded in 2 scenarios and have a high stranding chance in 3 scenarios.

Dominant scenarios

Scenarios that contain much causality, like the high regulation scenario, are more dominant than scenarios with less causality. The scenarios that evoke such causalities influence the outcome of other characteristics in that scenario which is the reason behind the dominance. The high regulation scenario and the low demand scenario are the two dominant scenarios because they have the highest impact on the value of the reserves. Thus, when these scenarios occur they have the highest possible impact on the reserves. When policy makers want to have an impact on the system, they should aim on addressing these dominant scenarios by implementing policies.

Scenario-based impact analysis

The impact analysis from the previous section has determined the level of vulnerability of certain individual characteristics of reserves in different scenarios. However, each oil reserve possesses all three characteristics. This section will continue the analysis by emphasizing on the stranding potential of reserves with a combined set of characteristics. Thus, instead of looking at the impact of a certain scenario on one characteristic, the focus shift to determining the impact of the scenarios on reserves containing all three characteristics. This makes it possible to reflect more accurately on the consequences of the scenarios for the specific reserves.

The scenario-based impact analysis is not a basic concept in the scenario analysis and impact analysis literature, however it builds on the same theories and concepts of the standard impact analysis as described in the previous section and by Amer et al., (2013) and Rounsevell & Metzger (2013). The approach differs from the other methods because it is more comprehensive than the standard impact analysis due to the integration of multiple characteristics of the reserves.

The set-up of the scenario-based impact analysis is established in the following way; there are 3 characteristics for every reserve; these characteristics are further divined in three sub-groups, which mean that there are 27 different possible types of reserves (3^3). These 27 types of reserves should be submitted to the 9 scenarios that are defined, resulting in 243 cases. Figure 26 shows the cases that will be examined for one scenario (scenario X) and indicates how table 13 on the next page is formulated.

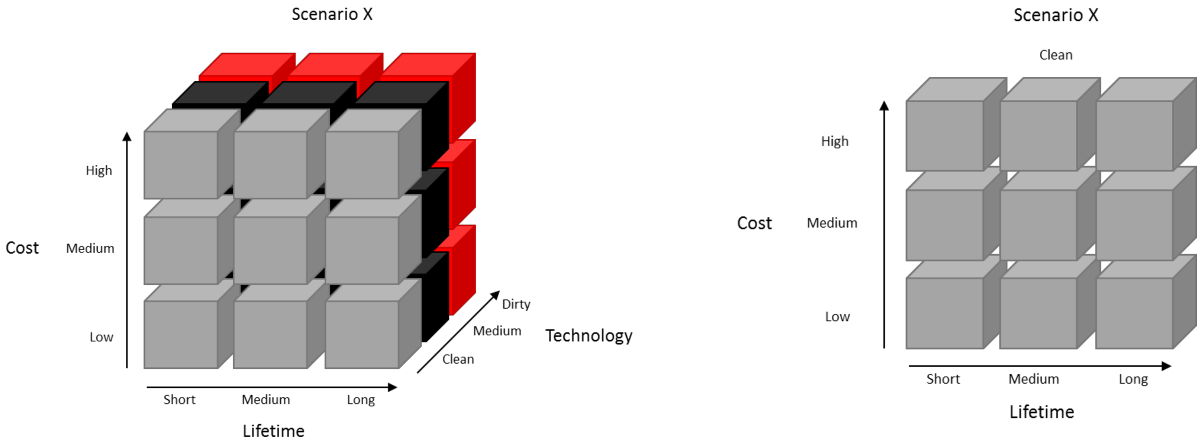


Figure 26 - Characteristics and scenarios

The picture at the right side in figure 20 shows all 9 (of the 27) types of reserves that score 'clean' on the technology characteristic. These reserves are the most competitive reserves based on technology. The black 'slice' in the left picture of figure 20 shows the medium clean reserves and the red slice the dirty reserves. Of the clean reserves, the reserves that are at the bottom left are the most competitive reserves based on cost and lifetime because they are low in breakeven cost and short in lifetime. In contrary, the reserves at the top right are the least competitive reserves of the clean reserves because they are high in breakeven cost and have a long lifetime. When these less competitive reserves are submitted to the scenarios they have a higher chance of getting stranded than the more competitive reserves. Table 13 on the next page shows the impact of the 9 scenarios on all 27 different types of reserves. Table 13 is again based on the characteristics of the reserves, the scenarios and the causal linkages between the reserves.

Scenario-based impact analysis

Low regulation scenario														
Techn.		Clean			Techn.		Mid			Techn.		Dirty		
Cost	H	🟩	🟩	🟩	Cost	H	🟩	🟩	🟩	Cost	H	🟩	🟩	🟩
	M	🟩	🟩	🟩		M	🟩	🟩	🟩		M	🟩	🟩	🟩
	L	🟩	🟩	🟩		L	🟩	🟩	🟩		L	🟩	🟩	🟩
		S	M	L			S	M	L			S	M	L
		Lifetime					Lifetime					Lifetime		

Medium regulation scenario														
Techn.		Clean			Techn.		Mid			Techn.		Dirty		
Cost	H	🟨	🟨	🟨	Cost	H	🟧	🟧	🟧	Cost	H	🟧	🟧	🟧
	M	🟩	🟩	🟨		M	🟨	🟧	🟧		M	🟧	🟧	🟧
	L	🟩	🟩	🟩		L	🟩	🟩	🟨		L	🟨	🟨	🟧
		S	M	L			S	M	L			S	M	L
		Lifetime					Lifetime					Lifetime		

High regulation scenario														
Techn.		Clean			Techn.		Mid			Techn.		Dirty		
Cost	H	🟨	🟧	🟧	Cost	H	🟧	🟧	🟧	Cost	H	🟧	🟧	🟧
	M	🟩	🟨	🟧		M	🟨	🟧	🟧		M	🟧	🟧	🟧
	L	🟩	🟩	🟩		L	🟩	🟨	🟧		L	🟧	🟧	🟧
		S	M	L			S	M	L			S	M	L
		Lifetime					Lifetime					Lifetime		

Low demand scenario														
Techn.		Clean			Techn.		Mid			Techn.		Dirty		
Cost	H	🟧	🟧	🟧	Cost	H	🟧	🟧	🟧	Cost	H	🟧	🟧	🟧
	M	🟩	🟨	🟧		M	🟨	🟧	🟧		M	🟨	🟧	🟧
	L	🟩	🟩	🟨		L	🟩	🟩	🟨		L	🟩	🟨	🟧
		S	M	L			S	M	L			S	M	L
		Lifetime					Lifetime					Lifetime		

Medium demand scenario														
Techn.		Clean			Techn.		Mid			Techn.		Dirty		
Cost	H	🟨	🟨	🟧	Cost	H	🟨	🟨	🟧	Cost	H	🟨	🟧	🟧
	M	🟩	🟩	🟨		M	🟩	🟩	🟨		M	🟩	🟨	🟧
	L	🟩	🟩	🟩		L	🟩	🟩	🟨		L	🟩	🟩	🟨
		S	M	L			S	M	L			S	M	L
		Lifetime					Lifetime					Lifetime		

High demand scenario														
Techn.		Clean			Techn.		Mid			Techn.		Dirty		
Cost	H	🟩	🟩	🟩	Cost	H	🟩	🟩	🟩	Cost	H	🟩	🟩	🟩
	M	🟩	🟩	🟩		M	🟩	🟩	🟩		M	🟩	🟩	🟩
	L	🟩	🟩	🟩		L	🟩	🟩	🟩		L	🟩	🟩	🟩
		S	M	L			S	M	L			S	M	L
		Lifetime					Lifetime					Lifetime		

Low price scenario														
Techn.		Clean			Techn.		Mid			Techn.		Dirty		
Cost	H	🟧	🟧	🟧	Cost	H	🟧	🟧	🟧	Cost	H	🟧	🟧	🟧
	M	🟨	🟨	🟨		M	🟨	🟨	🟨		M	🟨	🟨	🟨
	L	🟩	🟩	🟩		L	🟩	🟩	🟩		L	🟩	🟩	🟩
		S	M	L			S	M	L			S	M	L
		Lifetime					Lifetime					Lifetime		

Medium price scenario														
Techn.		Clean			Techn.		Mid			Techn.		Dirty		
Cost	H	🟨	🟨	🟨	Cost	H	🟨	🟨	🟨	Cost	H	🟨	🟨	🟨
	M	🟩	🟩	🟩		M	🟩	🟩	🟩		M	🟩	🟩	🟩
	L	🟩	🟩	🟩		L	🟩	🟩	🟩		L	🟩	🟩	🟩
		S	M	L			S	M	L			S	M	L
		Lifetime					Lifetime					Lifetime		

High price scenario														
Techn.		Clean			Techn.		Mid			Techn.		Dirty		
Cost	H	🟩	🟩	🟨	Cost	H	🟩	🟩	🟨	Cost	H	🟩	🟩	🟨
	M	🟩	🟩	🟨		M	🟩	🟩	🟨		M	🟩	🟩	🟨
	L	🟩	🟩	🟩		L	🟩	🟩	🟨		L	🟩	🟩	🟨
		S	M	L			S	M	L			S	M	L
		Lifetime					Lifetime					Lifetime		

Table 11 - Scenario-based impact analysis

Results from the scenario-based impact analysis

The more actively climate chance is addressed the more the reserves will be impacted because the use of oil declines in these scenarios resulting in reserves to end up stranded. This behavior becomes visible when comparing the high regulation and the low demand scenarios with the low regulation and high demand scenarios. Hence scenarios with low regulation and high demand will not limit the amount of GHG to below 2°C. These scenarios resemble the business-as-usual scenarios when climate change is not actively addressed.

The impact of all scenarios together lead to the following table; in this table the scores of the impacts are set by adding the outcomes of the scores of the impact analysis based on the 9 scenarios. Green 'fields' in the table do not affect the impact of the scenarios, orange fields add 1 to the impact and red fields add 2 to the score of impact. The combined scores of the 9 scenarios together form the eventual impact, which is again rated with low for scores from 0-4, mid for score from 5-8 and high for scores from 9-12.

Clean reserves				Mid clean reserves				Dirty reserves			
Lifetime	Cost	Impact		Lifetime	Cost	Impact		Lifetime	Cost	Impact	
Short	Low	0	Low	Short	Low	0	Low	Short	Low	3	Low
Mid	Low	0	Low	Mid	Low	1	Low	Mid	Low	4	Low
Long	Low	1	Low	Long	Low	6	Mid	Long	Low	8	Mid
Short	Mid	1	Low	Short	Mid	4	Low	Short	Mid	6	Mid
Mid	Mid	3	Low	Mid	Mid	7	Mid	Mid	Mid	8	Mid
Long	Mid	8	Mid	Long	Mid	9	High	Long	Mid	10	High
Short	High	8	Mid	Short	High	10	High	Short	High	10	High
Mid	High	9	High	Mid	High	10	High	Mid	High	11	High
Long	High	11	High	Long	High	12	High	Long	High	12	High

Table 12 - Impact of scenarios on different reserves

The scores (table 14) lead to the following ranking of competitiveness of the different reserves based on the impact analysis of the 9 different scenarios. This result in table 15 which reflect the competitiveness of oil reserves.

Techn.		Clean reserves			Techn.		Mid reserves			Techn.		Dirty reserves		
Cost	H	🟨 8	🟧 9	🟧 11	Cost	H	🟧 10	🟧 10	🟧 12	Cost	H	🟧 10	🟧 11	🟧 12
	M	🟩 2	🟩 3	🟨 8		M	🟩 4	🟨 7	🟧 9		M	🟨 6	🟨 8	🟧 10
	L	🟩 0	🟩 0	🟩 0		L	🟩 0	🟩 1	🟨 6		L	🟩 3	🟩 4	🟨 8
		S	M	L			S	M	L			S	M	L
		Lifetime					Lifetime					Lifetime		

🟩 Most competitive reserves 🟨 Medium competitive reserves 🟧 Least competitive reserves

Table 13 - Competitiveness of reserves based on impact of scenarios

General insights provided by the impact analysis

There will always be the need of a base load for the fabrication of certain products such as plastics. Only the most competitive reserves are able to fulfill this task and will not get stranded in any of the scenarios, not even the reserves with long lifetimes. These most competitive reserves are the reserves with low cost, have a short mid or long lifetime, and make use of a clean technology. Reserves that have such characteristics are the conventional reserves that produce light oil. Most of these types of reserves lay in the Middle East in countries such as Saudi Arabia, Iran and Iraq, but also in Russia and some smaller ones in Norway.

The reserves that have the highest chance of getting stranded are the reserves that are the least competitive. These are reserves with high cost, a long lifetime and make use of dirty technology. The least competitive reserves have scores between 9 and 12 for their impact and are the red reserves in table 15. The only scenarios in which they do not get impacted are the low regulation scenario and the high demand scenario. Reserves that are among this least competitive type are the (extra) heavy oil reserves in Venezuela, the shale oil reserves in Canada and, when discovered, the reserves in the artic areas.

Characteristic specific insights provided by the impact analysis

Technology

The technology of the reserves reflected in the clean, mid and dirty reserves has impact on the reserves. As can be seen in table 15, dirty technologies have a higher chance of getting stranded. 7 of the 9 dirty reserves are at least medium impacted in the different scenarios. From these 7 that are impacted, 4 are heavily impacted. Moreover, when considering the clean reserves only 4 are impacted by the scenarios from which 2 are heavily impacted.

There is not a large difference between the least competitive medium clean reserves and dirty reserves. This is because the effects of the regulation increase the cost of the more dirty type of reserves but at the same time, due to the causality the market starts declining and oil prices get lower, hence reserves that are expensive will already be impacted from the lowering market price as the result of the regulation.

Breakeven cost
The characteristic 'high breakeven cost' is of the three characteristics the least competitive and 9 of the 9 reserves with high breakeven cost are highly impacted in 6 out of the 9 scenarios. All but 1 reserve type with high breakeven cost experiences the largest impact from the different scenarios and therefore has a high chance of getting stranded. The breakeven cost is the main cause of reserves having a high chance to get stranded. This is due to the causality of the regulatory scenarios and the demand scenarios on the market price for oil. Hence, there are many scenarios in which the price decreases and reserves with high breakeven cost are impacted and face the chance of getting stranded. This outcome is inline with the outlook of the carbon-constrained world and the theory regarding peak oil demand.

Lifetime of reserves
Of the 9 types of reserves with long lifetimes, only the most competitive reserves are not impacted by the different scenarios in such a way that they have a chance to get stranded. Reason for this is the fact that the most competitive reserves (clean and cheap) will always be needed to produce certain products such as plastics. Hence these reserve do not get stranded and will be able to compete on price when the market for oil starts to decline, but these are only the clean, low cost reserves with long lifetimes. When one of the other characteristics gets less competitive (increasing cost, less clean) the chance of getting stranded immediately increases. Thus, from the reserves with long lifetimes, only the clean ones have a high chance of remaining in business, the dirty and costly ones will have a significant chance of getting stranded.

The competitiveness of standard type of reserves
The following two tables (16 and 17) show the competitiveness of the standard type of reserves by integrating the characteristics of different type of reserves (table 17) in the outcome of the scenario-based impact analysis. The data regarding the technology of the reserves is based on (Gordon et al., 2015), the data regarding the lifetime on the BP Statistical Review (2016) and the data regarding the breakeven cost of the reserves on data from Rystad (2016). Table 16 shows how there are many reserves that are among the least competitive type (dirty high cost and medium to long lifetime. These reserves are arctic oil, (extra) heavy oil, and tar sands and have a significant chance of getting stranded in a carbon-constrained world.

Table of competitiveness

		Technology								
Techn.		Clean reserves			Mid reserves			Dirty reserves		
Cost	High	🟨 3	🟧 3	🟧	🟧 3	🟧 3	🟧	🟧 4, 6, 7, 8	🟧 4, 6, 7, 8	🟧 4, 6, 7, 8
	Mid	🟩 2, 3	🟩 2, 3	🟨	🟩 2, 3, 5	🟨 2, 3	🟧	🟨 6	🟨 6	🟧 6
	Low	🟩 1	🟩 1	🟩 1	🟩	🟩	🟨	🟩	🟩	🟨
		S	M	L	S	M	L	S	M	L
		Lifetime			Lifetime			Lifetime		

🟩 Most competitive reserves
🟨 Medium competitive reserves
🟧 Least competitive reserves

Table 14 - Competitiveness of different type of oil reserves

#	Type of reserves	Technology [kgCO_2 eq./barrel]		Lifetime [years]		Breakeven cost [$/barrel]	
	Conventional	Type	Emission range	Type	R/P range	Type	Price range
1.	Onshore	Clean	0 – 50	Short - long	0 – 100	Low	0 – 40
2.	Deep water	Clean - mid	0 – 100	Short - mid	0 – 50	Mid	40 – 75
3.	Ultra deep water	Clean - mid	0 – 100	Short - mid	0 – 50	Mid - high	40 – 100
4.	Arctic oil	Dirty	100+	Short - long	0 – 100	High	75 – 100
	Unconventional						
5.	Shale oil	Mid	50 – 100	Short	0 – 25	Mid	40 – 75
6.	Heavy oil	Dirty	100+	Short - long	0 – 100	Mid - high	40 – 100
7.	Extra heavy oil	Dirty	100+	Short - long	0 – 100	High	75 – 100
8.	Tar sands	Dirty	100+	Short - long	0 – 100	High	75 – 100

Table 15 - Overview of different type of reserves and their characteristics

Secondary application of the outcome of the scenario based impact analysis

The scenario-based impact analysis is used to determine the vulnerability of the different type of oil reserves to the developments in a carbon-constrained world. This has lead to the overview with the competitiveness (table 16), which can be used to determine the urgency for reserves to value or revalue their reserves. If a reserve is vulnerable to the developments and therefore less competitive in a carbon-constrained world then the (re)valuation of the reserve by the owner is more urgent because it will have larger consequences.

The secondary application of the outcome of the scenario-based impact analysis is the usage of the table of competitiveness as a framework to analyze and enhance the value of a reserve or entire portfolio of an oil company. The table reveals the vulnerability of reserves to stranding risk by positioning the reserves in the table based on the three characteristics of a reserve that can make a reserve get stranded. Improving the position of a reserve on this table means increasing its competitiveness. Defining strategic measures that can improve the competitive position of a reserve will benefit its owner because it reduces the chance to get stranded and increases the value of the reserve. Chapter 6 will illustrate how the competitive position of an oil reserves can be used to improve the value of oil reserves by increasing the competitiveness and therewith reducing the chance that the reserves gets stranded.

5.3 Accounting for the developments in the value of oil reserves

As explained in the previous paragraph, the developments in the market associated with the decarbonization of the economy create additional risk for oil reserves. The traditional valuation methods do not account for these developments, which result in overestimations of the value of the reserves. Hence the true value of oil reserves may significantly differ when incorporating the developments in a carbon-constrained world. Especially for the reserves with a high vulnerability to get stranded should be determined whether they are economically viable in a carbon-constrained world by accounting for the developments in the valuation process. Accounting for the developments may prevent the reserves from getting stranded since it enables the owner to take measures before the reserve gets stranded.

This paragraph will focus on how companies should account for the developments when valuing oil reserves. There are two methods to account for the developments in the value of oil reserves. One method is to consider the development as an additional risk. Accounting for additional risk such as the risk to get stranded can be settled in the discount rate. Another method is through direct incorporation in the valuation process. Both methods are discussed in this paragraph and their appropriateness is determined. Although an attempt is made to fully account for the developments, completely incorporating is not possible due to the uncertainties surrounding the developments. Hence the emphasis lays primarily on the method of implementing the reserves.

Accounting for additional risk using the discount rate

The risk associated with the development can be incorporated in the discount rate when valuating oil reserves. The discount rate as explained in chapter 3.3 represents the factor for which cash flows should be corrected to represent the true value of the project. To be able to represent this true value, the discount rate should internalize the time value of the money invested, and the risks associated with the project. If the discount rate is not properly set, then the value of the reserve does not properly reflect the fair market price (Gustavson, 1999). Currently, companies in the oil sector do incorporate forms of additional risk, but these risks are primarily political risk, operational risk, and price risk but do not include the risk that reserves get stranded. As of today, reserves that are proved and developed are most often considered as 100% certain that they will be fully produced. However, the drop in oil prices since mid 2014 has shown that even the reserves that are currently producing still have additional risk in the form of stranding risk and they may not get fully produced at all when prices remain at a low level.

The risk-adjusted discount rate

The additional risk can be calculated through the risk-adjusted discount rate (RADR) (Moore, 2009), when projects have to cope with additional risk. The level of the RADR is determined through the risk-free interest rate and the risk premium (Fama & French, 2004b). The *risk-free interest rate* would be the appropriate rate to use if the investment contains no risks and when the full recovery of an investment is certain. However, no investment is completely risk free, hence the *risk premium* is the measure for the level of risk associated with the investment. The risk premium is the difference between the *market rate of return*, which reflect the risk of investments in a specific market, and the *risk-free rate of return*, which is the rate of return of an investment based on zero risk (Fama & French, 2004a). The risk adjusted discount rate suggest, that the risk premium should be multiplied by the level of the additional risk factor (β) that resembles the additional market risk to be able to calculate the discount rate that incorporates the correct level of risk. The additional risk factor by which the risk premium is multiplied, is a factor rate which has a value of 1.0 when there is no additional risk and can increase to for instance 1.5 or 2.0 when there is a lot of additional risk. The risk is set based on for instance perceived developments in the market, or in the case of oil, the risk in the oil market. The previous is summarized by the following two formulas:

$$risk\ adjusted\ discount\ rate = risk\ free\ rate + risk\ premium$$

$$risk\ premium = (market\ rate\ of\ return - risk\ free\ rate) * \beta$$

The reserve adjustment factor

The RADR gets widely used by companies and its use is relatively straightforward and easy to use, however the RADR assumes that all reserves are subject to the same level of risk because the same discount rate is used for different reserves since the discount rate is based on the market conditions. To distinguish between reserves with a different classification the reserve adjustment factor (RAF) is used which determines the levels of risk when valuing different type of oil reserves based on reserve classification such as proven and probable reserves (paragraph 3.1). Although some companies use this reserve adjustment factor they only distinguish between the classifications of reserves and do not (yet) correct for the specific type of reserves.

If a company wants to account for the stranding risk of oil reserves, a possible solution is to broaden the use of the reserve adjustment factor from solely distinguishing between classifications to also distinguish between reserve characteristics. To be able to determine the correct rate of the RAF for different reserves, the overview of the 'competitiveness of oil reserves' (table15) that resulted from the scenario-based impact analysis can be used. Reserve types that are highly impacted should get higher discount rates than reserves that are less impacted by the developments.

Although the approach of the RAF distinguishes between risks for different type of reserves and could include the stranding risk when the RAF is adequately set, it still assumes that the risk does not change during the entire lifetime of the reserve. Such a fixed discount rate implies a single period model (NYU Stern, 2007). Myers and Turnball (1977) note that a single period model is inappropriate when the systemic risk increases, which is the case for stranded reserves as the result of the decarbonization of the economy. Therefore, Myers and Turnball advise to use alternative methods when a dynamic period model is advised.

Alternative methods to account for stranding risk

The incorporation of additional risk in the discount rate is not the most accurate method according to Weitzman (2001) due to the sensitivity of the value to changes in the discount rate. Therefore, other methods to incorporate the risk for reserves to get stranded should also be considered because theoretically the discount rate does not allow for risk to increase during the project (Weitzman, 2001).

As stated in chapter 3, the value of a reserve is reflected by the following formula:

$$Net\ benefit = (Price * Quantity - Costs) * Timing$$

$$Price * Quantity = Revenue$$

Using the discount rate, integrates the risk in the timing component of the previous formula by correcting the cash flow with rates and factors. However, it is more accurate to directly integrate the developments in the value through the components to which they apply. Hence the implementation of environmental regulation applies to the cost component because it increase the operating cost as the result of additional payments for the emission of GHG associated with the production of oil from the reserve. Moreover, a declining oil market result in a lower output from the reserves and hence applies to the quantity component in the formula. The increased competition and the associated lower oil prices apply to the price component in the formula.

Figure 27 below reflects the value of an oil reserve using the traditional approach of the value of a reserve. It reflects a simplified depiction of the positive revenue from a reserve and is derived from the production profile of a reserve and is multiplied with the average oil price over the time period the reserve is active. The y-axis represents the revenue, which is the quantity of oil that is produced, multiplied with the oil price. The oil price is assumed to be a fixed average over the lifetime of the reserve. This makes it possible to show the effect of the developments on the value of a reserve. The CAPEX and OPEX in the figure represent all direct cost (capital and operational) associated with the production of oil from the reserve. The EBITDA reflect the "earnings before interest, tax, depreciation and amortization", hence only a small part of the area of the EBITDA is the profit or "net income" from the reserve. The economic limit shows the point at which the cost get equal to the revenue, meaning that there will be no net income left and further exploitation is no longer economically viable. The higher the CAPEX + OPEX the lower the net income will be. Likewise, lower revenue will also have a negative effect on the net income. Next sections will emphasize on the effect of the developments on the value of a reserve and how to account for the developments to accurately reflect the value of the reserve.

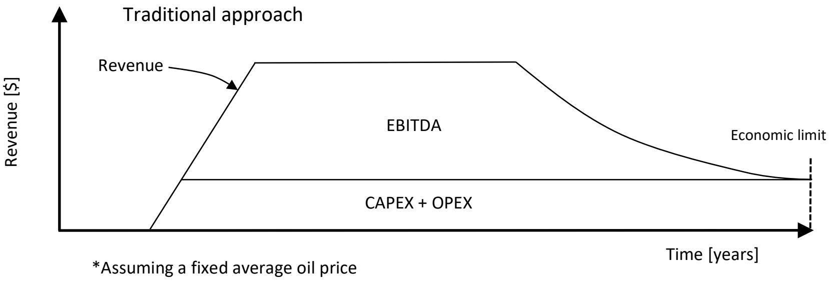


Figure 27 - Traditional approach of the value of a reserve

Accounting for regulatory stranding risk

The regulatory risk can materialize through a carbon pricing mechanisms of which a carbon tax is perceived to be the most effective form and has the highest chance to be implemented. A carbon tax will imply additional cost for upstream oil companies due to the emission of CO_2 and other GHGs during the production process. The additional cost may have a large impact for an oil company especially when the company has a relatively high footprint in combination with high breakeven cost. Hence it is more accurate to directly incorporate the tax in the cost function of the reserve instead of increasing the discount rate.

There are already some companies (primarily the majors) that incorporate the effects of a carbon tax when valuing oil reserves for their profitability by using a shadow carbon tax. A shadow carbon tax is not a real tax but is only used to calculate what the impact of environmental regulation will be for the viability of a project and is primarily used for the investment decision. Although some oil majors use the tax for investment decisions of new projects, most do not account for the carbon tax in reserves that are already producing, which still leaves the reserve vulnerable to get stranded or devaluated. Figure 28 shows the effect of a carbon tax for the value of an oil reserve.

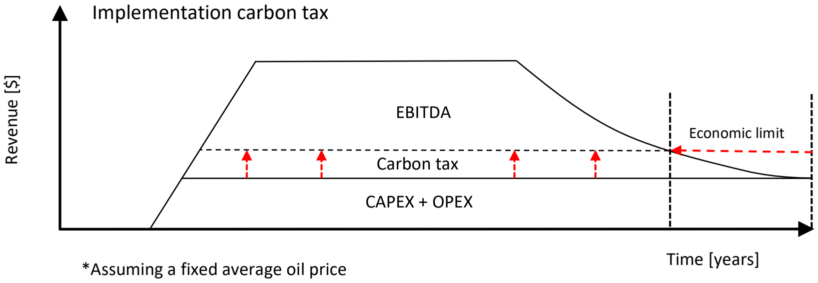


Figure 284 - Accounting for environmental regulation

Figure 28 shows how a carbon tax increases the operational cost of an oil reserve. Other forms of carbon pricing will have approximately the same effect on the value of a reserve. These increased costs will reduce the profit from the reserve because the revenue will remain the same because price for which the oil is sold is established in the market, which makes it impossible for oil companies to raise their oil price. Another effect of a carbon tax is a reduction in the economic limit of the reserve. The limit will be reached sooner due to the increased operating costs.

A carbon tax for an oil project is not as fixed as figure 28 shows. A smaller production will generate fewer emissions due to less activity. However at the end of the production cycle when the production declines enhanced oil recovery methods are used to get the last bit of oil out of the ground. These enhanced oil recovery methods generate a higher environmental footprint. But for simplicity the carbon tax is in this example assumed to be more or less stable during the entire project because the fewer emissions in the begin will more or less compensated by the higher emissions at the end.

The main uncertainties that companies have to cope with when incorporating a (shadow) carbon tax in their valuation process are the moment when the tax should be incorporated and the level of the tax. These two variables are dependent on (local) politics, which makes it impossible to determine beforehand. Shell as example already includes a carbon tax of $40 per kg$CO_2$ for every reserve that they valuate to prevent the reserves from getting economically unviable to extract in the future. However the question remains whether a price of $40 per kg$CO_2$ is sufficient to cover the additional cost when a carbon tax is implemented. If a carbon tax is implied and the tax rate increases over time then oil companies may be largely impacted due to the long lifecycles of oil reserves. Hence during the investment decision and appraisal phase multiple scenarios for the carbon tax should be explored to determine the viability of the reserve under different levels of carbon tax. Therewith reducing the chance that investment decisions that are made now will turn out to be economically unviable in the future.

An addition to the method of determining the value of an oil reserve under different scenarios for a carbon tax is to determine the maximum carbon tax for which the project is still profitable. This method is almost equal to determining the internal rate of return in NPV methods, thus an "internal rate of carbon tax" can be calculated to determine the maximum carbon tax with which the reserve will still generate a profit. This method makes it possible to determine which reserves of a portfolio are vulnerable to get stranded under a certain carbon tax.

Accounting for the risk of the declining oil market and oil demand

The abundance of oil, substitute products and social behavior force the demand for oil to gradually decline. The shrinking market result in reserves not able to operate at their full capacity. There are two ways to cope with such a reduction in oil demand; one, reserve will account for all necessary reduction or; two, the reduction is accounted for by multiple reserves. It may happen that an entire reserve (the least competitive) gets stranded in the case that one reserve accounts for all necessary reduction in order to maintain the production levels at the other reserves. In this case the value of the reserve will significantly decline and fall to zero if it will not be further produced.

A reduction in the output of a reserve reduces the revenues and lowers the value of the reserve. Oil companies should therefore, when determining the value of a reserve, account for a lower than expected oil output. The least competitive reserves of a portfolio will, in most cases, experience the highest impact from a decline in the oil demand. Hence the least competitive reserves should account for a higher reduction in output than the competitive reserves, which implies that the rate of reduction depends on the competitive position of the reserve within a portfolio. When multiple reserves must reduce their production the situation as depicted in figure 29 will occur. The production can only be increased, if the market share of the company or the demand for oil increases.

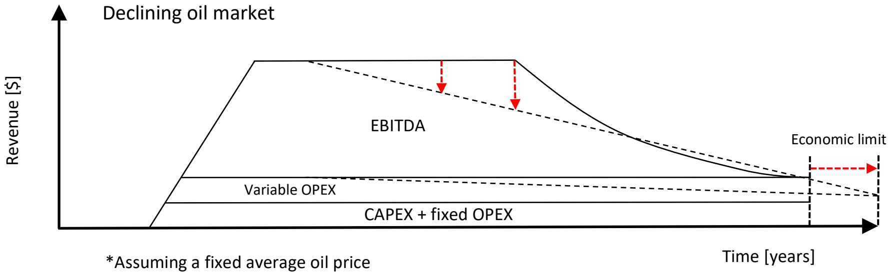


Figure 295 – Accounting for a declining oil market

Figure 29 shows how the declining production rate and the reduction in the variable OPEX extend the economic limit. The variable OPEX declines because the output from the reserve is significantly reduced. Moreover, a significant part of the EBITDA is lost. When a smaller reduction in the production is considered (figure 30) then some of the lost revenues are restored however the value still declines because of the time component (discount rate) in the valuation.

Money received now is worth more than money received in the future, therefore all delayed production will also reduce the value of a reserve.

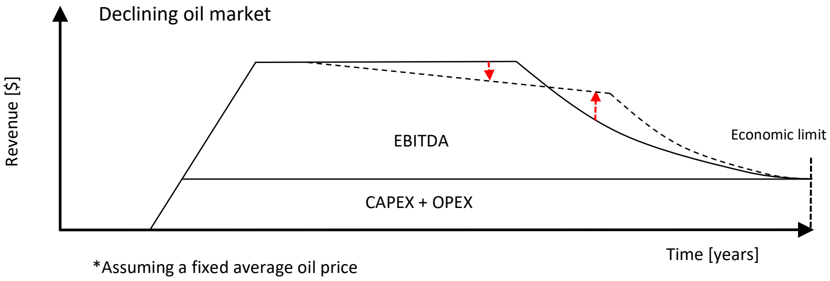


Figure 306 - Accounting for a declining oil market with smaller reduction

It is hard to effectively account for the decreasing demand in the value of oil reserves because the decline in the production rate of the reserve is dependent on many factors, uncertain developments and on decisions made by portfolio managers. When the market for oil starts to decline faster, then the reduction in the production rate will be steeper and more value is lost. The decline in the production rate also depends on the supply in the market. In case there is an undersupply reserves have to produce at their maximum capacity to fill in the demand from the market. A dynamic model can be made to get more insight in the demand and the supply in the market. However, such a model is based on many uncertain factors and therefore requires lots of very specific research regarding the global oil demand and the global oil supply. Figure XL shows the complexity of determining the demand and supply; and calculation of the demand and supply is even more complex due to the many uncertainties and unknowns regarding future oil projects and future oil demand.

Accounting for the risk of low oil prices

The developments result in increased competition in the market that increases the pressure on the value and economic viability of oil reserves. As figure 31 indicates, both the profit and the economic limit are largely affected by lower oil prices. The oil sector has seen many oil crises hence the low oil prices are not new for oil companies. However what changes the current crisis from the previous crises is that this crisis is associated with the view that oil may soon reach its demand peak. After the demand peak the ex-growth oil sector will start to decline resulting in lower oil prices that have the potential to maintain low till the end of the usage of oil due to the high amount of competitors that want to get rid of their (abundant) oil while it still has a value. Historically, periods with low prices where often succeeded by periods with high prices. These low and high prices compensate each other, especially on projects with a lifetime of 20 years or more. But, when oil prices structurally contract they may put the profitability of projects that are accepted under high price perceptions at risk. Figure 31 shows the negative effect of low prices on the value of oil reserves and how the economic limit is reduced.

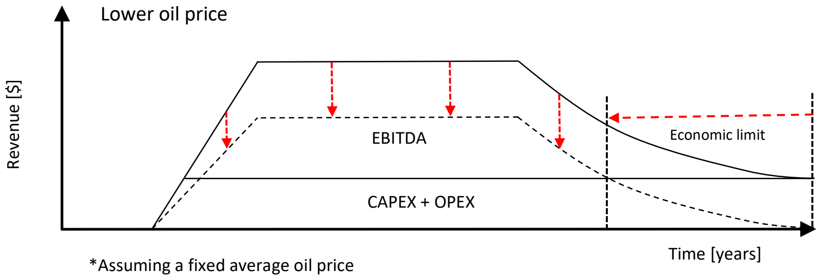


Figure 31 - The effect of lower oil prices on the value of oil reserves

The main uncertainties when accounting for the lower oil price are the level of the oil price that should be accounted for and the decline of the price throughout the years. In this case an average oil price is used, meaning that the average price should also incorporate the decline in oil price during the lifetime of the project. As is already explained, projects with longer lifetimes have to make use of lower prices if the decline in oil price is perceived to maintain.

When determining the profitability of oil projects that are under consideration to be developed the companies must account for and incorporate lower than expected average oil prices to account for the development in the value of the reserve. Hence companies should revise and reshape their oil price forward curves in line with the perception that oil is abundant, instead of scarce, and the market will see more competition associated with lower prices. If the project is still viable based on the revised and reshaped oil price forward curve than project is a sound investment. Otherwise the project should not be executed since it has a high risk of getting stranded based on the oil price.

Beside new projects, projects that are already producing should also be subjected to the lower oil prices based on the revised forward curve, especially projects that will continue to produce for many years. Hence a revaluation process is necessary to determine the viability of these reserves and to prevent them from getting stranded.

The combined effect of the developments
When combining all developments (figure 32) it becomes evident that the net income from the reserve has vastly decreased. Only the most competitive reserves will be able to generate a decent profit in the scenario when all developments add up. In such a situation oil companies will have a hard time to survive. However, it is evident that in a carbon-constrained world all developments will materialize due to the causality between the developments as described in paragraph 5.2. Therefore oil companies should start to account for all developments before their reserves will be significantly devaluated or stranded. Chapter 6 focuses on how companies can cope with the developments that are at play to limit the impact from the developments and increase the competitiveness of the reserves to prevent them from getting stranded.

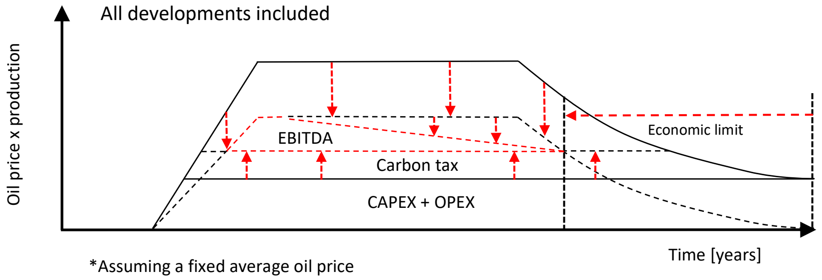


Figure 32 - Accounting for all developments

Intermediate conclusions

The research question that took a central role throughout this chapter is answered in this section. The research question was formulated as follows:

> 'Which types of reserves will experience the highest impact from the developments and how to account for these reserves in the valuation method?'

Highest impact from the developments
The scenario-based impact analysis has resulted in a usable table that makes it possible to determine the stranding potential and the competitiveness of different type of oil reserves based on the three pillars of competitiveness in a carbon-constrained world; the technology, the lifetime and the breakeven cost. This table (table 14 and 15) reveals which reserves experience the highest impact from the developments being the tar sands, the (extra) heavy oils, arctic oil and in some cases ultra-deep oil reserves. These types of reserves must start accounting for the developments in a carbon-constrained world because they will experience the highest impact and have a significant chance of getting stranded.

Accounting for the reserves in the valuation method
Accounting for the stranding potential in the value of the oil reserve can be implemented in two ways; through increasing the discount rate of reserves with high stranding risk or through direct implementation in the value. Direct implementation in the valuation approach is considered to be more effective because it defines the value of the reserve more accurately than an increase in the discount rate. The effects of environmental regulation should be accounted for with a shadow tax that incorporates future taxes on GHG emissions. The declining demand for oil can be incorporated through a reduction in the production rate and producible quantity, a dynamic model should be made to calculates future levels of demand and supply in the market. The perceived lower prices can be accounted for through downward adjustment and reshaping of the forward curves that oil companies use when valuing oil reserves. However, when using direct implementation there are still many uncertainties that the companies have to cope with such as a future carbon price, the total oil demand and oil supply and the price for oil.

5.4 Added value of the new valuation approach

This paragraph describes the added value of the new valuation approach by means of a small comparison. At first the currently used valuation method and its limitations are briefly explained, after which the new valuation method its added value and the secondary application of the new valuation method are stated. The paragraph ends with an intermediate conclusion regarding chapter 5.

The currently used valuation method

The current valuation method makes use of Discounted Cash Flows and Net Present Values, as explained in chapter 3. At the basis of the method is the perception that the oil available in the reserve can be sold for the market price. This generates a return that should be corrected by the costs that are made to extract the oil and the timing of the cash flows. The method is capable of assigning a monetary value to the reserves however there are some limitations.

The method is capable of adjusting prices and volumes to perceived market conditions but still build upon the perspective that all oil will be sold. However, the developments in a carbon-constrained world challenge this perspective resulting in oil reserves getting stranded due to fundamental changes in the market (paragraph 2.2). Hence, the currently used valuation method does not sufficiently account for the developments that are apparent in a carbon-constrained world. If the consequences of the developments are not incorporated in the value of the oil reserves then it may lead severe losses during the productive lifecycles of the reserves due to lower returns or reserves getting stranded. To reflect the true value of the reserve the developments should be incorporated in the value. The current valuation methods do not or only to a limited extend account for the developments.

The new valuation approach

The valuation approach that is presented in this research is an extension of the current approach based on DCF and NPV. The new valuation approach extends the current method through analyzing the developments, formulating scenarios of the developments, conducting a scenario-based impact analysis and accounting for the developments in the value of the reserve. With this extension the limitations of the current valuation approach can be overcome.

The new valuation approach add value because it accounts for the developments that are at hand when the world actively addresses climate change and global warming. The method accounts for the developments by operationalizing the developments, designing and analyzing scenarios of the developments and identifying the reserves that are vulnerable for the developments. Incorporating the developments in the value of the reserves makes the value more accurate and resilient when the developments materialize.

The consequences of the developments are explored through analyzing and operationalizing the developments (chapter 4) and conducting a scenario-based impact analysis. The outcome of the scenario-based impact analysis makes it possible for reserve owners to determine the competitiveness of their reserves and the vulnerability to get stranded in a carbon-constrained world. Reserves which are less competitive and more vulnerable to get stranded benefit more from the new valuation method because early valuation with the new method enables the owner to prevent the reserves from getting stranded through increasing the value of the reserve.

The value of the reserve becomes more accurate and resilient to market changes by incorporating the developments in the value of the reserves (paragraph 5.3). The incorporation in the value is carried out through three methods of accounting that are dependent on the development and the characteristics of a reserve. The development determines the method of accounting and the characteristics of the reserve the rate with which the reserve must be discounted.

The secondary application of the new valuation approach

The new valuation approach also holds a secondary application that is already briefly explained at the end of paragraph 5.2. The secondary application of the new valuation approach is the usage of the table of competitiveness as a framework to define strategic measures to enhance the value of a reserve and prevent it from getting stranded. The reason that this secondary application is included in this research is because it provides further insight the situation in the oil sector and the measures that can be taken to increase the value of oil reserves. Without emphasizing on these measures would be the same as observing a problem and not offering a solution for the problem. Hence, chapter 6 is aimed at using the new valuation approach to prevent oil reserves from getting stranded by increasing the value of the reserves.

PART IV – Illustration

‘Todays oil companies were built around the perspective that oil would be scarce at one day. However, this perspective changes’.

Handscomb, Sharabura, & Woxholth (2016)

The oil and gas organization of the future

6. Reduction of the impact of the developments by enhancing the competitiveness

Chapter 5 has analyzed the impact of the developments, the competitive position of certain reserves and explained how companies can account for the developments in the value of oil reserves in a carbon-constrained world. The next step of the research is to determine the strategic measures that can be taken by oil companies reduce the impact of the developments and prevent their reserves from getting stranded when the developments in a carbon-constrained world materialize. The outcome of the scenario-based impact analysis from paragraph 5.2 is used to determine adequate strategic measures in order to prevent oil reserves from getting stranded. Therewith answering the following research question:

> 'How to reduce the impact of the developments and prevent oil reserves from getting stranded in a carbon-constrained world?'

Paragraph 6.1 describes the changing market conditions and the effect of the changing market for the strategy of oil companies. Paragraph 6.2 focuses on the competitive position of reserves to formulate strategic measures that can be taken at the portfolio & reserve level to increase the competitiveness and value of a reserve. The last paragraph, paragraph 6.3, explains how the strategy at the corporate level should be adjusted to be able to cope with the developments in a carbon-constrained world. Paragraph 6.3 ends with an intermediate conclusion and an answer to research question addressed in this chapter.

6.1 Changing market conditions require changing strategies

The developments in the oil sector and the carbon-constrained world pose a threat for oil companies and may result in fundamental changes for the business of oil companies. These fundamental changes make it increasingly important for oil companies to focus on making their company resilient for the future. Hence, oil companies should create a sustainable and competitive business model that is not only able to cope with the developments and prevent reserves from getting stranded but at the same time use the developments as an opportunity to grow and excel.

Align strategy with the developments

Most oil companies (with exception of Statoil, Total and Shell which are starting to invest in renewable energy projects) do not yet account for a scenario in which the world actively addresses climate change. But, due to the commitment to the Paris Agreements there is a significant chance that the developments will materialize since the governments are assumed to pursue the goals set in Paris. Therefore companies must incorporate measures in their strategy to cope with the developments when they materialize. It is important for oil companies to start focusing on projects that are competitive and sustainable in a carbon-constrained world in which; stricter regulation regarding emissions, a peak in the demand for oil and lower oil prices shape the oil industry. Sustainable in this sense meaning that they are economically viable including any form of carbon pricing and that they have a low chance to get stranded.

The increased competition and the abundance of oil make it increasingly important to remain competitive and prevent reserves from getting stranded. This requires oil companies to increase their performance on the three pillars of competitiveness (technology, lifetime and breakeven cost) therewith obtaining a more competitive and sustainable position in the market. Such a competitive position reduces the negative impacts from the developments. Hence, oil companies should embrace and incorporate the developments in their strategy to obtain such a competitive position and to be able to cope with the developments when they materialize. The table of competitiveness, which is the outcome of the scenario-based impact analysis, can be used as a framework to determine the competitive position of a reserve or portfolio in a carbon-constrained world. Based on the competitive position strategic measures can be formulated, which enhance the competitiveness of the reserves. Hence the new valuation method also holds a secondary application that can be used by projects managers, portfolio managers and strategists to increase the competitive position and value of a reserve or portfolio.

All strategic levels should be aligned for the measures to be successful and address the developments in both the portfolio & reserves level and the corporate level (Skaf, 1999). Strategy at the portfolio & reserve level emphasizes on the composition of the portfolio by determining in which type of reserves the company should invest and how the company can best exploit its reserves to obtain a competitive position in the market and gaining the highest return from its reserves (paragraph 6.2). The corporate level is aimed on setting the right targets and objectives that function as a guideline for the portfolio & reserve level and will be explained in paragraph 6.3.

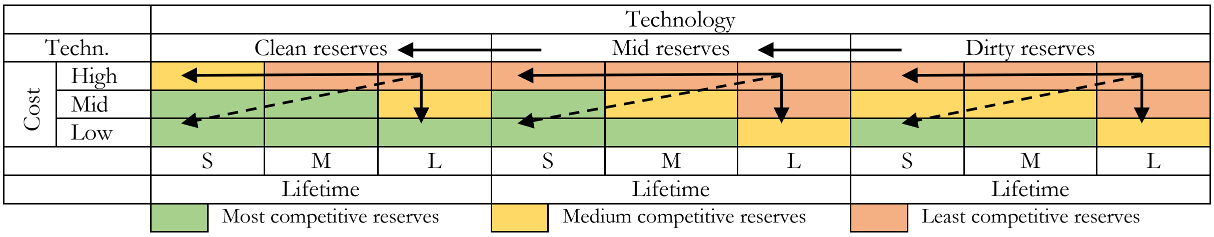
6.2 Coping with the developments at the portfolio & reserve level

Enhance the competitive position of a company in a carbon-constrained world

The competitive position of oil companies in a carbon-constrained world is dependent on the technology, lifetime and breakeven cost as explained in chapter 5. The competitive position depends on the different type of reserves that a company owns and operates. The table below reflects the table of competitiveness. Hence the competitiveness of a company is the position of a company in the table based on the average of its reserves. Increasing the competitiveness of a company means performing better on the three pillars of competitiveness in a carbon-constrained world and will reduce the impact of the developments. Such increases in the competitive position make reserves shift through the table of competitiveness toward the lower left corner (table 18) with clean, low cost reserves with short or medium lifetimes. Such a shift can be achieved in two ways:

- Through competitive growth
- Through adding value to the reserves

Table 16 - Increasing competitiveness



		Technology								
Techn.		Clean reserves			Mid reserves			Dirty reserves		
Cost	High	🟨	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	Mid	🟩	🟩	🟨	🟩	🟨	🟧	🟨	🟨	🟧
	Low	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟨
		S	M	L	S	M	L	S	M	L
		Lifetime			Lifetime			Lifetime		

🟩 Most competitive reserves
🟨 Medium competitive reserves
🟧 Least competitive reserves

Competitive growth

Competitive growth entails increasing the positioning of the company in the market through investing and exploiting reserves that are competitive and sustainable in a carbon-constrained world. This increase in the position can be achieved through focusing on the developments of new projects that are more competitive than the current reserves or by acquiring more competitive reserves while divesting from less competitive ones. This makes it possible for a company to shift through the table to the more competitive side (left and below). Hence, achieving competitive growth is possible through:

- Acquisition of competitive reserves and divestment of uncompetitive reserves
- Development of new competitive reserves

Added value

Another way of increasing the competitiveness is by adding value to the reserves. Adding value focuses on the reserves that are currently owned and being operated. Adding value can be accomplished in many different ways and are primarily focused on the reduction of the costs and emissions associated with the exploitation of the reserves (Munro, 2016). Added value can be achieved through:

- Technological developments and innovations (decrease cost and emissions)
- Supply chain efficiencies (decrease cost and emissions)
- Strategic alliances (decrease cost and share risks)

Technological competitiveness

Oil companies should focus on implementing measures that reduce the environmental footprint of the company and enhance its technological competitiveness. This reduces the impact of environmental regulation on the company when for instance a carbon tax is implied. When such measures are implemented correctly companies shift to the left in the table of competitiveness from for instance dirty technology to medium dirty technologies which severely reduces the companies vulnerability to environmental regulation and makes the company more competitive in a carbon-constrained world. The arrows in the table below show a shift through the table that increases the technological competitiveness. Both competitive growth and added value can be applied to make such a shift to enhance the technological competitiveness.

Competitive growth measures to increase technological competitiveness

- Divest from dirty oil (especially the expensive ones)

- Invest in clean competitive reserves
- Only undertake exploration projects that have a chance of finding competitive reserves
- Diversify to other resources with a lower environmental footprint (such as gas and eventually wind) if there are not sufficient competitive oil reserves available

Divest from dirty reserves with high cost
IOCs should divest from dirty type of oil reserves because the support for the implementation of carbon pricing mechanisms is increasing as the result from the goals set in the Paris Agreement. These dirty reserves are already among the least competitive reserves and the implementation of any type of carbon pricing will deteriorate its competitive position even further compared with the cleaner types of reserves. The dirty reserves are almost all at the expensive side of the breakeven cost curve, which makes them also vulnerable for low oil prices. Some of these reserves are already not economically viable under the current market conditions and increasing competition in the carbon-constrained world will make their competitive position even worse.

The reserves from which oil companies should divest are the heavy and extra heavy oil reserves such as the Canadian tar sands (oil sands), the Venezuelan oil reserves, and the arctic oil reserves. These reserves are the most critical type because they also have high breakeven cost. The implementation of any type of carbon pricing may instantly make these types of reserves get stranded. When this occurs selling these reserves will be too late because other companies would not want to purchase reserves that are not economically viable. Divesting form these reserves will increase the position of the company by shifting the portfolio of the company to the left in the table of competitiveness. The income from the divestments can be invested in projects that are less polluting and more competitive to make up for the lost revenues.

Only undertake exploration projects that are aimed at finding competitive reserves
Exploration projects are only worth the investment if they are aimed on discovering reserves that are competitive in a carbon-constrained world. Hence exploration projects in arctic area and in regions with (extra) heavy oil reserves should be abandoned because they are not competitive and only add to the amount of reserves that get stranded in a carbon constrained world.

Diversify towards other resources with a lower environmental footprint
Most of the competitive reserves are already being developed and are the onshore conventional oil reserves of which the most are located in the Middle East or Russia. There exists a chance that the more competitive reserves are already being developed and acquisition is not possible. In such situation IOCs have the opportunity to increase their activity in competitive gas reserves or even in renewable forms of energy such as offshore wind. More and more oil companies are slightly shifting toward renewables. Total has bought a solar developing company while Shell and Statoil are starting to invest in offshore wind farms (Cunningham, 2017).

Added value measures to increase technological competitiveness
- Technological innovations
    - Carbon Capture and Storage (CCS)
    - Carbon Capture and Utilization
- Supply chain efficiencies
    - Increase energy efficiency throughout the supply chain
    - Reduce and end flaring of associated gas
    - Increase and update facility designs to be more energy efficient
    - Operational excellence

Lifetime competitiveness
Competitiveness based on lifetime increases the flexibility of a company because with shorter lifecycles companies must sooner renew their portfolio which enabling them to change their portfolio through investing in reserve with different technologies. However gaining competitive based on lifetime is hard to achieve through adding value. This is due to the physical characteristics of an oil reserve. Thus increasing lifetime competitiveness should primarily come from competitive growth shifting the company and the reserves to the left side of the table. This may prevent them from getting stranded in the future when the market and the demand for oil are reduced.

Competitive growth to increase lifetime competitiveness
- Don’t invest in long-lasting projects that are not among the most cost- and technology competitive

- Invest in projects with short lifecycles such as shale oil that generate quick returns

Focus on reserves with low upfront cost and reserves with short development times
Due to the volatility in the oil prices and the uncertainty regarding the developments in the market oil companies are less eager to invest in projects with long development times and projects with high upfront capital investments. Due to long development times reserves may come online after 5 years. In these 5 years the market conditions may severely change making such high upfront cost and long development times critical for the profitability of the project. Shale oil reserves have relatively low upfront cost and quicker returns due to the short development time. This makes them ideal to exploit in uncertain times with volatile prices. The technology to extract shale is quickly improving which increases their competitive position and relative value in the market.

Added value to increase lifetime competitiveness

- Invest in extra capacity to increase the output and decrease the lifetime of a reserve.

Breakeven cost competitiveness
An important focus point for oil companies, especially with the current low oil prices, is to reduce the breakeven cost of the reserves in order to enhance the cost competitiveness. An increase in cost competitiveness enables a company to generate profits even under low price scenarios. Both competitive growth and added value are able to increase the cost competitiveness and shift to the lower side of the table.

Competitive growth to increase breakeven cost competitiveness

- Divest from expensive technologies such as arctic, tar sands and extra heavy oil plays
- Invest in onshore conventional oil reserves, shallow offshore projects and shale oil

Divest from reserves with high breakeven cost
The breakeven cost of a reserve is probably the most important characteristic that reflects the competitiveness of a reserve. Especially when oil prices are uncertain and low. Hence, companies should divest from these types of reserves because most of these reserves are not viable with the current low oil price and especially not when in the carbon-constrained world the competition increases leading to even lower oil prices.

Invest in low cost, competitive reserves
The income from the divestment of the reserves with high breakeven cost should be invested in reserves with low breakeven cost that are competitive with low oil prices. Such reserves are reserves at the lower side of the table and are reserves such as conventional onshore reserves, the competitive shale oil reserves and reserves in shallow water.

Added value to increase breakeven cost competitiveness
Accomplish supply chain efficiencies through:

- Technological innovations
    - Enhanced more efficient oil recovery processes
    - Digitalization (industry 4.0)
        - Cloud services
        - Internet of Things (IoT)
        - Data analytics
- Strategic alliances through entire supply chain (sharing costs and risks)
    - Other oil companies
    - Service providers
    - Engineering companies
    - Reserve operators
- Smart contracting
    - Focusing on short term adjustable contracts to remain flexible

Example case

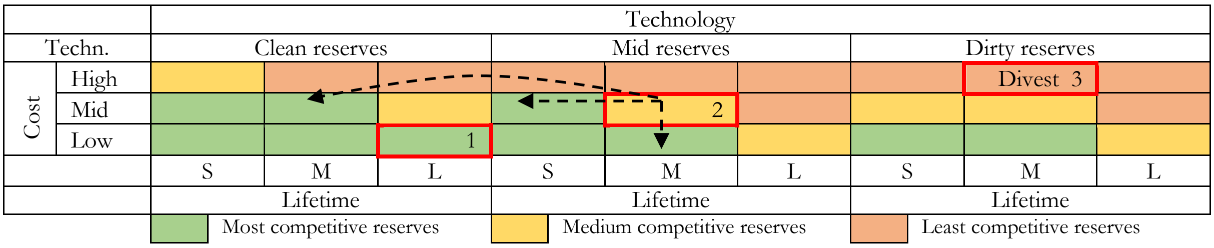
Upstream Oil Company X has a portfolio containing 3 reserves with the following characteristics:

Reserve:	1. Onshore UAE*	2. Offshore Nigeria**	3. Canada Athabasca***
Technology	Onshore conventional 36 kgCO2/barrel (low)	Deep water offshore 93 kgCO$_2$/barrel (mid)	Tar sands (oil sands) 163 KgCO2/barrel (high)
Lifetime	60 years (long)	30 years (mid)	40 years (mid)
Breakeven cost	$25 (low)	$50 (mid)	$85 (high)

* Based on United Arab Emirates 'Murban'
** Based on Nigeria 'Pennington'
*** Based on Canada Athabasca 'DC SCO'

Table 17 - Information of the example case

Identify their competitive positions in a carbon-constrained world using the table of competitiveness. In order to prevent the reserves from getting devaluated or stranded in a carbon-constrained world, their exposure to the causes of getting stranded should be reduced, which makes the reserve shift through the table towards a more competitive place with lower vulnerability to get stranded.



		Technology								
Techn.		Clean reserves			Mid reserves			Dirty reserves		
Cost	High	🟨	🟧	🟧	🟧	🟧	🟧	🟧	🟧 Divest 3	🟧
	Mid	🟩	🟩	🟨	🟩	🟨 2	🟧	🟨	🟨	🟧
	Low	🟩	🟩	🟩 1	🟩	🟩	🟨	🟩	🟩	🟨
		S	M	L	S	M	L	S	M	L
		Lifetime			Lifetime			Lifetime		

🟩 Most competitive reserves 🟨 Medium competitive reserves 🟧 Least competitive reserves

Table 18 - Possible increase in competitiveness

Reserve 1 – Onshore United Arab Emirates

Reserve 1 is already among the most competitive reserves and will not get stranded in a carbon-constrained world. However, it is advised to keep adding value to the reserve to remain competitive under its peers by further reducing costs and therewith optimizing profits now and in the future.

Reserve 2 – Offshore Nigeria

The Offshore reserve located in Nigeria is a medium competitive reserve in a carbon-constrained world and has a chance to get impacted when the oil price lowers due to the increasing competition and due to the implementation of a carbon tax. Increasing the competitive position of this reserve is possible through adding value to the reserve and therewith getting more competitive. Getting more competitive is possible in three ways:

- By shifting to the clean reserve type and focus on reducing the emissions from the reserve. Decreasing the emissions with 43 kgCO$_2$/barrel will make the reserve shift to the cleaner type of reserves.
    - Limit or stop the amount of flaring, by installing an additional facility that uses the associated gas and turns it into natural gas or LNG.
- By reducing cost, shifting downwards in the table to the low-cost reserves. A reduction of at least $10 per barrels is needed. This cost reduction can be realized in the following ways:
    - Invest in the cooperation with the service providing and operating companies to lower the margins on their services.
    - Invest in digitalization and optimization of the production process using data analytics and Internet of Things.
- Through decreasing the lifetime of the reserves with 5 years will make the reserve shift toward the short lifetime reserves.
    - Increase the amount of oil that can be produced from the reserve by installing additional production capacity.

The process of increasing competitiveness is a dynamic process because increasing the production capacity or reducing flaring from the reserve increases the costs. Hence a strategy should be chosen that accounts for all three pillars.

Reserve 3 – Canada Athabasca
The Canada Athabasca oil reserve is among the least competitive reserves due to its high cost and dirty production technology. To make this reserve competitive on cost it should also reduce its emissions because a carbon tax will vastly increase the cost. However it is hard for tar sand projects to lower the emissions due to the physical characteristics of the oil and the production process of the oil. Moreover, solely reducing the emissions will not increase the competitiveness of the reserve and hence both emissions and costs should be reduced, which is not possible with the current technology. This prospect makes the Athabasca oil reserve a very risky investment; thus, Company X should divest from the reserve and with the income from the divestment invest in another type of reserve that is more competitive under current and future market conditions. Such reserves are for instance conventional onshore reserves, shale oil and the competitive offshore deep-water reserves.

Difference between IOCs and NOCs

The possible strategic measures to cope with the developments differ for IOCs and for NOCs. IOCs are more flexible than NOCs because they operate on global scale and are not solely bound to exploit the reserves that are owned by the country to which the NOC originates. Hence, the optionality of IOCs is much higher than the optionality of NOCs, which make the IOCs better able to cope with the developments by focusing on different type of reserves or on other regions that are less impacted by the developments. Although the IOCs are better able to adjust to developments in the sectors, the NOCs primarily own the vast majority of the cheap and voluminous reserves, which make them already competitive based on their reserves. Especially the countries in the Middle East own reserves that are among the most competitive due to the low costs, easy to access and high quality of oil. Therefore, competitive growth is not very applicable for NOCs because they already own and exploit the bulk of the most competitive reserves. Thus, NOCs should primarily focus on adding value to these competitive reserves to remain competitive.

The main challenge for NOCs

NOCs own the largest share of the most competitive low cost reserves. Due to this position in the market they are able to compete with the other companies. When the competition in the market will increase, the NOCs will start to win market share due to their strong competitive position. The BP Group (2017) has calculated the market share of NOCs to increase from 56% to 63% in the coming decade. This indicates that NOCs will use their competitive advantage to increase their market share. BP Group argues that the market share is prompted by the abundance of oil and the slowing oil demand that will change the market and makes NOCs want to get rid of their reserves, which often have a long lifetime. In a future with no or little oil even these often highly competitive reserves may have no or little value. NOCs and governments that are highly dependent on the revenues from the production of oil should diversify their economy (Verbruggen & Van De Graaf, 2015).

Portfolio managements

Classical portfolio management as described by Nobel laureate Markowitz (1952) is aimed on diversification of the portfolio. However, does this make sense in a carbon-constrained world? Not really, because reserves that are among the least competitive regarding price and emissions will not suddenly become competitive because there is no upside potential for the emission of GHG other than the current situation in which GHG is not priced. Even when breakthrough technological developments occur that make for instance tar sands and extra heavy oil financially competitive to extract, the problem with the physical characteristics of the oil remain to exist and they will need extra refinement compared to less polluted lighter oils. This will make tar sand always less attractive than competitive forms of conventional oils. The same holds for the difference between shallow water, deep water and ultra-deep water. Ultra-deep water will not get cheaper than deep water and deep water will not get cheaper than shallow water. This makes the competitiveness of certain type of reserves hard to fundamentally change and therefore makes no sense to diversify the portfolio of reserves by preferring less competitive reserves that have a chance to get stranded.

6.3 Coping with the developments at corporate level

The previous paragraph has illustrated how the table of competitiveness can be used to define measures that increase the competitiveness and value of a portfolio or a reserve at the portfolio & reserve level. This chapter will focus on how executives can incorporate the developments in the strategy of oil companies at the corporate level.

The performance indicators of a company should be aligned with the strategy of a company to make it possible to effectively monitor and steer the company in line with the strategy that is laid out. If there is a mismatch between the performance indicators and the strategy it is highly possible that the company does not reach its goals (Venkatraman & Ramanujam, 1986). Thus, changing strategies have as a result that the performance indicators should be changed as well to be able to effectively carry out the strategy and steer the company in the right direction. If an objective is to increase the competitiveness of the company through adjusting the composition of the portfolio, then the corporate level should monitor this objective by adopting effective performance indicators that monitor the progress for to reach the objective (Bertocco & McCreery, 2014) such as the competitiveness. Meaning that if a company wants to cope with the changing market evoked by the carbon-constrained world and the Paris Agreement; then other new performance indicators should be applied that monitor and steer this change. Therefore, Leaton, Campanale, et al., (2013) argue that some of the performance indicators need to be updated, reversed or even abandoned to reflect the performance of oil companies in a carbon-constrained world.

The indicators that reflect the competitiveness of a company are important indicators for the overall performance of the company, especially in a carbon-constrained world. The next paragraphs will illustrate how some of the performance indicators should be adjusted, updated or replaced by others to incorporate the developments of the carbon-constrained world at the corporate level.

Changing the performance indicators to cope with the changing market

Currently the most important performance indicators used by oil companies are; the return on capital (ROC), the gearing or net debt ratio, reserve replacement ratio (RRR), total production, shareholder return, operating cash flow, and some indicators regarding safety and health.

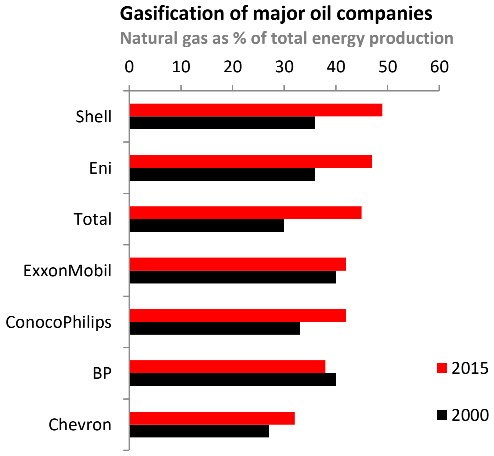
The performance indicators should be able to monitor the three pillars of competitiveness to align the corporate strategy with the portfolio and reserve strategy. Hence an update of the performance indicators is necessary to update old indicators such as Reserve Replacement Ratio (RRR) or Return On Invested Capital (ROIC) by implementing new metrics based on the three pillars; Technology [emission], Lifetime [years], and Breakeven Cost [$/barrel]. Metrics based on the three pillars of competitiveness will be sustainable in a carbon-constrained world. Next section will focus on each of the three pillars

Monitoring on technology

To perform better on technology a shift to reserves that have a lower environmental footprint should be made and incentivized by the indictors that monitor this specific progress of the company. Currently the companies that are studied for this matter (Shell, BP, ExxonMobil) only measure the total GHG emission of CO_2 as a performance indicator in kgCO_2. This indicator doesn't allow for companies to grow and does not give an indication of the competitiveness of the company. Hence an additional indicator that measures the 'total emissions per barrel of oil produced' [kgCO_2/barrel produced] should be implied. This indicator incentivizes companies to invest and develop technological more competitive oil reserves and also justifies further growth.

Monitoring the lifetime of a reserve

Currently one of the most important performance indicators is the reserve replacement ratio (RRR). The RRR reflect the relation between the replacement rate of reserves that are produced, and new reserves that are added to the companies' portfolio. Companies strive to keep this rate above 100% meaning that they have replaced their entire production with new proven oil reserves therewith assuring that they have sufficient reserves to exploit the future. However, in a carbon-constrained world where oil is abundant, not all reserves need to be replaced. Replacing all reserves with new discovered reserves will make the abundance of reserves even larger resulting in more reserves to get stranded when the market for oil starts to decline. Therefore simply measuring the RRR does not suffice to reflect the assurance of future business. Hence, the RRR should be update and incorporate performance indicators that do reflect the potential that the company will be in business when the market for oil declines and the demand reduces. An indicator that can function as an update or adjustment of the RRR should not solely focus on oil but also on which fuel is next. Most oil companies also produce gas, which is often seen as the transition fuel. Hence companies should increasingly emphasize on replacing oil reserves with gas or even with renewables. Hence, the companies should complement the RRR with indicators that monitor the replacement of oil by gas or renewables. Such indicators are for instance the Replacement of Oil by Gas (ROG) or the Replacement of Oil by Renewables (ROR). When companies score high on these indicators it shows that they are strategically positioning themselves for a future without oil and shift to gas that is seen as a transition fuel after and in the end shift to renewables. Figure 33 shows the current gasification of the oil majors. A higher gasification rate implies that the company is more resilient in a carbon-



Source: Bloomberg, economist

Figure 337 - Gasification of major oil companies

constrained world when environmental regulation may be implied because GHG emissions from gas are half compared to the emissions from oil. Therewith reducing the exposure of a company for oil reserves to get stranded.

Monitoring on price and margins

The current way of monitoring a portfolio of oil reserves is through the return on capital (ROC) (Leaton, Ranger, et al., 2013). This indicator assumes that margins on oil reserves and oil projects can be maintained, however the ROC has halved over the past 10 years, which indicates that maintaining ROC is hard and will be even harder in a carbon-constrained world. Moreover, the ROC does not incorporate any form of competitiveness with respect to the developments in a carbon-constrained world. An indicator that does include competitiveness and the profitability of the company is the Company Average Breakeven Cost (CABC) [$/barrel], which reflects the total (upstream) operating cost divided by the total amount of barrels that are produced. The CABC gives a clear indication of the minimum price from which positive returns will be made and hence about the profit margin. Corporate strategies should be aimed at reducing the CABC to make the entire company more cost efficient and competitive. Both competitive growth and added value can be implied to enhance the CABC of the company.

Intermediate conclusion

During this chapter the following research question is answered:

> 'How to reduce the impact of the developments and prevent oil reserves from getting stranded in a carbon-constrained world?'

The changing market conditions caused by the developments in a carbon-constrained world require an adjustment in the strategy of oil companies to increase the competitiveness of oil reserves and prevent them from getting stranded. The table of competitiveness that follows from the scenario-based impact analysis can be used as a framework to increase the competitiveness of oil reserves. Increasing the competitiveness reduces the impact of the developments and reduces the chance of reserves to get stranded in a carbon-constrained world. Oil companies can increase the competitiveness and the value of oil reserves by applying 'competitive growth' and 'added value'. Both competitive growth and added value will increase the competitive position in the market and are aimed at improving the reserve on the three pillars of competitiveness in a carbon-constrained world (technology, lifetime, breakeven cost). Competitive growth can be achieved through acquiring or developing new competitive reserves while divesting from reserves that are not competitive. Value can be added to reserves through supply chain efficiencies, strategic alliances, innovation and technological developments.

At the corporate level oil companies should align their corporate strategy with the necessary changes that should be encountered in the portfolio and at the reserves. This is alignment is possible through adopting performance indicators that adequately incentivize an increase in competitiveness. Examples of such performance indicators are the replacement of oil by gas (ROG), the replacement of oil by renewables (ROR) the 'emission per barrel oil produced' [kgCO_2/barrel produced] and the 'company average breakeven cost' [$/barrel].

7. Discussion and reflection

The current low oil prices and the breakthrough of the Paris Agreements have put a lot of pressure on the oil sector. However, these events have also resulted in more in-depth research regarding the future of the oil sector of which this research is part. This paragraph will discuss the result from the research as well as the methods and theories that are used. Moreover, the results will be laid in a larger context to determine the additional value of the research to the research area.

Discussion of the methodology

The methodology, which is based on the integration of developments in the oil sector and the value of oil reserves, has made an attempt to bridge the gap between the uncertain developments in the oil sector and the certain character of reserves valuation. These different characteristics made the research interesting but also difficult because when valuing oil reserves certain, quantified, exact numbers and figures are preferred while the developments in a carbon-constrained world are all but certain. This has meant that at both sides concessions had to be made which resulted in the limitation of the uncertainty through the formulation of scenarios regarding the developments and for the valuation to implement additional risk or additional measures. These concessions implied that certain assumptions had to be made, especially with regard to the formulation of the scenarios. Although the assumptions that are made are scientifically and rationally sound they still remain assumptions and their validity can be discussed.

Even tough assumptions had to be made it is important to be aware of these assumptions and to design the methodology in such a way, that when the assumptions have to be adjusted that not the entire research approach fails to produce meaningful results. I am confident that the method that is defined in this research can also be used when other developments evolve and that the same approach as presented in the research can be conducted to determine the influence of the developments on the value of oil reserves.

The method that is used also resulted in the construction of a framework that can be used to formulate strategic measures that enable companies to cope with the developments in a carbon-constrained world. The measures are based on the outcome of the scenario-based impact analysis and are aimed at enhancing the competitive position of the company and therewith reduce the impact of the developments on the value of the reserve. Some recent events that are worth mentioning support the strategic measures as composed in chapter 6. These events partly verify the functioning of the method and the result from the scenario-based impact analysis.

Recent events that support the strategic measures

Although the true reason of some events in the oil sector are often hard to grasp because oil companies want to hide and protect their strategy, some current events in the market are discovered that are in line with the outcomes of this research.

- Shell is divesting from all of its Canadian tar sands, which are among the least competitive reserves due to their high environmental footprint and expensive production technology.
- Shell has abandoned their exploration plans for artic oil. Arctic oil is among the most expensive production techniques and is not feasible in a low price scenario.
- ExxonMobil is currently increasing its investments in shale oil because they want to increase the flexibility of the company and create early revenues with lower risk realized by short-cycle shale drilling.
- The SEC has forced ExxonMobil to write-down on its tar sand reserves because they are not profitable under current market conditions.
- Saudi Aramco is preparing an IPO to sell part of the company to investors. This way they sell a part of the company and reduce the impact for the company and the country when reserves get stranded. According vision 2030 they will use the income from the IPO to divest the economy of Saudi Arabia and prepare for the times when oil is out of grace.

Discussion of the theories

The theories that are used are primarily valuation theories, these theories have assisted in understanding the value of oil reserves and in determining what the consequences of developments for this value. However, they have also revealed that it is not possible to fully account for the stranding risk of oil reserves beforehand because there remain too many uncertainties and dependencies in the system. These uncertainties and dependencies make it impossible to accurately account for reserves that are instantly and completely stranded, because both the exact moment that the reserve will strand should be known beforehand as well as the market conditions. Hence the available theories fall short to cope with abrupt stranding.

Although the theories are not able to fully cope with some types of stranding, they provided sufficient support to comprehend the oil system and the dependencies that determine the value of reserves. Moreover, they have provided the possibility to draw useful conclusions from the research with which third parties are able to strengthen their portfolio of oil reserves that enables them to reduce the potential for oil reserves to get stranded.

Interpretation of the results

The research has shown that if climate change is actively addressed, then there is a significant chance that oil reserves get stranded. This stranding may not only have severe implications for the value of oil reserves but even for entire companies. The focus of this research was not on the value of oil companies but the results impose also a significant threat for the value of companies when the world will actively address climate change.

The primary outcomes of the research are the three additional methods of incorporating the developments into the valuation process. These three methods remain pretty rough and seem straightforward because they are not concise in terms of strict quantified measures. The reason behind the fact that the methods cannot be quantified is again the fact that the developments are uncertain. When it is sure that a carbon tax will be implied of $40 per ton of CO_2 then the effect on the value of a reserve can be easily calculated. But when the amount and even the measure remain uncertain then quantification is not possible and only the method of implementation can be explained. The problem with uncertainty to be able to quantify a possible future demand reduction also brings one of the limitations of the research to light because estimating the possible future demand of the entire market is very complex and dependent on too many unknowns. This makes it impossible to determine to what extend the demand for oil will be reduced and hence the effect on the value of oil reserves. Thus, what is still a nonexistence is an accurate model that is available for scholars to determine the future oil demand and supply and use it to get insight in the future of the oil sector. Such a model can be derived from the very sophisticated oil price forecast models that oil companies and (investment) banks use. For determining the oil price the level of the supply and demand should be known. Hence adjusting the oil price forecast model might decline the extra effort that needs to be put in making a new model that is capable of determining the supply and demand in the market.

The secondary outcome of the research is the table that reflects the competitiveness of the different type of oil reserves that followed from the scenario-based impact analysis. This table reflects the risk for certain type of oil reserves to get stranded as well as the competitive position of reserves in the market. The table is generic which means that it can be used to identify the levels of risk for all sorts of reserves without adjusting the table. The only information that one should know to determine the risk and competitive position of a particular reserve; are the environmental footprint of the reserve, the lifetime of the reserve and the breakeven cost. This table can function as an appropriate framework to determine the stranding risk and competitiveness of oil reserves, as chapter 6 illustrate. The design of such a framework was not the goal of this research, however it is very convenient that the side product is a usable framework. The verification of the framework is not carried out in this research because the intention was not to design a framework but only use the method of scenario-based impact analysis. In order to be fully functional as a framework it should be tested and verified and the method should be further refined to have a chance to be adopted by third parties.

The third outcome of the research are the strategic measures for oil companies to cope with the developments. The measures are based on the table of competitiveness that is the result of the scenario-based impact analysis and are aimed at enhancing the competitive position that enables them to cope with the developments by reducing their impact. Appendix F has translated the measures in actor specific recommendations. Some recent events as mentioned above support these measures meaning that the measures that are proposed are useful for companies active in the oil sector.

Robins (2014) has focused on the essence of integrating the sustainability of companies in the financial analysis and statements. This research strengthens the perspective of Robins and shows the earnest and the possible impact when the developments regarding the transition towards a sustainable world and the exposure and consequences of stranded oil reserves are not incorporated in the financial analyses.

The meaning and value of the results

The value of the results depend mainly on the course of action and the world complying with the goals set at Paris. History has shown that strange developments occur in the oil sector, which are sometimes all but rational. This means that the developments that are used in this research may in reality turn out to be different. If for instance the Paris Agreement will never be achieved and the demand for oil keeps increasing, then oil reserves never get stranded and prices will remain increasing until the last drop of oil is extracted from the ground. This perspective will fundamentally change the outcomes and results from this research, since this research assumes that the world will actively address climate change. However, if in reality the world ends up between not complying with the Paris Agreement and meeting the goals of the Paris Agreement then the research and the results are useful. Hence, even when the Paris Agreements are not achieved and oil reserves will never get stranded then the research may still provide insight in the functioning of the oil sector.

Reflection on the information

Some information that is used in the research may be biased since it is adopted from sources such as the BP statistical review. Although such resources are used throughout the oil industry and are seen as trustworthy, there is a chance that they may be biased to serve the interest of the publisher. Personally I do not consider the chance to be significant that this is the case because the information got checked and reviewed by multiple institutions. However the chance remains it holds a certain bias.

Information gathered using interviews is always vulnerable for the devaluation of this information through the multiple chains that the information has to go through and the possibility for misconceptions and different interpretations of information. The information from the interview is first gathered by the interviewee after which is passed through to me and at last formulated in the research. Through every "transaction" in this information flow, the information can be slightly changed which may have affected the research.

Reflection on the scope

The oil sector is a complex sector and it took a while to understand the functioning of the sector. The scope of the research was set to only incorporate the upstream part of the sector and exclusively oil, however, I encountered that the complexity and entanglement between upstream and downstream and oil and gas is very firm and for some parts such as emissions they cannot be seen in full isolation. Although this has led in some cases to make choices and assumptions, I am glad that the scope was set this way because including other parts of the supply chain and gas would have made the system even more complex than it already is. Hence narrowing the scope from oil and gas to solely gas was a wise decision.

8. Conclusions and recommendations

This last chapter presents the conclusions of this research by giving answers to the main research question and discussing the research approach. Thereafter, recommendations for owners of oil reserves are given. The research question as formulated in chapter one and addressed in this chapter is as follows:

'How to valuate oil reserve in a complex, carbon-constrained world?'

8.1 Conclusions

After having focused on the valuation of oil reserves in a carbon-constrained world as well as the interaction between these two elements, an answer to the main research question can now be formulated. First, the conclusions of the developments in the carbon-constraint world are presented that are based on chapter 2 and 4. Second, the conclusion regarding the valuation of oil reserves is presented. Third, the incorporation of the developments in the valuation method is explained which answers the research question. Next, the conclusions regarding the implementation of the new valuation method to prevent reserves from getting stranded are presented. And last, the scientific added value of this research is discussed.

The developments in a carbon-constrained world

The Paris Agreement as the result of a growing environmental awareness and climate change result in the fact that the emission of greenhouse gasses such as CO_2 is limited. The dedication of 197 governments to the Paris Agreement shows the tendency to fight global warming. This implies active roles of almost all governments to lead the way through the transition resulting in forms of regulation to keep the world on track of meeting the 2°C pathway and decarbonize the global economy. When decarbonization is effective, it reduces the global demand for oil which will lead to a switch in paradigm from peak oil supply to peak oil demand resulting in a world where oil is abundant. The abundance of oil and a declining oil demand can destabilize the oil price and increase the competition among oil producers. Increasing competition may lead to market share driven policy resulting in oversupply and low oil prices. Concluding; there are three main developments that will influence the oil sector:

- Increasing regulation
- Declining demand for oil
- Increased competition and low oil prices

Regulation

Oil companies are currently not incentivized to reduce their emissions and to implement more sustainable production techniques. Effective implementation of environmental policies will create these incentives and stimulate the appropriate behavior of reducing the emission of GHG. The main barrier for the implementation of a carbon pricing mechanism is political alignment because carbon pricing is only fully effective when implemented on global scale. Explicit carbon pricing is by most parties seen as the most effective way of setting adequate incentives to both lower emissions and reduce the demand for oil by stimulating substitutes for oil.

Carbon pricing mechanisms result in higher cost for dirtier oil reserves, which will reduce their competitive position, and they may even be pushed out of the market due to the abundance of oil. The types of oil reserves that are mostly hit when carbon pricing is implemented are the heavy oils, the extra heavy oil and the tar sands. Moreover, reserves that are opposed by the public and oil reserves in extreme conditions such as arctic oil also face high cost or may even prohibited in case of the implementation of strict regulatory regimes.

Declining oil demand

Oil is abundant when the goals of the Paris agreement are achieved. There are already sufficient discovered oil reserves to follow the 2°C pathway of the IEA. However, the major oil companies do not account for the situation in which oil is abundant and where the world complies with the 2°C pathway and meet the goals set in Paris. This may lead to higher risk of a significant amount of oil reserves that may get stranded due to continued explorations for oil reserves, adding additional reserves to the resource base. The drivers that will cause the reduction in the demand for oil are the penetration of low- and no-carbon technologies such as renewable energy and electric vehicles, together with increased end-user efficiency and social behavior.

The stranding risk will increase over time due to the decline in the oil demand. Hence the declining demand forces the supply to decline as well; otherwise there will be a strong price decrease. A declining oil supply results in reserves getting obsolete, especially reserves that have; long lifetimes or are not yet producing. Hence the duration till the end of production of the reserve (lifetime) is important. Reserves with long lifetimes have a higher chance of facing devaluations or getting stranded due to the decreasing demand for oil.

Sustaining low oil price

Sustaining low oil prices are the result of increased competition evoked by the decarbonization of the economy. A low oil price can force reserves to stop producing if the oil price gets below the break-even cost of the reserve. Enduring low oil prices may result in severe devaluations and hence a reduction of the value of the reserve. OPEC has the ability to increase the value of oil reserves by cooperating and setting production quotas, however incentives to cooperate are not present because not complying with the quotas will be more beneficial. An increase in the size of the resource base has the potential to destabilize the oil price. The more resources that are added to the resource base through exploration projects, the larger the potential (over)supply of oil will be and therewith the competition between oil producers, resulting in a large amount of stranded reserves.

The valuation of oil reserves

Analysis of the valuation methods and the oil system that influence the value of oil reserves shows the complexity of the value of a certain reserve, the complexity of the system and the factors that influence the value of oil reserves are presented in Figure XL. The discounted cashflow method is best able to assign a value to an oil reserve due to the physical characteristics of an oil reserve that determine the future cashflows of the reserve. But due to the developments the uncertainties in the market increase and solely using the discounted cash flow method does not suffice. An integrated approach should be used that adds qualitative aspects to the discounted cash flow method to be able to cope with these developments and the associated uncertainties. Scenario-based impact analysis is the most suitable method to complement the discounted cash flow method to determine how the developments impact the valuation method and the value of oil reserves.

Scenario-based impact analysis considers different scenarios for the developments by using qualitative methods to determine the impact and risk of the developments on the reserves and whether they get stranded. The outcomes of the scenario-based impact analysis are generic and can be used as a framework for companies to identify the level of risk for every type of reserve. To use the framework for identifying the risk exposure for reserves to get stranded, only three characteristics of a reserve should be known, the emission associated with the extraction of oil from the reserve (technology), the duration till the end of production (lifetime) and the breakeven cost of the reserve (breakeven cost). The scenario-based impact analysis reveals that (extra) heavy oils, tar sands and arctic oil reserves are the least competitive reserves.

Valuing oil reserves in a carbon-constrained world

The qualitative impact analysis based on multiple scenarios in a carbon-constrained world shows that many reserves are vulnerable to get stranded. Reserves that are vulnerable to get stranded have a large chance to not get fully exploited in a carbon-constrained world. Hence, the stranding potential may have a large impact by decreasing the value of the reserve. Resulting in the fact that the stranding potential should be directly incorporated in the value of a reserve to reflect an accurate value.

The regulatory stranding risk can be incorporated in the value through the use of a shadow tax. This shadow tax takes a possible taxation on GHG emissions into account, but does not have to be paid yet. Incorporating such a shadow tax when valuing oil reserves enables the valuator to determine whether the reserve is profitable when regulation regarding GHG emissions is applied. Some oil companies, especially the majors, already incorporate such a shadow tax when valuing new projects, but a shadow tax should also be used for assessing projects that are already producing. If the reserve is not viable with such a carbon tax then measures need to be taken to reduce the emissions or to divest from the reserve. The main uncertainty regarding a carbon tax is the level of the tax. This level remains unknown until the tax is implemented. Therefore oil companies should take several levels of tax under consideration when determining the value. Additionally, they should determine the maximum level of tax for which the reserve is still profitable. The higher the maximum tax the more resilient a reserve is to regulation.

The stranding potential evoked by a declining oil market and reducing oil demand can affect the value in two ways. One, all reduction is put on one reserve, which is often the least competitive one. Two, the reduction is spread over multiple reserves from a portfolio reducing their output with a little. When all reduction is inclined on one reserve it may be the case that the (least competitive) reserve is fully or partially stranded which may have a severe impact on the value of the reserve and even set it to zero, assuming that the market does not start to grow. In the second case the reduction of the output should be accounted for by decreasing the output and hence the revenue of the reserve. A reduction in the output of a reserve reduces the revenues and lowers the value of the reserve. Oil companies should therefore, when determining the value of a reserve, account for a lower than expected oil output. The least competitive reserves of a portfolio will, in most cases, experience the highest impact from a decline in the oil demand. Hence the least competitive reserves should account for a higher reduction in output than the competitive reserves, which implies that the rate of reduction depends on the competitive position of the reserve within a portfolio. The rate of reduction that is inclined on a reserve depends on many factors and is therefore hard to predict. These factors are market based such as the total demand in the market, but also the decisions of for instance portfolio managers. The total demand in the market can be modeled as a dynamic model. However such a model depends on many uncertainties in the market and is therefore not very accurate.

Lower oil price resulting from increased competition can have a severe effect on the value of oil reserves. However, accounting for oil prices is not new. However, until recently most companies always thought that prices would increase as oil becomes scarcer. The carbon-constrained world and the abundance of oil change this view resulting in lower future oil prices. Companies should account for these lower prices by adjusting their long-term forward curves in line with the projections of the carbon-constrained world. Lower oil prices decrease the value of their reserves therefore reassessment of their portfolio is necessary to determine their viability in a carbon-constrained world.

When calculating the value of oil reserves in a carbon-constrained world companies should incorporate a shadow tax, decrease the projected output of their reserves relative to the competitive position of the reserve in the portfolio of the company and downwardly adjust their long-term oil price forwards curves to fully account for the developments in a carbon-constrained world.

Preventing oil reserves from getting stranded in a carbon-constrained world

The changing market conditions caused by the developments in a carbon-constrained world require an adjustment in the strategy of oil companies to increase the competitiveness of oil reserves and prevent them from getting stranded. The table of competitiveness that follows from the scenario-based impact analysis can be used as a framework to increase the competitiveness of oil reserves. Increasing the competitiveness reduces the chance of reserves to get stranded by the developments that are at hand in a carbon-constrained world. Oil companies should focus on enhancing the competitive position of their reserves and their portfolio to be able to cope with the developments in a carbon-constrained when they materialize. Enhancing the competitive position is possible by focusing on 'competitive growth' and on 'added value'. Competitive growth and added value will increase the competitive position in the market and are aimed at improving the reserve on the three pillars of competitiveness in a carbon-constrained world (technology, lifetime, breakeven cost). This can make reserves 'shift' through the table of competitiveness toward a more competitive position. Competitive growth can be achieved through acquiring or developing new competitive reserves while divesting from reserves that are not competitive. Value can be added to reserves through supply chain efficiencies, strategic alliances, innovation and technological developments.

At the corporate level oil companies should align their corporate strategy with the necessary changes in the portfolio and at the reserves. This alignment should focus on steering the company in the right direction using adequate performance indicators that incentivize to increase the competitiveness of the reserves. Indicators such as the reserve replacement ratio should be adjusted because in a carbon-constrained world not all reserves need to be replaced, at least not solely by oil reserves but also by gas and in the longer term by renewables such as offshore projects. Indicators that support this view are for instance the replacement of oil by gas (ROG) and the replacement of oil by renewables (ROR). Moreover an additional performance indicator should be implied that monitor the competitiveness regarding emissions and profit levels. These indicators are the 'emission per barrel oil produced' and the 'company average breakeven cost'.

Scientific added value

With this research scientific value is added in the following ways:

The analysis of the developments in a carbon-constrained world has lead to comprehensive insight in the developments that may occur when the world actively addresses climate change. The analysis of the developments and valuation methods based on scientific literature, company papers and expert interviews has lead to the composition of figure XL. Figure XL can be used to clarify developments and determine the consequences of developments in the oil sector. It also gives a clear understanding of the driving forces behind the supply and demand in the oil sector.

The main scientifically added value is the extension of the current valuation method with the new valuation approach. The valuation approach overcomes some of the limitations of the currently used valuation method through analyzing and accounting for the developments that are at hand when the world actively addresses climate change and global warming. The method accounts for the developments by operationalizing the developments, designing and analyzing scenarios of the developments and identifying the reserves that are vulnerable for the developments. Incorporating the developments in the value of the reserves makes the value more accurate and resilient when the developments materialize.

Another scientific value of the research is the secondary application of the new valuation approach, which offers a method and a framework that can be used to increase the value and competitiveness of oil reserves. With this method companies are able to cope with the developments and prevent oil reserves from getting stranded.

8.2 Recommendations

The recommendations that follow from the research are presented in this paragraph. This paragraph contains general recommendations, recommendations that are specifically focused on different type of actors serving the oil sector and recommendations for further research. The section with actor specific recommendations is divided in two sub-sections being recommendations for; owners of oil reserves and investors in oil reserves.

General recommendation

The general recommendations are twofold: first, valuation methods should be adjusted in line with the developments in a carbon-constrained world to reflect a representative value of oil reserves. Second, companies should adopt strategies to cope with the developments in a carbon-constrained world.

Adjust the valuation methods to reflect a representative more accurate value

The valuation methods should be adjusted for the developments that are at hand in the oil sector. Without adjusting the developments in the valuation methods the calculated value will not accurately reflect a representative value when assessing oil reserves. Hence, to more accurately valuate oil reserves in a carbon-constrained world companies should incorporate a shadow tax, decrease the projected output of their reserves relative to the competitive position of the reserve in the portfolio of the company and downwardly adjust their long-term oil price forwards curves. Both the reserves that are already producing and the reserves that will be developed in the future should be subjected to the new valuation method to valuate and re-valuate the reserves.

Adopt strategies to cope with the developments and prevent reserves from getting stranded

Oil companies are often inflexible that cannot easily adapt to changing market conditions, which is due to their large size and long lifecycle projects. These characteristics make it important to identify and cope with future market developments long before the developments materialize. Hence, oil companies should adopt strategies to cope with the developments in a carbon-constrained world to make the company resilient for the changing market conditions. To make a company resilient for the developments they should focus on enhancing their strategy at the portfolio & reserve level as well as on the corporate level. To enhance their portfolio & reserve level companies should aim to improve their reserves on the three pillars of competitiveness through focusing on ‘competitive growth’ and ‘added value’. This will increase the competitive position of the company in the market. The corporate level strategy should be aimed at effectively steering and monitoring the progression in competitiveness using adequate performance indicators that incentivize the necessary change. Examples of such indicators are the ‘GHG emissions per barrel of oil equivalent’, the ‘company average breakeven cost’, the ‘replacement rate of oil by gas’ and the ‘replacement rate of oil by renewables’. Some actor specific recommendations that increase the competitiveness of oil reserves can be found in appendix I.

Recommendations for future research

One of the problems that are inherent with the stranding of oil reserves is that all reserves are in a way dependent on each other through resulting in the total oil supply in the market. If more reserves come online, then the oil price will start decline. Future research could focus on determining the balance between supply and demand in the oil market with special emphasis on the supply side by better estimating the oil reserves that will become online in the future. Additionally, research could focus on analyzing the behavior among large oil producers in different price scenarios to derive the long-term strategies from these oil producers. Of countries such as Saudi Arabia and Russia there is not much information regarding their strategy, however, the IPO of Saudi Aramco and the increasing emphasis on market share driven policy gives away much information regarding their strategy and their perspective on the carbon-constrained world.

The development of a framework that is able to increase the competitive position of an oil reserve was not the objective of the research. However, the framework that is created may add value for companies and expert that determine the viability of oil reserves in future market conditions. Hence, future research should be focused on testing and refining the framework to determine whether it can be used in practice.

Not all companies that own reserves currently keep track of the emissions and the environmental footprint from the specific reserves. Future research should be aimed on better analyzing the emissions originating from oil reserves and therewith supporting Gordon et al., (2015) and the Carnegie Institute. This way the emissions of oil reserves can be better monitored and the scenario-based impact analysis in this research can be made more accurate for the technology characteristic of oil reserves. When more data or a framework on how to measure emissions from oil reserves is available then oil reserves are themselves also better able to measure their emissions.

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Appendices

Appendix A_1 - Highlights interviews

The following experts are interviewed using semi-structured interviews. The themes that are handled in the interviews vary and can be found in the following table. Semi-structured interviews are often used during qualitative research because it allows diverting from the questions bringing additional ideas and point of views to the table. The full transcripts of the interviews are available upon request.

Expert	Function	Company	Topic
Hans van Cleef	Chief Economist Energy	ABN Amro	The oil system and oil prices
Eric Puik	Senior Strategy analyst	Shell	The future of oil, Shell scenarios, the oil system
Mark Sisouw de Zilwa	Director Upstream	ING	Valuation of oil reserves and stranded assets
Maarten Lechner	Resource assurance lead	Shell	Petroleum and reserve economics I
Remco Aalbers	Senior resource consultant	Shell	Petroleum and reserve economics II

Highlights of the interviews

Sisouw de Zilwa (2016)

Hoe waarderen jullie bij ING olie reserves?

Stel dat je een reservoir hebt met ongeveer en miljard barrels olie. Barrel is 159L. Een miljard barrels zit er berekent in de gesteentes maar daar van krijg je maar 25% tot 30% uiteindelijk uit de grond. Want de rest blijft gekleefd aan de poriën van het gesteente. dus dan krijg je er maar 300 miljoen barrels uit. Dat is het volume dat je kan recoveren uit het project. Wij kijken naar de olievelden of gas velden die een klant heeft. Dan laten we dat berekenen en wij controleren het wat er zeg maar nog te winnen valt. Want ze hebben vaak al een heel gedeelte geproduceerd en wij kijken wat er nog te produceren valt. En dat productieprofiel daar moeten we het mee eens zijn. Dus de klant zelf zegt dat ze bijvoorbeeld 100.000 barrels per dag produceren en dan kijken we daar met veel kennis naar en we laten het ook bekijken door experts en consultant bureaus zoals Ryder Scott, STS Horizon, Exodus, Je hebt een hele grote lijst met een stuk of 30 consultants die echt op de petroleum engineering zitten. Zijn vaak mensen die lange tijd bij een oliebedrijf gewerkt hebben. Nou die huren we in. Zij schrijven een rapport wij beoordelen dat en dan nemen we vaak nog een afslag. Soms denken we dat die productieprofielen en de set van die velden eigenlijk minder goed zijn dan wat de klant zegt of wat de consultant zegt. Dus dan risken we dat nog een beetje. Maar goed uiteindelijk heb je dan een profiel waarvan je denkt nou dit jaar die komende 5 tot 10 jaar gaan ze dat ongeveer produceren. Dus dan heb je het productieprofiel. Wat we vervolgens doen is het kijken naar de prijs. En dat is natuurlijk heel moeilijk. De banken hebben een soort van 'bank price deck' dat is een forward curve eigenlijk zoals je ook normaal in de olie wereld hebt. Zo hebben wij ook een 'bank price deck' en die bank price deck ligt altijd iets lager dan de forward curve. Als bank ben je namelijk altijd wat conservatiever dus die ligt altijd ongeveer 20% lager dan de forward curve. Onze bank price deck loopt nu ongeveer vanaf $47 dollar.

Wat we dan eigenlijk doen van een klant zijn alle productieprofielen bij elkaar van de olie en er van uit gaan dat de olie evenveel waard is. Dat wordt door discounting allemaal gecompenseerd zodat de verschillende olies met elkaar te vergelijken zijn. Die productieprofielen vermenigvuldigen we met de price deck. Nu op dit moment loopt hij van $47 naar $57 in de toekomst. Dus dat is lager dan de forward curve. En dan kan je daar een NPV van berekenen. Dus dan heb je een waarde van al die olie dan verkocht wordt en die cash flows verdisconteer je met een discount factor van meestal 6 of 7% afhankelijk van waar het is, als het bijvoorbeeld in Afrika is dan heeft het meer risico en volgt een discount factor van 8 procent. In de Noordzee misschien 6%.

Dit is dus de cashflow van de olie productie x prijs maar daar moet je nog de kosten vanaf trekken. Dus je CAPEX, OPEX, G&A en je TAX. Dus in feite allerlei kosten worden er vanaf getrokken. En wat er over blijft is je net profit en die verdisconteer je. Dat is ook het geld dat beschikbaar is om bijvoorbeeld banken terug te betalen. En dan heb je NPV van je field life of life of field. Wat je ook kan doen is de waarde nemen over de loan life. Dus je kunt die waarde voor de hele field life uitrekenen. Dat is dan bijvoorbeeld 2 miljard dollar. en je kunt ook zeggen dat je een loan life hebt van 5 jaar en dan alleen maar naar die 5 jaar kijkt en dan heb je ongeveer 1,4 miljard. Dus dat is een verschil. Als je het hele veld neemt heb je dus een groter NPV dan dat je alleen over de periode dat de lening loopt kijkt.

Wat we dan doen is als je die twee NPV waardes hebt, de field life en de loan life waar van de field life wat hoger is. Dat delen we dan door een factor. Een soort buffer. Dus dan nemen we bijvoorbeeld de field life van 3 miljard en delen we die bijvoorbeeld door field life cover ratio (FLCR) van 1,5 en nemen we dus eigenlijk een buffer van 1,5. En dan heb je 2 miljard over op 3 miljard.

Maakt ING die 'bank price deck' zelf?
Ja die maken we zelf. In Amerika heb je wel een soort van standaardisatie tussen 40 banken die daar actief zijn. Maar wij bepalen het hier voor ons zelf. Maar we hebben wel een soort van overleg met andere banken. Niet echt overleg want we spreken het niet af maar we bespreken wel wat voor de ene bank acceptabel is. Aangezien we soms ook leningen delen met andere banken moeten we het wel ongeveer zeker kunnen zijn dat zij het ook accepteren met onze berekeningen. Dus je kunt haast zeggen dat de 'bank price deck' door banken zelf wordt bepaald maar ze liggen wel allemaal ongeveer even hoog. Het kan wel eens een dollar per barrel verschelen maar niet zo heel veel. Dus je kunt van een soort van consensus prijs spreken die eigenlijk wel gerelateerd is aan de olie forward curve. De forward curve wordt eigenlijk gewoon gepubliceerd en daar doen traders veel mee en hedgebedrijven die olieprijzen hedgen. Die kijken naar de forward curve en kijken vaak 5 tot 6 jaar vooruit. Dat is dan ook vaak een inschatting van wat de prijs gaat worden alleen het probleem met die forward curve is dat hij elke dag verandert. Morgen is hij weer anders dan vandaag. Het is dus wel voorspellend maar de ene dag gaat hij weer omhoog en de andere dag omlaag. Dat is dus wel een beetje lastig.

En de vorm van de curve kan natuurlijk ook nog veranderen?
Ja de vorm kan ook nog veranderen, ene dag is hij wat platter andere dag steiler. Dat hangt een beetje af van de visie van de oliehandelaren over de toekomst en dat heeft weer alles met voorspellingen enzo te maken. Dus banken nemen altijd een prijsdeck die een stuk lager ligt maar ook minder fluctueert. Maar als de olieprijs bijvoorbeeld van 30 naar 100 gaat dan moeten wij ook onze prijs omhoog bewegen en andersom ook.

Hoe vaak passen jullie de bank price deck aan, ook elke dag?
We passen de bank price deck ongeveer elk halfjaar aan. En die is dan dus afhankelijk van de prijs bewegingen in de markt. Dus dat is de price deck.

En de risico's worden altijd verrekent in de discount factor?
Ja dat klopt en dat is met name afhankelijk van de locatie. Maar het is niet dat er bijvoorbeeld met 13 of 15 en 6 of 4 wordt gerekend maar het varieert zo'n beetje tussen 6 en 8%.

Hoe kan dan bijvoorbeeld de waarde die je vast stelt beïnvloed worden door bijvoorbeeld een klimaat akkoord?
Dat is een goede vraag en ook best wel moeilijk om te beantwoorden op een kwantitatieve manier. Maar de waarde kan natuurlijk heel goed veranderen. En dat heeft dan denk ik met name te maken met niet zo zeer de technologie van het produceren of het feit dat de productie van het veld meer of minder wordt maar meer aan de kant van de demand. Want de demand kan over tijd veranderen. En dat is eigenlijk iets wat eventueel gedwongen kan gebeuren of gewoon door technologische ontwikkelingen of door politieke effecten zoals regulering of doelstellingen. Dat gaat veel sneller dan je denkt. De olie wordt vervangen door EV's wat ook veel sneller gaat dan verwacht en de prijzen gaan ook zeer snel omlaag. En energy efficiency speelt ook een hele belangrijke rol in de reductie van de groei van olie en gas maar om te beginnen denk ik dat je moet zeggen dat de wereld bevolking stijgt en daarmee de vraag naar olie ook stijgt. Dat ligt in principe aan de basis. Alleen in Europa en de VS wordt veel aan efficiency gedaan waardoor de energievraag eigenlijk niet zo heel hard toeneemt maar ook vlak blijft. En GDP groei betekent dan ook niet altijd een groei in energie in deze wereld, maar wel in ontwikkelende landen zoals China en India en natuurlijk ook Afrika. Over het algemeen gaat die groei in de wereldbevolking.

Maar als er dus minder vraag komt naar olie dan zal er een oversupply komen in de markt en dan gaat de prijs naar beneden en worden de reserves minder waard. Dan praat je ook over stranded assets, dat is die stranded asset theorie en ik zal je aanbevelend om naar Carbon-Tracker te kijken. Dat zijn erg goede rapporten. Wij hebben ze bij ING ook gebruikt. En het zijn ook ex-bankers die met een goed manier hebben gekeken naar vraag en aanbod en wat er mogelijk stranded is.

Hoe kan bij het waarderen van reserve omgaan met al deze ontwikkelingen en onzekerheden?
In een wereld die zo onzeker is en waarbij de effecten van verschillende acties onbekend zijn of niet helemaal goed in te schatten. Wel kwalitatief maar niet kwantitatief is best moeilijk dan is een scenario planning wel echt een goede

manier. En dan schets je een aantal werelden die totaal anders zijn met de scenarios. Dat kan heel veel inzicht verschaffen in zorgt dat je enigszins met de onzekerheden om kan gaan. Dus als op een gegeven moment aan de renewable kant veel sneller gaat en de supply is er nog wel maar de demand valt weg dan heeft het een enorm effect op de waarde van je assets en zelfs zodanig dat het van reserve naar resources gaat.

Hoe kunnen olie reserves stranded raken?
Een reserve is een reserve als het economisch geproduceerd kan worden en in economisch zit een aanname van de olieprijs. Want als de olieprijs 60 - 70 dollar of meer is dan kan je de reserves met breakeven costs van 50 economisch winnen maar als de olieprijs naar 30 gaat dan kan je reserves met breakeven cost van $50 niet economisch winnen en dan zijn het dus eigenlijk geen reserves meer maar resources. Dus dan kom je bij die Carbon Tracker curve, dat is deze breakeven cost curve van jou welke dat heel duidelijk aan. Als een reserve hogere kosten heeft dan de olieprijs dan is hij al eigenlijk niet meer economisch haalbaar. Hieruit blijkt dus dat de oliezanden en ultra-deep water boven een olieprijs van $50 liggen en als de olieprijs lange tijd onder de $50 blijft dan kunnen de duurdere reserves zoals oliezanden en ultra-diep water stranded raken op basis van de lage olieprijs.

Wij gaan over een paar maanden ook zo'n kosten curve maken en dat gaan we presenteren aan de board en ons onderzoek wat we nu doen tegen dit plaatje aanhouden. Heel interessant. Ik denk dat je heel erg op de goede weg bent als je dit zo gaat doen.

Aalbers (2017)

Welke ontwikkelingen in de markt beïnvloeden de waarde van een reserve? Als er minder CO2 uitgestoot dient te worden, heeft de CO2 dan ook direct invloed op de waarde?
Dat heeft zeker allemaal invloed want wat je ook ziet dat er hoogst waarschijnlijk CO2 taxes ingevoerd gaan worden. Dat is ook een kostenpost. Dus je praat hier over royalties, taxes en government take, daar zit op een gegeven moment ook CO2 tax in. Als wij als maatschappij zeggen dat we voor iedere ton CO2 uitstoot 8 dollar moet betalen dan drijft dat de kosten en daarmee de waarde van reserves naar beneden. Ook betekent dit dat er aan de andere kant weer incentives zijn wnat als er een CO2 tax is en je kan ondergrondse berging faciliteren waarbij CO2 wordt opgeslagen in lege velden en de CO2. Alleen zijn we hier nog steeds niet duidelijk over als maatschappij.

Maar gaat dan niet de olieprijs omhoog en worden dan deze kosten niet doorgerekend aan de consument?
Niet per definitie, omdat de prijs niet wordt gedreven door alleen de kosten maar door de supply en demand balance. Dus afhankelijk van die balance wordt de prijs bepaald en is CO2 tax gewoon een kostenpost. Wat het wel is, is dat het meehelpt aan de marginal barrel. Op het moment dat supply omlaag gaat, kunnen mensen alleen maar investeringsbeslissingen nemen als ze denken dat hun investment een positieve cash flow gaat geven op een lange termijn olieprijs forecast, inclusief de kosten en daar zit de CO2 tax in. Stel het kost $30 development en productiekosten als er een tax bij komt van $8 dan is die marginal kost van 30 naar 38 en als de olieprijs daar onder ligt dan wordt er niet of minder geïnvesteerd.

Veel projecten waar nu in geïnvesteerd is gaan ook nooit volledig hun investering terug verdienen en dat weten we ook bij Shell. Maar over het portfolio gezien wil je wel winst blijven maken. Als de olieprijs nooit zo hoog was geweest als voor 2014 dan waren veel unconventionals nooit mogelijk geweest. En dan was bijvoorbeeld shale ook nooit zo groot geworden. Maar nu daar tijdig in geïnvesteerd is zijn ook die kosten sterk verlaagd waardoor het nu wel mogelijk is. Want bij een hoge olieprijs zijn bijna alle projecten rendabel

Geldt dat ook voor Arctic oil?
Ja, arctic oil is hetzelfde probleem, want toen de olieprijzen op $140 stonden was dat nog een interessant investering. Zelfde geldt ook voor heavy oil reserves in Amerika die alleen maar ontwikkelbaar zijn bij hele hoge olieprijzen. Dus op het moment dat de olieprijzen in elkaar stortte zijn die projecten meteen weer in de ijskast gezet. Alaska heeft nog een aantal andere issues. Ja het is heel kostbaar en het risico is heel groot. Want als er in de Arctic iets mis gaat dan is het een environment waar je nog heel veel jaren de omgeving beschadigd doordat op die lage temperaturen olie niet afbreekt. Dus als je daar een spill krijgt is je exposure giga. Dus er zijn ook nog andere overwegingen die meespelen. Shell heeft daar een tijd naar gekeken maar ik ben daar persoonlijk altijd op tegen geweest.

Maar stel nou dat de vraag naar olie gaat afvlakken en op een gegeven ogenblik zelfs gaat dalen.

Ja dan kom je in dat grote macro economische plaatje uit met een supply en demand maar er is een instantane en toekomstige verwachtingswaarde en die toekomstige verwachtingswaarde hangt dus af van al die macro economische elementen dus van de groei van de populatie en de energiebehoefte van de populatie. En dat verschilt per land. Gaan de ontwikkelingslanden snel naar een westerse economie toe of blijft dat veel langzamer, gaan ze dat doen in een olie economie of met renewable energie. Dus die demand hangt af van dus populatie groei, energie demand en de mix van energie. Maar dat is niet instantaan maar ook naar de toekomst toe. Dus wat je dan als maatschappij gaat doen is een verwachting maken van de supply en demand gap en op basis daarvan proberen economen een afschatting te maken van prijs en op basis daarvan kijk je wanneer er ruimte is in de markt en als je over 20 jaar projecten wilt doen dan moeten we dus nu exploratie doen. En je kijkt ook binnen de energie cap of de exploratie nog succesvol is. Op een gegeven moment ben je gewoon klaar. Als je kijkt naar de Noordzee. Daar zijn al zoveel exploratie putten geboord. Daar is gewoon geen ruimte meer voor nog een groot veld. Er zijn misschien wel hele kleine veldjes maar die zijn dan weer niet economisch haalbaar. En hoe groter het veld moet zijn hangt ook weer van de prijzen af. Dus al die dingen hangen met elkaar samen naar de toekosmt toe.

En op lange termijn aspect van het verschil in supply en demand. Als je de aanname maakt dat de demand gaat afnemen door decarbonization?
Dat hangt af van de balans tussen supply and demand. Dus het tempo waarin supply and demand zich aanpassen genereert de marge en het is de marge die bepalend is voor de prijs. In het verleden hebben ze gezegd dat als je de trading marges eruit haalt en de sentimenten, dan kom je op een punt uit dat om er weer nieuwe projecten in de markt moeten worden gezet om de supply op te krikken. En er zijn bijna geen projecten meer waar voor $2 per barrel de olie uit de grond komt. Als dat zo was dan zou de prijs $2 per barrel zijn. Dus er zit een vloer in omdat het meer kosten met zich mee brengt. Uiteindelijk wordt de prijs gedreven door de marginal barrel. Wat kost het om de volgende slice aan reserve te produceren, maar die slice wordt ook weer gedreven door government take en de kosten van supply. En het is dus een oneindig complex systeem. Wat je ziet in Amerika is dat het fracken ook een bepaalde prijs heeft maar toen de olieprijs omlaag ging hebben de contractors hun marges verlaagd en dus zijn de kosten verlaagd en dus zijn de marginal barrel voor shale ook weer goedkoper geworden. Je kunt momenteel shale olie economisch maken voor een lagere prijs dan voor de prijs in elkaar zakte. En dat is omdat de supply industrie ook in hun kosten heeft gesneden. En wat je ziet is niet dat alleen de oliemaatschappijen hun marges hebben moeten laten schieten maar ook alle andere service bedrijven constructie bedrijven de drilling companies. Allemaal krijgen ze minder orders en hebben ze dus minder werk. En merken alle bedrijven gelieerd aan olie er ook heel veel van. En zelfs in Stavanger gaan alle chique restaurants en taxi bedrijven en chique juwelier failliet omdat de mensen die veel geld verdiende nu veel minder verdienen en geen rolexen meer kopen en de hele bedrijvigheid afneemt.

En als de vraag naar olie nou echt gaat beginnen met dalen, wat heeft dat dan voor effect op de olieprijs?
Dat zie je dan uiteindelijk terug in de prijs. Want wat er gebeurd is wat er nu ook aan de hand was. Waarom was de olieprijs eerst zo ontzettend laag, omdat OPEC hun productie niet terug schroefde, want uiteindelijk is de supply demand price een marginaal kosten verhaal en een perceptie van de markt of er voldoende is of niet. Dus op het moment dat jij zegt de werkelijke olie demand, iets van 93 miljoen, als jij zorgt dat supply op 92 miljoen blijft hangen dan is er 1 miljoen tekort in de markt en dat betekent dat er een trading marge ontstaat die de olieprijs opdrijft. Want partijen hebben olie nodig en gaan dan tegen elkaar opbieden. Daarom heeft het heel erg te maken met het marginale verschil. Op het moment dat er een kleine oversupply is dan heeft dat een hele grote drukkende werking op prijs en als er een klein tekort is dan gaat dat omhoog. Tussen supply en demand heeft OPEC een regulerende werking want als je hier op of neer gaat dan verander je de marge tussen de supply and demand. En OPEC heeft nu een stapje terug gedaan omdat de unconventionals in amerika op een gegeven moment heel succesvol werden doordat ze meer konden fracken en horizontal putten konden boren waar heel veel olie en gas zit maar op een lage dichtheid en als je dan horizontaal boort kan je daar toch goede rates uit krijgen dus er is een heleboel olie op de markt gekomen door Amerika. En op een gegeven moment heeft OPEC het gevoel gehad dat hun marktaandeel minder werd en toen heeft OPEC gezegt dat ze de oil shales terug wilde drukken en hebben zich daarom verrekent dat de marge tussen supply en demand de prijs drijft. Dus toen er een oversupply kwam, OPEC ging niet langer de kraan dichtdraaien want ze konden onderling ook niet overeenkomen hoeveel ze van de markt gingen halen. En Saudi Arabie kreeg een steeds lager marktaandeel omdat al die OPEC acties vanuit Saudi vandaan moesten komen. En op het moment dat Saudi de kraan open draaide is de markt ontzettend in elkaar gezakt en het heeft veel langer geduurd dan bedoelt. En ja, Saudi heeft misschien iets meer marktaandeel gekregen maar de prijs is zo veel lager dat ze ook veel minder verdienen. En zelfs Saudi is naar de markt gegaan om geld te lenen want hun economie rekent op een bepaalde hoeveelheid geld uit de olie en die krijgen ze momenteel niet. Ja het is een heel complex systeem dat al die waardes en prijs aan elkaar hangt.

Wat is de rol van de SEC bij het waarderen en controleren van de waarde van olie reserves?

De SEC wil dat investeerders een afschatting kunnen maken van de waarde van bedrijven op basis van hun inschatting in reserves op basis van een systeem dat voor iedereen ongeveer hetzelfde is. Dus daarom pinpoint de SEC een aantal dingen vast en weet dat er een onzekere prijs is en elk bedrijf een andere aanname maakt. Dus de SEC zegt dat voor investeringen in bedrijven alle bedrijven op dezelfde manier hun waarde bepalen. En dat doe je op basis op het gemiddelde van afgelopen jaar en daar is ook geen discussie over mogelijk. Dat maakt het mogelijk om de bedrijven met elkaar te vergelijken en te besluiten in welke een investeerder zijn geld wil steken. Dus dat is weer binnen een bepaald framework van aannames.

Puik (2016)

Welke factoren zijn er belangrijk voor het bepalen van de olieprijs en de supply en demand?
Als ik het zelf zo uit elkaar zou rafelen zoals jij in je figuur XL hebt gedaan, dan kom ik min of meer op de zelfde factoren uit. Ik zou zeggen dat belangrijkste drijfveer voor oliedemand de *economic activity* is. Je kunt GDPs van landen statistisch correleren aan olie demand en dan zal je zien dat vooral voor non OECD countries echt een fantastische correlatie bestaat. Dus als China met 6 procent groeit, dan groeit het demand met laat zeggen 3 procent. Dus dat is een goed gedefinieerde correlatie. En de reden daarvoor is dat als je een fabriek bij bouwt, dan heb je meer energie nodig en heb je dus meer olie of gas oid nodig. Dus global economic activity is de key driver voor demand. De tweede die heel belangrijks is, is *global policy making* op het gebied van climate change.

Op de lange termijn is het echt *economic growth, geopolitical stability, economy prosperity, livingstandards, global GDP, technical efficiencies* is enorm belangrijk*, environmental policy making*, niet zo zeer awareness, maar echt wat wordt er gedaan. Geopolitieke stabiliteit, competition mogelijk maar neemt Shell niet echt mee, omdat shell denkt dat over 20 jaar het landschap van spelers niet heel erg anders zou zijn. Major Resource Holders (MRH) zijn hele belangrijke groep die een interest hebben omdat het landen zijn die voor hun inkomsten afhankelijk zijn van olie en gas. Saudi Arabia en Rusland bijvoorbeeld moeten van hun resources af voordat het waardeloos wordt. Daar worstelen de MRHs mee en Exxon en Shell niet omdat hun reserves duur 10 jaar is en daarna houdt het wel zo'n beetje op. Als Shell bijvoorbeeld geen nieuwe reserves zou vinden dan hebben ze over 10 jaar zo'n beetje niks meer in het portfolio zitten en is het allemaal geproduceerd.

Levenstandaarden en *wereld populatie* zijn heel belangrijk, *substitutie* is van belang en koppelt close naar regelgeving omtrent klimaat. Wereld economy hangt een beetje met wereld populatie en levensstandaarden samen maar niet helemaal, carbon budget valt koppelen we aan klimaat regulering. Wat je mist en moeilijk te quantificeren is de *Social behavior*, dit houdt het effect van digitization, artificial intellegence, de deel-economy, circular economy. De uberization waardoor mensen dingen besluiten te delen. Domweg doordat mensen op een sociale manier anders met elkaar omgaan dan ze vroeger deden. Dit zou wellicht een hele grote impact kunnen hebben op toekomstige energievraagstukken. Afspraken OPEC zit aan de supply kant. De grote vraag aan de supply kant, is hoeveel olie en gas is er eigenlijk. En tegen welke *kosten* kunnen die geproduceerd worden. Belangrijker nog dan afspraken OPEC is de *size of future resource base.* Je hebt gezien dat recentelijk shale oil enorm in opkomst is gekomen, en vijf jaar geleden wisten we bij wijze van spreken nog niet van het bestaan af. Nu zien we lagere prijzen omdat er zoveel shale olie in de markt is vanuit de US. En dat is die shale oil resource base ontsloten die elk jaar groter en groter wordt en de kosten om te ontwikkelen lager en lager worden. Dus die olie wordt in de markt gedrukt. En OPEC krijgt het er benauwd van dat er zoveel geodkope olie is en vandaar dat opec een andere strategie heeft gevolgd. Dus de *size of the resource base* is belangrijker dan *afspraken OPEC*. Wat ook belangrijk is, is de technologie, aan de demand side (*end user efficiency*, twee). Meer efficiënte motoren, omdat technologie goedkopere en efficiënter wordt. Maar er is ook technologie aan de resource / supply kant dus door bijvoorbeeld slimmer te boren en andere technologieën te gebruiken maak je de productie van die bronnen goedkoper en goedkoper. Dat maakt het ook moeilijker om te substitueren. Dit staat denk ik onder *supply chain efficiencies*? Die supply chain efficiencies grijpt echt in op de kost side van de development of the resource base. Op de lange termijn is dat belangrijker dan wat landen als OPEC doen enzo. OPEC soort van secundaire speler. En de reden daarvoor is dat OPEC ook niet heel veel spare capacity in de markt heeft, dus voor OPEC om de markt te kunnen beïnvloeden, zij kunnen de productie terugbrengen als ze vinden dat de prijs te laag is, maar als straks de prijs te hoog is, waardoor kopende partijen de olie te duur vinden, waardoor bijvoorbeeld andere bronnen zoals bijvoorbeeld de renewables, dan heeft opec niet heel veel power meer om de prijs naar beneden te drukken doordat ze niet zoveel spare capacity hebben.

Kan je de belangrijkste factoren die we zojuist besproken hebben voor mij ranken op belangrijk (rechts) en minder belangrijk (links)?

Reden waarom het carbon budget wat aan de onderkant linkt is, is dat de regelgeving omtrent klimaat uiteindelijk ingrijpt op het energiesysteem. Het carbon budget is iets dat je meet en is niet echt een factor, daarom meer kijken naar de regelgeving. Het is interessant om ze allemaal nog even door te praten, en zodat je een indicatie krijgt van de onderliggende drijvers.

Size of the resource base: De resource base is onbekend en onduidelijk hoeveel olie en gas er nog zit, maar 30 jaar geleden zei de club van Rome, over 30 jaar hebben we geen olie meer. Maar nu, 30 jaar verder hebben we meer olie dan ooit tevoren. De size of the resource base zal in de toekomst enorm gedreven gaan worden door unconventionals zoals shale oil en shale gas volumes. Met name de shale gas volumes worden gezien als enorm en de verwachting is dat de wereld heel snel zal omschakelen van olie naar gas, juist omdat er zoveel goedkoop gas is en omdat het ook gunstiger is voor het klimaat. Wat de resource base drijft, is veel goedkope OPEC olie, heel veel goedkope OPEC olie voor honderden jaren aan reserves waar ze vanaf moeten. En aan de andere kant de non-OPEC shale oil and gas resources. En dat spel zal in de toekomst enorme impact hebben op olie en gas prijzen.

Wereldpopulatie: die gaat groeien met 3 miljard tot 2050, dus 50% meer mensen komt erbij. De grote onzekerheid is dat die 3 miljard mensen komen allemaal te wonen in geürbaniseerde omgevingen. Dus we zullen een wereld zien waarin we multi-miljoen steden hebben. Die steden zullen alleen maar groter worden en gaat in volle speed ahead. De manier waarop die steden worden gebouwd en hoe mensen voorzien zullen worden in energie zal in onze optiek een hele belangrijke drijfveer zijn in termen van de energie demand die in zo'n stad gevraagd zal worden. Als die steden heel efficiënt ontworpen worden, in termen van publiek transport, stadwarmte ipv individuele warmtevoorzieningen. Als daar heel slim naar gekeken wordt, dan kunnen die steden enorm energiezuinig ontworpen worden. Maar dat moet dan wel gedaan worden. Shell is van mening dat een van de belangrijkste onzekerheden in die wereld va de toekomst omdat die steden enorm gaat groeien, en dat we enorme grote en meer steden zullen hebben in de toekomst dan dat we ooit hebben gezien. En hoe je om gaat met energiedistributie en hoe je omgaat met water en voedsel stromen in die steden zal enorm ingrijpen op de toekomstige energiebehoefte.

Wereld economie: Als de economie groeit dan zal de vraag toenemen.

levensstandaarden: voornamelijk in non-OECD landen zullen vermoedelijk aanzienlijk toenemen met de focus op Afrika en landen als Nigeria, en Azië met landen als India. En als die levensstandaarden daar net zo hard zullen groeien als dat we hebben gezien in Europa in de laatste 50 jaar, dan zal de energieconsumptie per capita verdubbelen of verdriedubbelen. Nu heeft daar niemand een auto, maar twee generatie later heeft iedereen daar een auto. Dus de levensstandaarden zijn een key driver voor energiebehoeften. Als je dat optelt bij een groeiende economie en een groeiende wereld populatie. Dan voorzie je een verdubbeling in de totale energie in de aankomende 10 tot 30 jaar. En die moet dan maar wel afgeleverd worden.

Regelgeving klimaat: Daar zijn de onderliggende krachten, je kunt een aantal dingen doen, taxeren, maar ook wetgeving om CO2 emissies te verbieden zonder dat je de gebruiker daarvoor belast. En tot slot kan je ook nog subsidies instellen of laat ik zeggen de industrie helpen om als CO2 gegenereerd wordt om het op te slaan zodat het probleem wordt opgevangen, dus je kan ook nog met subsidies aan de slag om de industrie te helpen het CO2 probleem aan te pakken. Hoe die regelgeving uitpakt zal enorm ingrijpen op hoe de behoeft van fossiele energie of niet ontwikkelt. De grote onzekerheid is hier, kunnen de global leaders daadwerkelijk de handen ineen slaan en gezamenlijk de handen ineen slaan. Want als het hap snap zoals het nu gebeurd dan blijft het een inefficiënt en niet succesvol manier om global warming te teckelen.

End-user efficiency: is van belang omdat als je histories gezien, een stijging van ongeveer 1% efficiënter. Lampen worden efficiënter etc. Maar stel dat dit 2 of 3 procent wordt, dan zal dit enorme impact hebben over het energie demand van 30 jaar. Dat kan zo 20 of 30 procent schelen.

Social behavior: is de grote onzekerheid, de vraag is hoe bijvoorbeeld artifical intellegence, digitization ingrijpt op energie demand. Je hebt een hoop tools, waarschijnlijk in de toekomst om zuiniger om te gaan. Je kent het beroemde kastje van Eneco wel, de Toon. Maar het kan best zijn dat er nieuwe technologie ontwikkeld wordt, dat er nieuwe gadgets komen nieuwe customer producten worden die eigenlijk ook weer energie vragen. Hoe dat gaat uitwerken zal onzeker zijn.

Substitutie: is uiteraard van belang het is onduidelijk hoe snel dat zal gaan en ik heb aangegeven dat het sneller zal gaan als het gedreven wordt door economische incentive. Dus als de fossil fuel prijzen stijgen terwijl de kosten van renewables naar beneden gaan, dan zal het substitutie effect gedreven door economische drijfveren sneller gaan. Dat zal ook kunnen leiden dat mensen denken van oké de energie is nu groen en niet meer zo duur dus we hoeven er niet zuinig mee om te springen. Daar kunnen allerlei rare effecten gaan plaatsvinden in termen van energiebehoeften. Maar substitutie zouden wel de behoefte aan fossil fuels naar beneden kunnen drijven, sneller, of langzamer als dat economisch of qua regelgeving gedreven is.

Carbon budget is meer een meet component

Afspraken opec: is van belang voor de korte termijn, maar minder van belang voor de lange termijn en supply chain efficiencies grijpen in op kosten van het produceren van fossils en dat linkt een beetje naar die resource base toe. Ligt links maar werkt nauw samen met de resources base. Dus als we dat goedkoper kunnen doen dat de economische substitutie daardoor minder snel gaat. Dus er is een focus op dit, door dat je de competitie met concurrenten moet aan gaan. Maar misschien denkt de industrie wel, hoe goedkopere olie we kunnen produceren des te trager gaat de economische substitutie. Daar is niet echt een industriemening over, Shell heeft er geen mening over, wij willen gewoon geld verdienen, en zullen dit altijd zo goedkoop mogelijk proberen te doen.

Dit is echt een heel erg belangrijk onderwerp. Zeker voor bedrijven zoals Shell, maar niet alleen zoals bedrijven als shell maar ook voor overheden zoals de Nederlandse overheid die zich zorgen maakt over hoe Nederland in de toekomst voorzien kan worden van goedkope energie op een klimaat verantwoordelijke manier. We hebben dat klimaat akkoord en regeringen zijn heir ook mee bezig. Alle regeringen zijn hier mee bezig. Als klant voor het importeren van energie maar ook regeringen die moeten exporteren. Die doen niks anders dan hierover nadenken op het allerhoogste niveau. Een bevriende concurrent collega stelde de vraag. Wat denk je dat het belangrijkste betaal middel is in de wereld? Energie, de joule, vroeger toen we half aap waren was de kwestie dat je aan voedsel moest denken om te overleven. Als je geen energie hebt was je ten dode opgeschreven. Als je geen toegang hebt tot energie kun je geen activiteit ontplooien. Joule is dus het belangrijkste.

Appendix A_2 - Interviews

Interview Hans van Cleef
(Full transcript available upon request)

Interview Eric Puik
(Full transcript available upon request)

Interview Mark Sisouw de Zilwa
(Full transcript available upon request)

Interview Maarten Lechner
(Full transcript available upon request)

Interview Remco Aalbers
(Full transcript available upon request)

Appendix A_3 - The impact of the developments by interviewees

Ranking of factors by experts

In the table below, the experts that are interviewed rank the drivers that cause the developments from having a low impact to a high impact. To allow multiple perspectives not only experts working at oil companies are interviewed, but also experts that are active in the oil industry but also those that work at a bank serving the oil and gas industry. The group of interviewees consists of 2 bankers involved in the oil and gas industry and 3 experts working at an oil company. The experts are chosen on their knowledge of the functioning of the oil system and the future developments or on their knowledge of valuing oil reserves. The impacts are ranked using the Q-sort method in which the experts could rank the different drivers of developments from 1 (low impact) to 5 (high impact).

	Drivers of development and their impact on the reserve value	Ranking by expert A_{MC}	Ranking by expert B_{EP}	Ranking by expert C_{MS}	Ranking by expert D_{ML}	Ranking by expert E_{RA}	Average impact
Reg.	Carbon budget	3	2	4	3	-	3
	Climate regulation	3	4	4	3	-	3,5
Demand	World economy	3	5	5	3	-	4
	Living standards	5	4	3	4	-	4
	World population	3	5	5	5	-	4,5
	Substitutes	4	3	2	2	-	3,66
	End-user efficiency	4	4	4	2	-	3,33
	Social behavior	-	3	3	3	-	3
Price	OPEC	2	1	2	3	-	2
	Size of resource base	-	5	1	4	-	3,33

1= low impact, 5= high impact

Table 19 - Ranking of the drivers of the developments and their impact on the value of oil reserves

The rankings of the experts form an average for the impact that the different factors have on the value of oil reserves. These averages are further analyzed on if they have a positive or negative effect on the value of the reserves and on the duration of the impact of the factor (long-, medium-, short-term). Since a short-term effect has less influence than a long-term effect, factors that have a long-term effect are more important and have a higher impact.

Drivers of development and their impact on the reserve value	Average impact	Positive or negative impact?	Duration of factor on value	Add to the carbon-constrained world?	Impact *
Carbon budget	3	Negative	Long-term	YES	Medium
Climate regulation	3,5	Negative	Medium-term	YES	Medium
World economy	4	Positive	Long-term	NO	High
Living standards	4	Positive	Long-term	NO	High
World population	4,5	Positive	Long-term	NO	High
Substitutes	3,66	Negative	Long-term	YES	High
End-user efficiency	3,33	Negative	Long-term	YES	Medium
Social behavior	3	Negative	Long-term	YES	Medium
OPEC	2	Positive	Short-term	NO	Low
Size of resource base	3,33	Positive/negative	Long-term	YES	Medium

*low = 1 to 2,5; medium =2,5 to 3,5; high = 3,5 to 5

Table 20 - Impact of the drivers of the developments on the value of oil reserves

The table of the factors and their impact on the future value of oil reserves show that some factors that have a large impact do not add to the decarbonization of the economy. These factors are for instance the population growth, living standards and the world economy. They are all factors that will have a major impact on the demand for oil, but these factors have a demand increasing effect. To be able to provide a complete reflection of the system, these factors are also taken into account in the following section, which will emphasize on the impact of the developments on the value of the oil reserves.

Appendix B - Analysis of the functioning of the system

In chapter 2 - The developments that affect the value of oil reserves in a carbon-constrained world, the factors that influence the value of oil reserves are identified. This appendix continues with analyzing the factors we identified on how they influence the value of the reserves. The factors do not solely influence the value of the reserves but also each other, which shows the complexity and interrelations within the system. In the first section, the focus lays on how the factors influence the value of the oil reserves, using the causality of the factors. In the second section, the relations and interrelations between the factors are studied as well as their combined effect.

Figure XL clearly shows that the value of an oil reserve is very complex because it is dependent on many factors, which are in turn dependent on many other factors. The factors that influence the value of oil reserves have their foundation in all sort of disciplines such as economics, social science, politics, commerce, operations and technology. This makes the system even more complex and uncertain. This multi-discipline character also makes it impossible to solely use a, for instance, technical or economical approach to valuate a reserve because the social and political factors are hard or even impossible to quantify.

Some characteristics of the system

The following sections give insight in the most important characteristics of the system.

Balance between demand and supply determines the oil price

Reduction in demand decreases the value of the oil reserves through declining oil prices, but only until the supply is matched to the demand. Thus, a structural demand decline does not necessary mean that oil prices remain low while the demand declines. The balance between demand and supply will be restored, when supply matches the demand again, and there with the oil price.

Oil demand

The oil demand is caught between two contradictory developments. First are the demand increasing developments. These developments are increasing the demand for oil due to an increase in the global population, increasing living standards and growing global economy. Second are the demand reducing developments. Developments such as electric transportation, renewable energy, increasing end-user efficiency and social behavior of consumers are decreasing the demand for oil.

The main factors that increase the demand for oil are population- and economic growth and increasing living standards

The demand increasing developments as where described in the previous section are mainly due to population growth, economic growth and increasing living standards. These developments are primarily the result of the developing countries that will go through a significant growth in the years to come.

Oil supply must adjust to the demand

The supply of oil is in general in balance with the demand. Oil producers are always willing to sell more oil since selling additional oil increases their cash flow. When the supply of oil is not matched with the demand from the market, then the oil price will increase or decrease. Therefore, it's important for oil producers to match the supply of oil with the demand to prevent price spikes. OPEC is the only party that has an impact on the supply of oil. Although this impact is not significant it has influenced the price of oil many times. There is no such party as OPEC that influences the demand side, therefore, the supply side must adjusted to the demand side to restrain the oil price.

The challenge in reducing the emission of GHG is at the demand side

Oil companies will keep producing oil while there remains a demand for oil from the market and when it is economically viable to produce the oil. Therefore, a change in the emissions of GHG from oil should come from the demand side of the system. Consumers should be incentivized to adopt new technologies that reduce their footprint on the environment. Thus the challenge lays at the demand side.

Production profile of oil reserves

The production profile of oil reserves as well as the volume as the producible fraction of the reserve are dependent on the state of technology. New geotechnical measurement systems can better estimate the volume of the reserve and hence the production profile of the reserve. In addition, the production technology with which the oil is recovered from the soil can be enhanced which increases the quantity of oil. This has led in some cases old that oil reserves that were thought to be fully exploited can be ramped up again and additional oil can be produced from the reserve due to the new technologies.

The main uncertainties are at the system level

Oil companies have no impact on practices of other oil companies; neither do they have on governments of petroleum states. Hence they are not able to influence the system level other than an increase or decrease of their own production. The only aspects that they can control are within the company, thus at the reserve level. At the reserve level the production profile of the reserve is dependent on the geographical characteristics of the reserve, which can only be influenced to a minor, extend. Therefore, the only aspects where the oil company has the most control over are the cost of exploiting the reserves and to some extend to the timing.

The responsibility of reducing the carbon footprint lays at the consumers

The trade and usage of oil and the associated emission of CO2 is the result of market forces and the interaction between supply and demand in the oil market. Consumers demand a certain amount of oil to use their cars, fabricate certain products and produce energy etc. The suppliers of oil meet the demand of the market and fulfill a service-providing task of delivering oil and meeting the demand. The producers will provide oil for the consumers as long as there remains a demand for their oil. Only when the demand from the market shrinks or when there is no oil left to produce, then the producers will stop or reduce the production of oil (reference). Thus, the production of oil depends on the needs of the consumers, which makes the oil sector a demand driven sector (demand-side problem).

Oil companies cannot be held responsible for supplying oil that people need for transport and for their livelihood. Hence the supply of oil is hard to regulate other than paying CO_2 taxes or buying certificates. The real action to limit the emission of CO_2 should come from the demand side of the market. By means of increasing efficiency and switching to substitute green(er) products such as renewable energy and electronic vehicles. This will decrease the demand for oil and therewith decrease the oil that producers provide.

Appendix C - Explicit and implicit pricing

Explicit pricing

Explicit carbon pricing directly taxes the emission of GHGs by for instance oil companies. There are various forms of carbon pricing of which the most popular are a simple tax on carbon emissions and another for is cap-and-trade. A carbon tax is a pricing mechanism in which the government puts a direct tax on the emission of CO_2 from specific sources in various forms of the economy. A cap-and-trade mechanism is a cap that is placed over the total amount of emissions from an economy and companies active in the economy have to purchase certain allowances to emit GHGs. These allowances are tradable in and valued by the market. Europe already has such a cap and trade mechanism, the EU ETS, however this system does not work properly because the amount of allowances that are on the market are too high which resulted in the collapse of the prices for the allowance (Zakeri, Dehghanian, Fahimnia, & Sarkis, 2015). Due to the failure of the cap and trade mechanism and because of the straightforward and transparent way a carbon tax works almost all major oil companies (ExxonMobil, Conoco Philips, Chevron, BP, Total and Shell) opt for such a carbon tax, even tough it will increase the cost of the oil companies because they have to pay for the emissions associated with the extraction of oil. The price of oil is set in the market; therefore oil companies cannot simply raise the price of their oil products and shift the cost of the carbon tax to their consumers. Even though the majors will face higher cost when a carbon tax is implemented they are in favor of such a tax because they believe that they will be able to make up for the additional cost of the carbon tax by generating additional revenues from the increasing demand for natural gas and therewith take market share for energy generation at the expense of coal (Atkin, 2015). Moreover, the implementation of a carbon tax will also decrease the regulatory uncertainty in the oil sector.

Implicit pricing

Implicit pricing indirectly taxes the emission of GHGs by for instance setting standards or targets. These standards can be on the performance of certain companies or through targets set on the future energy mix. Implicit pricing is often seen as less effective because it is more complex and does not directly price the negative effects but works through other mechanisms and instruments (Zakeri et al., 2015). It is also argued that implicit pricing does not give the right incentives on company level due to their indirect effect (Jenkins, 2014). Both public and private companies therefore advise governments to implement explicit pricing because their intensions are straightforward and they do not unnecessarily complicate the system.

Barriers for adopting carbon pricing policies

There are a few barriers that have to be overcome before carbon pricing can be implemented. A major barrier is that there remains political disagreement regarding the best form of carbon pricing. Besides the political disagreement, a carbon-pricing mechanism is most effective when it's implemented on global scale (Baranzini et al., 2015; Jenkins, 2014; Shell, 2016). This requires collective action by governments and the alignment of their preferences, which remain a large barrier. When there is no collective action, countries that first adopt a carbon pricing mechanism will suffer from the first mover disadvantage and a reduction of the competitiveness of the companies that will be subject to the carbon pricing mechanisms.

Another different problem of climate regulation on international basis is the dependency on the environmental preferences of the current political elite. Hence, when the political elite changes, like it did in the United States, the perception and dedication to the Paris Agreements may change as well, for better or for worse. Thus, climate regulation is dependent on the geopolitical state and the interest of the political elite to comply with the Paris Agreements.

Appendix D - Factors that influence the value of oil reserves

Climate regulation

What does it entail

- Active regulations by governments to limit the emission of CO_2 and to stay within the carbon budget.

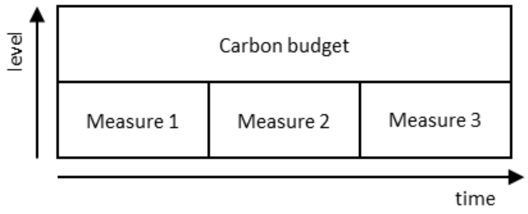
What are the drivers

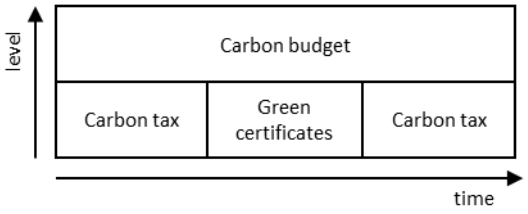
- Climate change
- Increase environmental awareness

What is the effect

The dedication of governments and companies to the Paris Agreements 'assure' that the severe forms of climate change are prevented and global warming is limited to 2°C. Which indicates that measures such as a carbon tax and CO_2 certificates should be put in place that decrease the global size of the oil demand. Hence the total amount of oil that can be produced is limited which means that only certain oil field can be exploited. The remaining oil fields are left stranded and should be written off by the companies that own the reserves. Hence the dedication to the Paris Agreements and the carbon budget result in the establishment of a time constraint to the preservation of oil reserves, when considering a hard constraint carbon budget.

When dedicated to the carbon budget it becomes evident that many existing reserves and resources cannot be produced within the budget. When all measures are aimed to stay within the carbon budget, then the carbon budget is the highest-level goal that is pursued and the measures are implemented to reach that goal. In a short-term perspective, the measures and their effects are leading, however, measures can be for short periods due to changing administrations at governments or the implementation of new policies. But when the perspective is stretched to a long-term perspective, then the carbon budget is leading (see figure).

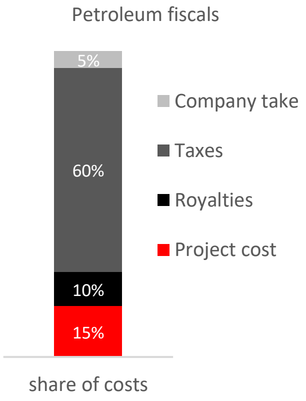




When the long-term perspective is adopted, then the carbon budget is taken as a 'measure' to decarbonize the economy. The implementation of a hard-constrained carbon budget leads to a cap on the total amount of carbon that can be emitted. The current trend must be broken (see figure 'the big picture') and an obligated reduction of carbon emissions must be realized to stay within the carbon budget. This means that oil (and gas and coal) demand must decline and oil reserves and resources must remain untouched. These reserves and resources that will not be exploited should in the end be written of the companies' balance and are stranded.

A carbon tax

Increases the costs for oil companies by adding extra cost to the price for a barrel of oil. This tax is an extra cost for the producing (oil) companies and makes projects less profitable. A CO_2 tax will be imposed on the production of oil at the supply side. This may have two effects; first, the tax should be paid by the producers and the oil price stays the same. This generates a cash flow to governments with which the negative external effects of oil can be compensated. Second the tax should be paid by producers which increases the cost of production of oil which may increase the oil price because supply that is not profitable at the cost including CO_2 tax will be pulled out of the market which generates an imbalance between supply and demand which result in an increasing oil price. The cash flow that is generated will flow to governments, which in turn should compensate the negative external effects of the usage of oil. This is an over-simplification of the fiscal system in which oil companies



operate. However, the problem is that oil companies are subject to already high levels of tax (M. Lechner, interview).

How to model the effect in a valuation model?

The problem with the Paris Agreements and the carbon budget is that it is a global problem and all emissions everywhere in the world add to the problem and reduce the amount of oil that can still be produced. Therefore, the remaining budget is a function of the global budget minus all cumulative emissions. This means that when more GHG are emitted, less oil can still be produced. Thus, the remaining budget is a function of the emissions which decreases over time. Reserves that are currently producing are the reserves that will be the least affected by the Paris Agreements and the carbon budget.

Obstacles

The problem with the Paris Agreements and the carbon budget is that none of it is certain and government intension should be taken for granted. However, regimes might change and makes the agreements may get less valuable than when they were signed.

Substitute products

The increasing usage of substitutes will reduce the demand for oil by decreasing the size of the oil market. This increased use of substitutes is among other factors driven by an increase in environmental awareness and technological development. Environmental awareness results into quicker adoption of renewable technologies. The renewable technologies displace oil for other sources of energy such as batteries charged by renewables, hydrogen fuels etc. The adoption of substitute products are driven by environmental awareness, climate regulation, economic factors such as lower costs for solar or EVs.

What does it entail

- Increased adoption of Electric Vehicles
- Increased use of renewable energy

What are the drivers

- Climate change
- Environmental awareness
- Technological developments
- Money, substitutes will increase when economically more attractive than the fossil fuel alternative

What is the effect

Increasing use of substitute products result in the demand (growth) for oil.

What is the impact

When substitute products are widely adopted, the demand for oil will increase less fast. If the adoption keeps increasing it might come at the point where the demand for oil starts to decrease to this point is called "peak demand".

How can the effect be modeled in a valuation model

The effect can be modelled through the decline in oil demand. Hence an increase in substitute products decreases the demand for oil. This decline in the demand for oil has a short-term effect on the oil price. When the demand decreases and the supply remains the same it causes the oil price to fall as the result of an oversupply in the market. The collapse of the oil price of 2014 until recent is the result of a declining demand and sustained supply by the producers. The long-term effect of declining demand growth may result in the peak demand scenario from which the demand will decrease. When the decrease in demand sustains then their will be less oil needed in the future to meet the demand of the global population, which result in reserves that are not needed anymore to meet the demand, which may result in stranded oil reserves.

Obstacles

The costs for substitute products are often higher than the alternative.
Lack of infrastructure.

Distribution of oil in markets

(energy, transport, industry)

Largest use of oil in transport sector → electric transportation has the potential to offset largest part of oil demand.

Electric Vehicles (EVs)

How will the market of EVs develop and reduce the oil demand?

S-curve → adoption of technique

Randall (2016)predicts that the increase in EVs can offset the oil demand by as much as 2 million barrels in 2023. This is more than the oversupply in the market that caused the collapse of the oil price in 2014.

End-user efficiency

End user efficiency is one of the main technical drivers of sustainable development. End use efficiency has weakened the link between economic growth and energy use (Jochem et al., 2000) and leads to decoupling of GDP and energy growth. The learning effect of companies and economies of scale are important sources of an increase in end use efficiency. An increase in end-user efficiency is among the most important factors to reduce the oil demand

What does it entail

- More efficient gasoline engines in cars, truck, airplanes and ships
- More efficient petrochemical industry

What are the drivers

Over the last decade, increasing environmental awareness and technological developments have caused the end-user efficiency to increase. People have gotten more aware of what they do and how the way they act affects the environment. This environmental awareness together with technological developments have a reducing effect on the demand for oil.

What is the effect

Increasing end-user efficiency decreases the demand for oil by increasing the efficiency of all sorts of products, machines and industrial processes. The demand for oil is offset by the efficiency gains. The reduction in value of oil reserves is due to the demand declining aspect of end-user efficiency. An increase in efficiency represents a decline in oil demand and works as a pressuring effect on oil prices under the assumption that other market conditions stay the same (ceteris paribus).

How can the effect be modeled in a valuation model?

Linear modelling through an efficiency rate for the demand for oil. Should be implemented in oil price calculations.

Obstacles

Often requires additional investments or new purchases. When reflecting on efficiency of cars, the system requires someone with an old car to buy a new car that is more efficient. However, it usually takes around 10 years before someone buys a new car, hence some life cycles of certain products are long which decreases the effect of end-user efficiency.

Social behavior

Resource sharing / transport sharing / uberization

1. Resource sharing
2. Environmental awareness

According to McKenzie (2015), in 2013, 76,4 percent of the people in the United States drove alone to and back from their work location. There are new movements which incentivize smarter and more social interaction between consumers which may result in a better and more efficient usage of oil. The rapid digitalization creates platforms where people offer a free seat in their vehicles which other people may fill up. This creates the same effect as carpooling but in an advanced way because people that need to go the same direction meet on the platform. These platforms bring together supply and demand in the transportation sector and might shake up the status quo. The development is often called the Uberization since Uber did the same thing in the taxi business. According to Eric Puik (ref) of Shell, social behavior may have severe consequences on the oil demand when these platforms are further developed and widely adopted by the public. The technological developments make it easier to couple the demand and supply in the transportation sector due to modern applications and technologies and an increased environmental awareness or the lack of own transportation means creates the possibility for people to share rides and transport means.

The same movement is visible in the energy sector, where communities are able to collectively purchase wind turbines, solar PV and other forms of sustainable energy that fit in the neighborhood an reduces the electricity demand.

What does it entail

- Sharing of resources such as cars by means of ridesharing and carpooling apps, but also sharing solar panels, and wind turbines with neighbors. But also sharing heat and other forms of energy
- Less use of oil due to social interaction between consumers made possible by modernized forms of carpooling driven by technological developments.
- Leads to increased efficiency in the transportation sector.
- Leads to increased
- Reduces the demand for oil
- Increases environmental awareness reduces the demand for oil via the increased social behavior, but also via substitute products, increased environmental awareness, and end-user efficiency

What are the drivers

- Digitalization and technological developments create the possibilities to bring together supply and demand in the transportation sector.
- Environmental awareness will justify and incentivize these movements

What is the effect

At current levels 76,4 percent of the people drive alone in their car. When people start adopting the platforms created by the social behavior movements the transport sector will become much more efficient. This will lead to a reduction in the demand for oil. Which in turn might result in an oversupply on the oil market and result in lower oil prices.

How can the effect be modeled in a valuation model

The effect on the value of oil reserves can be modelled through a declining oil demand that is incurred by the increase of social behavior. In a short-term perspective, the value of oil reserves may decline due to lower prices as a result of an oversupply due to declining demand. While in a long-term perspective, social behavior adds to decreasing oil demand and an earlier end of the oil age

Obstacles

The main obstacles for social behavior is the social aspect. Most people do not want to share their ride and like the comfort of riding alone, since they do not want to be dependent on others.

Environmental awareness

Environmental awareness is a powerful factor since it drives a quicker adoption of new technologies, environmental regulation, social behavior and end-user efficiencies. However, increasing environmental awareness is hard to reach and hard to monitor since it cannot easily be quantified. Environmental awareness itself is driven by climate change and environmental degradation. Environmental awareness is a social aspect and result in decreasing oil demand

What are the drivers

Climate change and increasing knowledge about the world as a whole, due to digitalization and accessibility of information.

What is the effect

The increased awareness for sustainability leads to a growth in the adoption of demand reducing technologies such as renewable energy, end-user efficiency, electric vehicles, resource sharing, and social behavior. An adoption of these technologies will decrease the demand for oil, resulting in a declining market for oil.

What is the impact

The impact can be very large since it reduces all forms of demand reducing technologies.

How can the effect be modeled in a valuation model

Environmental awareness is hard to quantify, hence it can best be modeled through the adoption of demand reducing technologies. When more people get environmentally aware, the adoption rate of products that represent an environmentally enhanced future is bound to increase.

Obstacles

People like their living standards and their comfort.

Resource base

All the reserves and resources add to the global resource base. When new reserves are discovered or potential resources are to be explored, they enlarge the size of the resource base. Oil companies invest in exploration projects assuming that when they find oil there might be a profitable project as the result of the exploration. Hence oil companies keep looking for oil to enlarge their own resource base to secure future projects and future cash flows.

What does it entail

1. Growing resources base
2. Increased investments in exploration projects

What are the drivers

The drivers for increasing the resource base are investments in future projects and the security of future cash flows. As well as security of supply of oil.

What is the effect

The decarbonization in the carbon-constrained world may result in a declining demand for oil. This decline in the demand has the potential to make reserves and resources that are in the resources base abundant. Hence capital is invested in the exploration or maybe even development of these reserves and resources and due to the declining demand they become unnecessary to fulfill the oil demand of the public. When these reserves or resources are not necessary anymore they are devaluated and the capital that is invested is destroyed. Or in other words the reserves become stranded. The larger the size of the resource base, the more resources will become stranded when the demand for oil declines. Hence additional exploration projects that add to the resource base may result in the destruction of the capital that is invested in the exploration of the projects.

How can the effect be modeled in a valuation model?

Only when resources have become reserves, which means that they are economically viable, then they have a positive reserve value. Resources that are temporary reserves, due to positive market developments, have a chance of getting developed, depending on the forecasts of the market.

Overview and summary of factors

	Environmental regulation			Substitutes	
	Carbon budget	Carbon tax / cap-and-trade	Subsidies	Electric transportation	Renewables energy production
Implies	• Taxes on supply side • Incentives on demand side	• Tax on supply side	• Incentive on demand side	• Reduce the amount of oil that is used by replacing oil for electricity	• Reduction in the growth of the energy demand and the oil demand
Drivers	• Climate change • Paris Agreements • Environmental awareness	• Climate change • Paris Agreements	• Climate change • Paris Agreements	• Climate change • Technological developments • Social behavior	• Climate change • Technological developments • Social behavior
Effect(s)	May result in stranded assets when effectively implemented (through taxes and subsidies).	1. Increases the cost for oil producers and therewith decrease the value of reserves. 2. Increase the relative value of clean reserves and decrease the value of dirty reserves	1. Incentivizes the adoption of demand decreasing technologies 2. Reduces the demand for oil	Decreases the growth in the demand for oil and may result in a shrinking oil market	Decreases the growth in the demand for oil and may result in a shrinking oil market
Long-term effect on the value?	1. Discourages the supply of oil using taxes and other measures 2. Increases demand reducing products using subsidies	Increases the cost associated with the production of oil. Thus, decreases the value of the reserves	Increases the demand for substitutes which may in the long term offset the demand for oil	• Decreases the long-term demand for oil. • Has a short-term negative effect on the oil price. • Decreases the value of the reserve	1 Decreases the long-term demand for oil. 2 Has a short term negative effect on the oil price. 1. Decreases the value of the reserve
Impact, low 1-2-3-4-5 high	3,5			3,66	
Potential high medium low	High	Medium	High	High	Low
Can oil companies influence the effect?	• Lobbying at governments • Sell reserves that are potentially stranded • Invest in cost reducing technologies	Yes, lobby at governments and government officials	No	No	No

	End-user efficiency		Social behavior		Resource base
Contains	Fuel efficiency	Industrial efficiency	Resource sharing	Environmental awareness	
Implies	Increase in fuel efficiency due to new technologies	Increase in the efficiency of petrochemical processes to reduce the amount of oil that these processes need.	Sharing of resources such as cars, wind turbines, solar PV under consumers	More emphasis on decarbonization and less use of oil	The size of the global resource base. The amount of potentially stranded reserves grows with the size of the resource base
Drivers	• Climate change • Technological developments	• Climate change • Efficient use of resources • Better more economic production	• Digitalization, • Technological developments Environmental awareness	• Climate change • Pressure groups • Shareholders •	• Security of supply • Security of future cash flows
Effect	The increasing fuel efficiency will decrease the demand for oil.	Higher efficiency in the petrochemical industry decreases the demand for oil	Decreases the demand for oil by sharing resources such as cars and renewable energy technologies	Decreases the long-term oil demand through stimulating: • Climate regulation • Substitutes • End-user efficiency • Social behavior	An increase in the size of the resource base implies that there are more reserves available. Which means that in a carbon constrained world more reserves are potentially stranded
Long-term effect on the value?	Decreases the long-term demand for oil. Increases the speed with which reserves get stranded.	Decreases the long-term demand for oil. Increases the speed with which reserves get stranded.	Decreases the long-term demand for oil.	Decreasing long-term demand for oil	When the resource base of reserves keeps growing, more reserves will be stranded when the demand for oil reduces
Impact low 1-2-3-4-5 high	3,33		3		3,33
Potential high medium low	High	Medium	Medium	High	Low
Can oil companies influence the effect?	Investments in development programs at car companies may increase the speed of increasing efficiency	Yes, many oil companies also refine and process oils into products. They can implement better technologies	No	No	Oil companies can increase the size of the resource base through exploration projects

Appendix E - Consequences of the developments

Consequences of increased environmental regulation

Regulation has the ability to limit the amount of GHG that is emitted by oil producers, through setting the right incentives in the form of regulation. Negative effects of oil production, such as the emission of GHG, should be taxed while at the other hand regulation should stimulate the adoption of low carbon and renewable technologies. Hence environmental regulation can and should have multiple forms as explained in chapter 4.1. The two main forms of regulation are a tax at the supply side, or a subsidy on the demand side. The tax on the supply side incentivizes oil companies to use and exploit the cleanest oil reserves because for the dirtier the reserve, the more tax has to be paid. The subsidy on the demand side stimulates the adoption and usage of low or no carbon technologies such as renewable energy and electric vehicles. Both forms of regulation have a different effect on the value of oil reserves.

The effect of a tax on the value of a reserve

A carbon tax is often seen as the most effective method of a supply side tax (paragraph 4.1) and is the easiest to apply on global scale. Such as carbon tax will increase the cost of the production of oil reserves based on the emissions associated with the production of the oil. The higher the emissions from the production of oil the larger the tax that has to be paid. Hence dirty oil reserves will get more expensive compared to cleaner types of reserves. This may have as a result that some oil projects will not be profitable anymore when the tax is incorporated forcing oil companies to stop producing from the dirty type of oil reserves or when possible to switch to cleaner oil reserves. Oil companies cannot easily shift the cost of the carbon tax to the consumers, because the market determines the price of oil.

System level implication

A supply side tax on the emission of GHG (CO_2) will increase the cost of a reserve (figure XL) and therewith decrease the value of the reserve. Another effect is that some reserves (especially the dirty ones) must stop producing oil because the costs are getting too high due to the additional tax. This will have a negative effect on the global oil supply. When this reduction in supply occurs, the oil price will increase and therewith the value of oil reserves that are still operating.

Reserve level implication

The supply side tax may have a significant effect on the value of oil reserves. Reserves that belong to the dirty type of the emission spectrum may not be economically viable to exploit and face severe devaluation and get stranded when the tax endures, while cleaner reserves will increase in value due to the higher demand for cleaner reserves and the better competitive position compared with dirty reserves. Oil companies cannot simply shift the additional cost of the carbon tax to the end-consumers because the oil price is established in the market and therefore cannot influence the price for which they sell the oil (assuming that the oil market works efficient and is transparent when considering carbon tax).

Summary of consequences

A supply side tax reduces the value of oil reserves through increasing cost. This effect will be much larger for dirty reserves than for cleaner reserves and may result in dirty reserves getting stranded. This forces oil companies to divest from dirty reserves and increase their focus on cleaner reserves, cleaner production techniques or other type of non-oil investments. A demand side subsidy increases the adoption of low carbon technologies, which will result in a lower oil demand. The long-term effect of a lowering oil demand may cause assets to strand, which will be explained in the next section.

Consequences of a decreasing oil demand

In a carbon-constrained world, the demand for oil will decrease to be able to meet the goals of the Paris Agreements and limit the amount of GHG emissions. The demand for oil is dependent on multiple factors (see figure XL). There are demand increasing factors; a growing world economy, growth in world population and increasing living standards, and demand decreasing factors; substitute products, increasing end-user efficiency and social behavior.

The effect of demand increasing factors on the value of oil reserves

The world economy, living standards and world population all follow a growing trend. This means that they will increase the demand for oil throughout the years. Growing oil demand result into a higher oil price and a higher oil price increases the value of oil reserves (ceteris paribus). Hence demand increasing factors have a positive effect on the value of oil reserves.

World economy
The world economy will continue to grow which will increase the demand for oil and therewith the price of oil. This will lead to reserves getting higher values.

Living standards
Increased living standards make it possible for more people to use oil by for instance driving a car. The more the living standards increase the more the demand for oil will increase, resulting in higher oil prices.

World population
More people on earth mean a higher global demand for energy. This requires more oil to provide in the needs of the people, hence more people also means a higher oil price caused by the growing demand for oil.

The effect of demand decreasing factors on the value of oil reserves
The demand decreasing factors have a negative influence on the value of oil reserves. This effect is observable in short-term through a declining price of oil because of a slowing demand (growth). And in the long term when all demand decreasing factors together are stronger than the demand increasing factors, then the entire demand starts to decline, which will make the market shrink. This will cause oil reserves with a long lifetime to get stranded due to a lack of oil demand in the future and the abundance of oil.

Substitutes
Substitute products will reduce the demand for oil due to the replacement of oil using technologies such as gasoline cars by sustainable energy technologies such as electric vehicles. This will make the price for oil decline due to the decreasing demand for oil.

End-user efficiency
End-user efficiency reduces the demand for oil by increasing the energy output of the same amount of oil. Cars that are more energy efficient use less oil, which result in a lower demand for oil. The lower demand will, on the short term, decline the price for oil and on the long-term result in a shrinking oil market and lead to stranded reserves.

Social behavior
Social behavior through resource sharing will reduce the demand for oil while social behavior through increased environmental awareness increases the behavior of people through the better and more responsible use of oil. Both result in a decreasing use of oil with the associated decreasing oil price.

Summary of consequences
The value of reserves will decrease in the long term because the demand for oil will starts to decline. A decline in the demand forces the supply to decline as well; otherwise there will be a strong price decrease. A declining oil supply results in reserves getting obsolete, especially reserves that have; long lifetimes (large in size) or are not yet producing. Hence the duration till the end of production of the reserve is important. Reserves with long durations till the end of production have a higher chance of facing devaluations or getting stranded due to the decreasing demand for oil.

Consequences of volatile and low prices
There will be a high chance for volatile and especially low oil prices in a carbon-constrained world, as the result of increased competition and oversupply to sell as much reserves as possible. The oil price has a direct effect on the value of oil reserves. When the price increases, then the value of the reserve increases. The same holds for a decreasing oil price. A low oil price may make some reserves not economically viable to produce when the oil price gets below the break-even price of the reserves this forces these reserves to stop producing. When the low oil price endures, the reserves may face severe devaluations or even get stranded. As is stated in paragraph 4.1 the chance on volatile and low oil prices is significant in a carbon-constrained world due to the increased competition and oversupply to sell as much reserves as possible before the demand for oil has stopped. Factors that influence the value of reserves during increased competition and oversupply are OPEC and the size of the resource base.

OPEC
OPEC is to some extend able to influence the market price for oil, as they did last December. OPEC influences the price through negotiating production quotas among OPEC members. These production quotas reduce the oil output of the OPEC members and therewith reduce the total oil supply, which has a price increasing effect when the demand remains equal. Hence OPEC has some (limited) influence on the oil price, which may increase the value of oil reserves. If OPEC starts to cooperate effectively, they are capable of stabilizing the oil price and avoid very low prices. However, the members of OPEC all have the incentive to produce as much oil as possible because this maximizes the revenue

of oil profits. Therefore cooperation within OPEC is limited and therewith the effect that they have on the oil price as well.

Size of resource base

The size of the resource base has the potential to destabilize the oil price. When the resource base grows in size, more reserves will be stranded due to the fact that there are too many reserves that can be exploited, while the demand for oil is set to decrease. Hence the more resources that are, through exploration projects, added to the resource base, the larger the potential supply of oil will be and therewith amount of stranded reserves.

Summary of consequences

The oil price has the ability to force reserves to stop producing when the oil price gets below the break-even price of the reserve. When low oil prices endure this may result in severe devaluations hence a reduction of the value of the reserve. OPEC has the ability to increase the value of oil reserves by cooperating, however incentives to cooperate are not present. When the size of the resource base increases it may add to the problem of stranded reserves/resources. Hence resources added to the resource base may decrease the value of oil reserves by increasing the potential oil supply.

Appendix F - Actor specific recommendations

Recommendations for owners of oil reserves

The scenario-based impact analysis has showed that many type of reserves have a chance of getting stranded in a carbon-constrained world. Oil companies that have reserves with a high stranding potential in their portfolio are recommended to quickly address the problem associated with these reserves. Although it may take years for reserves to get stranded, the lifetime of some oil reserves may cover decades. To reduce the exposure to stranding risk the following recommendations are made:

- Due to the increasing chance that environmental regulation will get stricter and new forms of regulation will be implied, companies should divest from dirty oil reserves such as tar sands (oil sands), extra heavy oil, heavy oil and arctic oil. These reserves are already the least competitive compared to other reserves due to their high costs and long lifetimes and will, when additional environmental regulation is implied, get even less competitive. Before the regulation is implied companies should divest from these types of oil reserves, otherwise they will be not able to sell to other companies.
- The research has indicated that the oil market will see increasing forms of competition in the market from the point that the market starts to decline. Oil companies should focus on positioning themselves in the market to be able to compete on price when the competition starts. To be able to strengthen this competitive position, oil companies should divest from expensive oil reserves as well as oil reserves with long lifetimes. The only types of reserves with long lifetimes that can be maintained are the reserves that have low breakeven cost.
- Due to the uncertainty and increased volatility in the market, oil companies should focus on reserves that have lower upfront capital costs and shorter lifetimes. This will prevent oil companies from getting entrapped in their previous policies and keeps the companies dynamic.
- New oil exploration should only be carried out when the reserve that might be found is able to compete in a low price environment with increased forms of regulation such as carbon pricing mechanisms. Hence exploration projects that are aimed at discovering forms of oil such as artic oil, extra heavy oil and ultra-deep oil are advised to abandon since they are not competitive in a carbon constrained world unless new technologies emerge.

Recommendations for investors in oil projects

The recommendations for investors depend on the amount of risk that an investment company is willing to take. Therefore two different recommendations are made, one focusing on investors that want to reduce the risk of their investment portfolio and the other focused on investors that are aimed at increasing the return of their portfolio by engaging in projects with higher levels of risk to generate higher returns.

- Investors should divest from all sorts of dirty oil reserves because there is a significant chance that to meet the goals from the Paris Agreement environmental regulation will be implied. This will increase the chance that environmental regulation will be implemented that will tax the emissions of GHG resulting in a chance that dirty reserves get stranded. Divesting from dirty reserves will both improve the image of the company and at the same time reduced the exposure to the risk that the reserves get stranded.
- When the market starts to decline, then the competition in the market will increase, resulting in oversupply and lower oil prices. Oil projects and companies that are not competitive will not be able to compete and therefore may end stranded. Hence investors should invest only in reserves that do not have a significant chance to get stranded because this may have a large impact on the value of a reserve and therewith in the return of the investment.
- Investors should prevent from committing to long-term investments in reserves with elevated stranded risk. Therefore investors should focus on smart contracting, which enables the investor to easily stop their investment and get their invested money back.