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TITTEL:

ENGELSK TITTEL: INVESTMENT REQUIREMENT FOR EXTRACTION OF THE REMAINING OIL & GAS RESOURCES IN THE NORWEGIAN CONTINENTAL SHELF

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Abstract

The oil and gas industry is a major contributor to Norway's economy and the country as a whole. In the last 50 years, 6.6 billion standard cubic metres of oil equivalents have been extracted from the Norwegian continental shelf (NCS). There are an estimated 7.7 billion standard cubic metres of oil equivalents left in the ground. This includes both oil and gas. To be able to extract the remaining resources, there is a significant need for further investments. This thesis will try to answer the following question: What is the estimated future requirement for investment in the NCS in order to extract the remaining oil and gas resources? The Norwegian Petroleum Directorate (NPD) has a database that contains information of all the resources. The resources are divided into four: undiscovered resources, discovered resources, resources in production and sold resources. This information has been used to find the remaining resources for each class in barrels per oil equivalent. Rystad Energy has a database containing costs per field at fields in the NCS. Using this database they have estimated the future unit costs to be 8 for exploration, 14 for development and 9 for production. All costs are in USD per barrel of oil equivalents. The conclusion of this paper estimate future requirement for investment in the NCS to extract the remaining oil and gas resources to be USD 1058.6 billion. The need for investment to explore, develop and produce the undiscovered resources is USD 569.4 billion. Discovered resources have a need for investment of USD 368.8 billion to be developed and produced. Resources in production have a need for investment of USD 120.4 billion to be produced. NCS is divided in three regions, The North Sea, the Norwegian Sea and the Barents Sea. The estimated need for investment for each region is USD 475.3 billion for the North Sea, USD 261.2 billion for the Norwegian Sea and USD 321.8 billion for the Barents Sea. In the work of this thesis there have been used different unit cost scenarios to show how this affects the overall need for investment in the NCS and for each region. Results regarding an overall unit cost increase, investment needed at different sizes of undiscovered resources and resource life are also presented in this paper.

The results are uncertain for many reasons. The undiscovered resources are only estimated values based on geological methods and the exact size of the remaining resources can only be taken for granted when the resources eventually are produced and sold. The unit cost per barrel of oil equivalents is an estimation of future costs which is by nature uncertain.

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Foreword and acknowledgements

My motivation for this master thesis was the past, current and likely future importance of the oil and gas industry. I have derived considerable benefit and ideas from my supervisor, lecturers, students, friends, family and colleagues who were willing to discuss and provide me with information to fulfil my research project. I would particularly like to thank:

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I offer my gratitude to you all.

1 Introduction

The oil and gas industry is a major contributor to Norway's economy. The income from sale of these natural resources has been substantial. According to the Norwegian Petroleum Directorate (NPD 2016 b), the industry has produced 6.6 billion standard cubic metres of oil equivalents since the first production licenses were granted in the mid-1960s. There have been large investments in exploring, development including necessary infrastructure and producing to retrieve these resources. There are estimated to be 7.6 billion standard cubic metres of oil equivalents left in the Norwegian Continental Shelf (NCS) (NPD 2016 b). To be able to produce these resources there is a significant need for further investments.

This thesis will try to answer the following question:

What is the estimated future requirement for investment in the Norwegian Continental Shelf in order to extract the remaining oil and gas resources?

This issue is important for many reasons. The world needs more energy due to increase in the population and the income per capita (Proposition to the Storting, prop. 114 S (2014-2015). Natural gas is important for Europe, and Norway is a major gas exporter. Due to the importance of oil and gas to the Norwegian economy, it is very important to ensure further and continuous activities in the NCS. Even small development projects offshore in the NCS would be seen as large onshore industry projects. The industry employs directly and indirectly 240 000 people (Proposition to the Storting, prop. 114 S (2014-2015). This ensures employment, development of business, technology and the society all over the country. There are employees from the petroleum sector in 424 of 428 municipalities in Norway even though most employers live at the western part of Norway (Ekeland 2015). In the construction phase of the Johan Sverdrup-field it is estimated that 51 000 man-labour year will be generated in Norwegian companies in the period 2014-2026 (Proposition to the Storting, prop. 114 S (2014-2015). When phase one of the fields is in operation, it is estimated that this will generate 2 700 man-labour per year in Norwegian companies. The export from the oil and gas service industry is substantial. The cost has increased a lot since the year 2000 (Proposition to the Storting, prop. 114 S (2014-2015). Thus the potential cost reduction and effectiveness is become very important and necessary. This also include reduce of unnecessary bureaucracy and standardising of technology. This will ensure a robust oil and gas industry in the future. This is also important for Norway that the investment is used optimal to be sure that all of the profitable fields of the NCS actually will be developed. This will then ensure long time and stable deliveries of oil and gas to the world and a good future for the service industry.

The investment environment in the NCS is constantly changing. This is due to several factors. Major changes in the oil and gas prices and expectations regarding their future behaviour are important. Success rates of explorations, size of the fields, developing cost, operating cost, and the availability of finance are other factors. The net result is that the longer-term outlook for investment in the NCS might be more unclear than usual at the moment.

The oil price and the oil production determine how much income that can be transferred to the Government Pension Fund Global. The Governments 4 percent fiscal rule is deciding how much oil money the Government can use in the yearly national budget (Haugen 2015). To ensure continuous revenue from the oil and gas industry in the futures, further investment is needed. This will then give important contribution to the Norwegian national budget.

The Norwegian Petroleum Directorate (NPD 2016 a) has stated: “The overall objective of Norway’s petroleum policy is to provide a framework for the profitable production of oil and gas in the long term. The value creation shall benefit the Norwegian society as a whole, activities must take place within a sound HSE framework, and environmental concerns and coexistence with other industries are to be taken into account throughout the industry.” To ensure that the society get optimal benefits from the oil and gas sector, it is important to know how much value it has under the ground and to ensure stable investment to be able to produce it.

There are four main issues that will be addressed in this thesis. Geological conditions are the frame of depletion of the petroleum resources. Petroleum resources are non-renewable resources which imply that when extracted and produced, it cannot be renewed. Petroleum resources have to be explored before it can be developed, produced and sold. Easy accessible resources are explored and produced first while more difficult accessible resources are explored and produced later. Depletion of petroleum resources in offshore areas such as the NCS is more difficult and costly than onshore areas.

The development and application of advanced technology is vital for the oil and gas industry at their task of exploring and developing oil and gas resources. New and increasingly better technology has made it possible for the industry to develop large oil and gas installations offshore. Technology can be seen as having a battle against the scarcity of petroleum resources. The “winner” of this battle will decide whether the costs of exploring, developing and producing the remaining resources will increase or not in the future.

The economic conditions are important for depletion of the remaining petroleum resources. The owner of the oil and gas resources faces an opportunity cost. This is the cost of using up the fixed stock at any point in time or being left with smaller remaining reserves. To maximize profit the opportunity cost of depletion has to be covered. Another feature concerns the value of the resource rent over time to decide how quickly to extract the resources. The price of the resources is another important economical factor for investment in oil and gas resources.

The forth aspect related to depletion of oil and gas resources are the political conditions. This relates to several issues such as the tax system, risk of expropriation, laws, regulations and environmental concerns. It is important for the country that owns the resources to establish a tax and political system that encourage investment. The environmental concern regarding pollution from non-renewable resources such as oil and gas is an important political issue. There are also discussions regarding whether to restrain from oil and gas exploration, development and production in certain areas, such as Lofoten and Vesterålen due to the effect oil and gas activities might have for the fish life in these areas. There are also concerns for oil spills. This will have an influence on future investment in the NCS.

Chapter two describe the background information for this paper. This includes status of the NCS, the situation for the Norwegian oil and gas industry and the importance of the industry for the nation. The importance the oil price has had on the activity in the oil and gas industry is outlined and NPD’s oil and gas classification system is explained.

Chapter three present the economic theory behind oil and gas resources and how this kind of resources differs from other resources. Theory behind exploring, developing and producing of petroleum resources in an optimal way is presented. The theory behind resource rent, resource life and forecasting methods is described. Findings of previous researches are presented in the end of this chapter.

Chapter four explain how the research has been performed. The main information of this thesis is collected from the NPD and Rystad Energy. Different costs scenarios that have been used in the work of this paper are explained.

Chapter five presents the results from the work of this thesis. The different cost scenarios are used to describe the total need for investment and different variations in the NCS and for each region. The results are analysed and discussed.

Chapter six outlines an overall conclusion of the work of this paper and further recommendation.

2 Background

2.1 The Norwegian Continental Shelf and petroleum resources

The NCS can be divided in three areas, the North Sea, the Norwegian Sea and the Barents Sea. The area of the shelf is six times the area of Norway mainland according to the Norwegian Petroleum Directorate (NPD 2016 a). Two third of the NCS have sedimentary rocks with a potential for petroleum discoveries. The NCS is gradually opened for oil and gas activities since oil companies got access to 78 blocks in the North Sea in 1965 (NPD 2016 a). This is the largest amount of awarded blocks in the NCS. Blocks in the Norwegian Sea and the Barents Sea was first time announced in 1980. Until 1989 there were several announcement and awards of blocks in the Norwegian Sea and the Barents Sea. The Barents Sea was then not accessed until 2013.

As presented in figure 1, NPD (2016 b) estimates the discovered and undiscovered petroleum resources in the NCS to be about 14.2 billion standard cubic metres of oil equivalents. Approximately 6.6 billion standard cubic metres of oil equivalents of the total resources are produced and sold. It is also estimated that 2.8 billion standard cubic metres of oil equivalents are still to be discovered. The rest of 4.8 billion standard cubic metres of oil equivalents is resources that have been discovered. The estimates have increased every year since NPD started with these analyses in 1973. There is by nature uncertainty regarding the amount of oil and gas that has not been discovered. NPD (2016 b) estimates the volume and the uncertainty intervals to be between 5.5 and 10.5 billion standard cubic metres of oil equivalents.

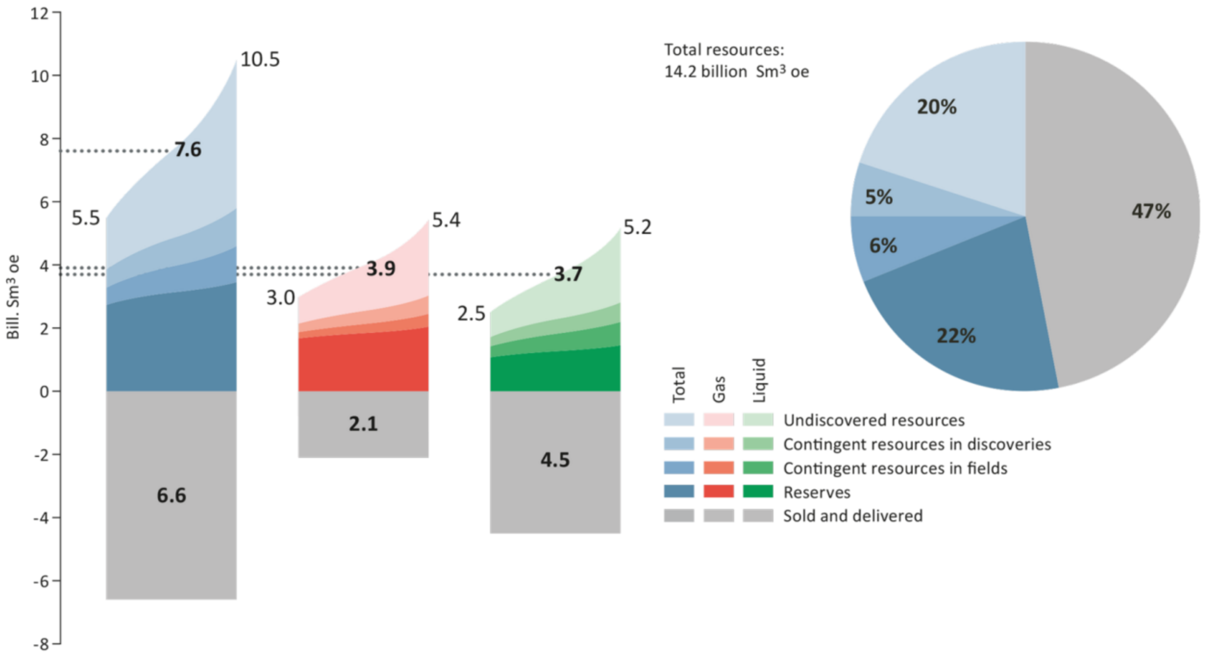

Figure 1 Petroleum resources in the NCS per 31.12.15 (NPD 2016 b)

Investment in the oil and gas industry can be divided in three main phases, exploration, development and production (Favero and Pesaran 1994). The estimation from NPD (2016 b) regarding different types of resources and phase stage is presented in table 1. The resource type oil, condensate and sum oil equivalents are measured in million standard cubic meters. Gas is measured in billion standard cubic meters and NGL is measured in million tonnes.

Project category	Oil	Condensate	NGL	Gas	Sum o.e.	Change sum o.e. y-o-y
Produced	4075	114	179	2100	6630	229
Reserves*	1023	28	116	1856	3128	167
Contingent resources in fields	328	2	22	222	594	11
Contingent resources in discoveries	375	13	15	323	739	-382
Possible future measures for improved recovery	155	0	0	60	215	-20
Undiscovered resources	1315	120	0	1485	2920	85
Total	7272	277	333	6047	14227	90

Table 1 Total recovery potential (NPD 2016 a)

2.2 The importance of the prices for petroleum resources

Historically, the investment has been much related to the oil price. This is because the oil companies do not invest if they do not get high enough prices related to the cost of their products. The size and then the value of the remaining stocks of oil and gas are thus dependent of the oil price.

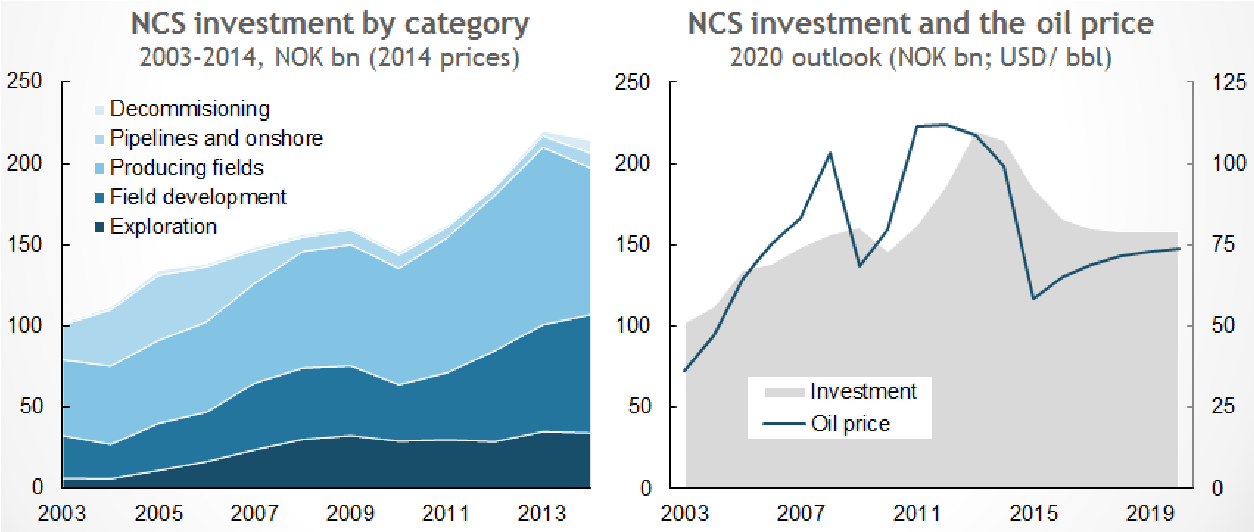

Figure 2 NCS investment outlook (Norges Bank 2015)

The price for Crude Brent Blend has decreased significantly since July 2014 where it was around USD 110 per barrel of oil equivalents to July 2015 where it was around USD 45 per barrel of oil equivalents (Nasdaq 2016). This has resulted in a significantly reduced investment at the oil & gas industry. The reduction in investment will then influence the future production of oil & gas.

From 2010 to 2013, the investments in the NCS increased with 72 % from NOK 104 billion to NOK 179 billion (NPD 2016 a). There are different reasons for this increase. The oil price was high and the Norwegian Governments policy to attract smaller oil companies made this possible. It might be legitimate to argue that this was a too big increase. If the investment had increased in a slower rate, the oil price shock in 2014 might have had reduced the consequences for the Norwegian oil industry.

The North Sea and the Norwegian Sea are largely matured fields and have reached the peak regarding production. The easiest and most valuable fields have already been developed and produced. However, the field of Johan Sverdrup is an example of exploration of a new and large oil-field in a mature area. This field was one of the largest fields in the world to be explored in 2010 and is among the five largest oil discoveries in Norway ever (NPD 2016 a). The reservoir is in addition to be large, of a very high quality (Det Norske Oljeselskap 2011).

There are likely to be many small pockets with petroleum products near existing fields and areas and the likelihood of discoveries in these areas are higher than in new areas (NPD 2016 a). It is important to be able to discover and develop these fields while the surrounding infrastructure still exists. This will ensure that these small fields will be economically valuable and larger existing fields will be able to produce longer before shut down. The new oil field Maria, is an example of the importance of exploration near to existing infrastructure according to the Norwegian Minister of Petroleum and Energy, Tord Lien (Ministry of Petroleum and Energy 2016 b). The field will be developed with two underwater installations that are connected to existing host platforms and infrastructure at Haltenbanken outside mid-Norway. The development concept implies that the well stream is sent to the Kristin platform for processing and that the oil then will be shipped from Kristin to the Åsgard field for storage and export by shuttle tankers. Gas for gas lift will come from the Åsgard B gas platform via existing gas pipeline to the Tyrihans field and water injection will come from the Heidrun platform. This is an example of cost efficient development with the use of available capacity and is thus important in a discussion regarding future need for investment.

2.3 The costs of petroleum resources

The scarcity of the oil and gas resources will be more and more important for the costs. After the plunge in the oil price, the oil and gas companies have reduced its cost level, not only due to less investment, but also in production and administration costs. Technologies that reduce the costs are also important as well. However, the overall trend is that the cost of exploring and developing new areas is likely to increase. The Barents Sea has been seen as the new frontier of future oil and gas production in Norway. New and immature areas are seen as having larger likelihood of large discoveries (NPD 2016 a). The estimated cost to explore, build and produce oil and gas in the Barents Sea is likely to be higher than in the two other regions due to issues such as the need for new infrastructure and the long distance to the marked.

The oil and gas industry plays a significant role in the Norwegian economy. In 2014 22 % of Norwegian GDP, 31 % of fixed capex, 29 % of government revenue and 49 % of the export was related to sale of oil and gas (Mohn 2015). This is far more than for example the British oil sector's part of investment even though the industry is similar in size. According to the Energy Information Administration (2014), Norway's oil production was at 15th place among the world's oil producing countries in 2014. When it comes to natural gas, Norway is seen as the 5th largest supplier globally. Thus Norway is one of the most important energy nations in

Europe. The NPD (2016 a) expects the overall oil production to remain stable, while natural gas is expected to increase weakly.

Wildcat drilling in the NCS is very connected to the oil price NPD (2016 a). This even though the estimated overall resources have increased all the time and there has been a continued technological development. This might show that it is important to have an economical view on the resources, and not only a geological and technological view.

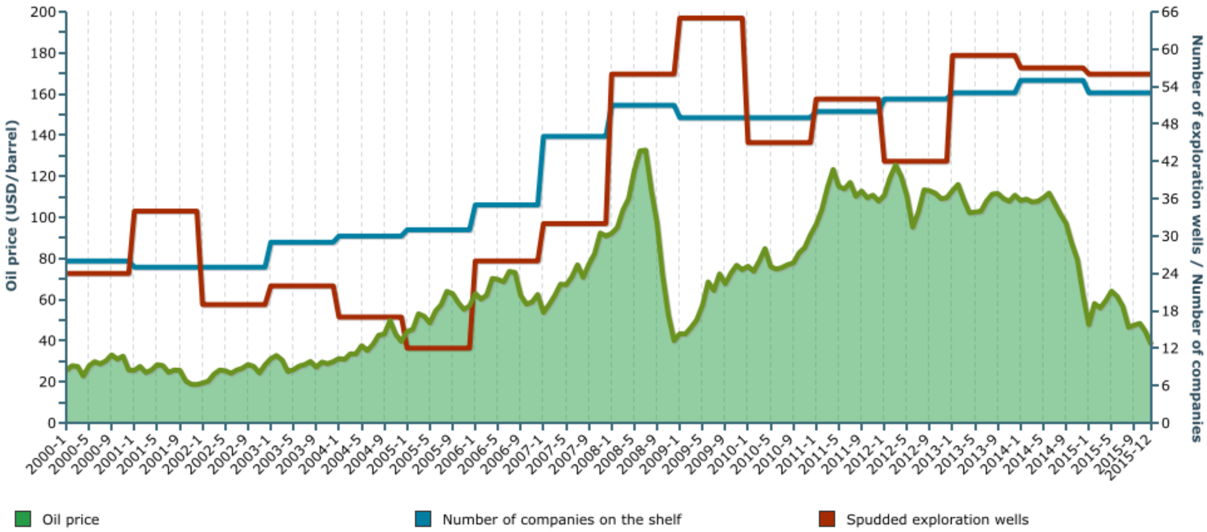

Figure 3 NCS expenditures (NPD 2016 a)

There has been an increase in exploration wells in the NCS, especially since 2000. Figure 3 outlines the relation between exploration activities (red line), number of companies in the NCS (blue line) and the oil price per barrel of oil equivalents (green line).

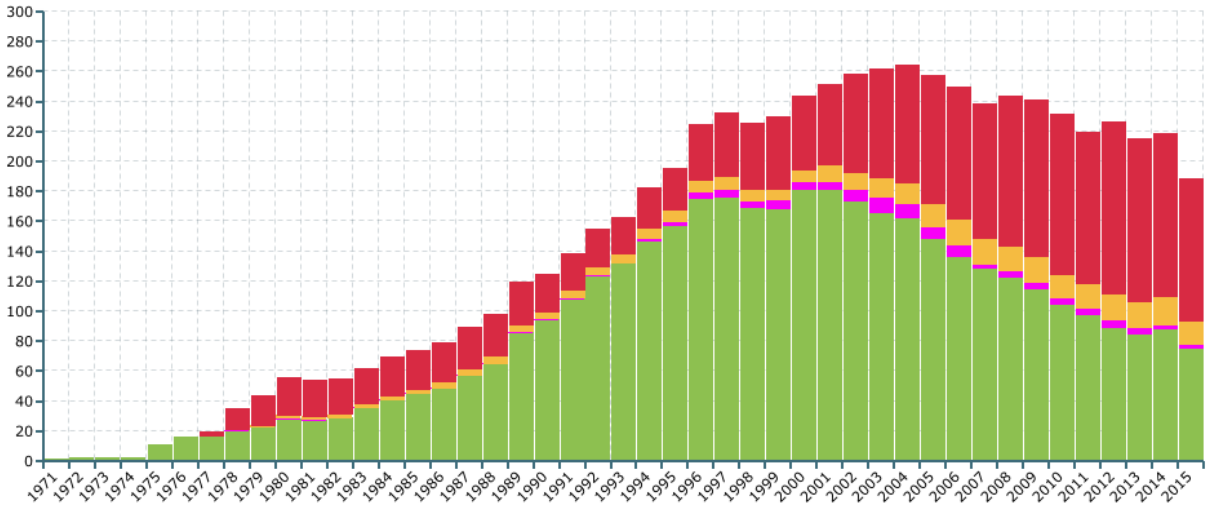

Figure 4 NCS production (NPD 2016 a)

Figure 4 present the yearly petroleum production in the NCS since the start in 1971. Oil is green, condensate is pink, NGL is yellow and gas is red. The numbers are in million standard cubic metres of oil equivalents. This describes how the oil production has reached its peak while gas is increasing.

The energy sector stimulates investment, production, employment and wages in nearly all non-oil industries (Bjørnland and Thorsrud 2013). The most stimulated sectors are construction, business services and real estate. Studies have also shown that foreign capacity comes in addition and not on the expense of the capacity in Norway (Boston Consulting Group 2012). It is estimated that oil and gas sectors part of Norway's GDP and total demand will be more than halved the next 20 years (Cappelen, Eika and Prestmo 2010). This decrease is expected to start at around year 2020 and continue until 2040 (Cappelen, Eika and Prestmo 2013). This will characterize the economic development in Norway in this period.

Norwegian economy is sensitive to the change in the oil price in different ways. The government income from the petroleum sector is determining for the use of the oil spending in the long term. However, in the short and medium long term, the demand from the sector is more important for the economic development (Cappelen, Eika and Prestmo 2014).

The western part of Norway is most affected by the oil industry. The effect of more activity and employment in case of more oil and gas research further north is very uncertain (Econ 2010). For example, if there are no resources in the ground, the effect of exploration is minor. Other factor is that the activities depends on how the oil and gas is handled, on land or offshore, and how the infrastructure overall will be handled by the oil and gas companies.

It can be argued that the petroleum sector has reduced the potential for economic growth in other sectors (Fjose 2012). This is due to higher salary and general higher cost level. Without the oil and gas revenue, Norway is likely to have had lower wage level and more unemployment. However, it is also likely that Norway would have had a more diversified industrial structure. In addition, the most significant effect might be that the Government income would have been much lower, and thus less possibility to spend money on public goods such as welfare and scattered settlement. The direct employment in the petroleum sector has increased from 48 419 people in 2003 to 83 779 in 2014 (Ekeland 2015). This has resulted in high increases in the wages and low unemployment rate.

2.4 Norwegian Petroleum Directorate's classification system

Oil and gas resources can be classified according to whether the resource is a prospect, discovered, in production or sold and delivered. There are different classification systems due to different needs. However, there has been a consensus since 2000 that it is important with an overall system (NPD 2016 a). The classification system used by NPD is shown in figure 5.

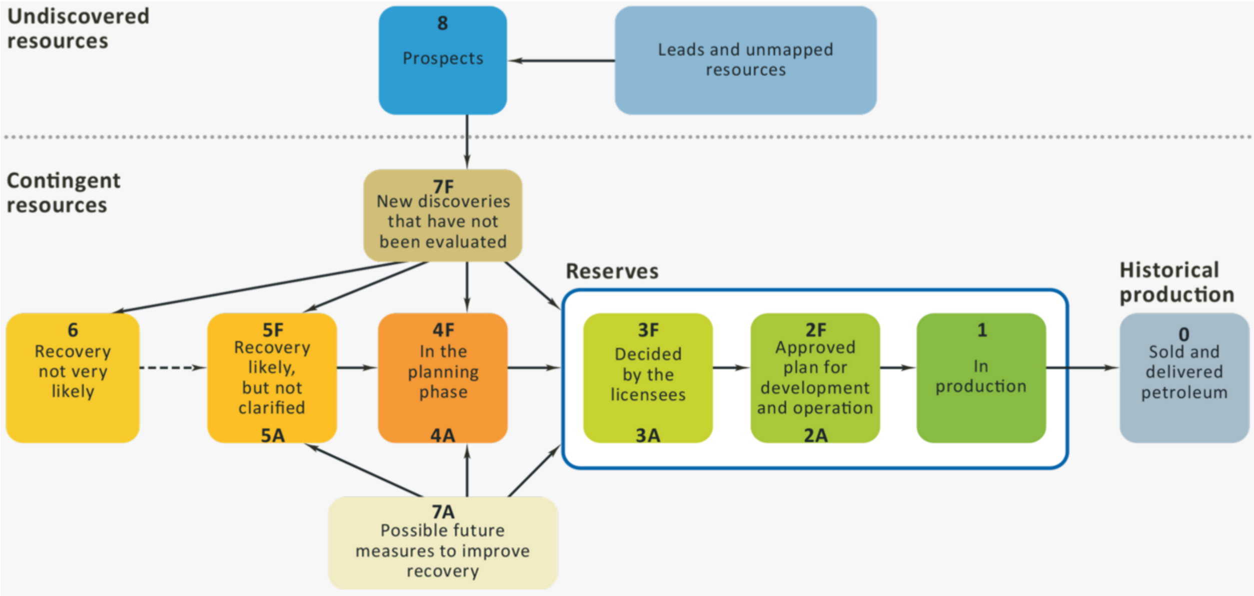

Figure 5 NPD's classification system (NPD 2016 b)

The stages in figure 5 shows how the resource status turns from expected leads and unmapped resource to eventually produced. The main principle of this system is that the original recoverable resources in a field or a discovery can be classified according to where in the development process the resource is. This include new actions to increase the exhaustible resources all the way to the resource is produced (NPD 2016 a). Each stage has its own risks and challenges that will affect the investment that is required. This system takes into account undiscovered resources and that a field or a discovery might have resources in different categories. The resources shall be given high and low estimates in addition to the basis estimate to be able to describe the uncertainties regarding the quantity of the resources. This system is an important assumption for NPDs estimation of the remaining resources and forecast of production from the NCS. This is thus important for an estimation of the need for investment of exploring, developing and producing these resources. The petroleum resources are split in classes and project status categories and apply only to recoverable resources. The classes are historical production, reserves, conditional resources and undiscovered resources. The resources are categorized from 0 – 7 where some of the categories have the sub-categories F (first oil and gas) and A (additional oil and gas). F indicates resources that are included in the existing estimate of the present resources. Resources that can be produced through improved producing beyond the existing estimates are placed in sub-category A. Oil and gas resources that have been produced and sold are in category 0. This includes petroleum resources from existing fields and fields that have been closed. This is the only category where there are exact numbers of the resource quantities. Category 1 applies for remaining recoverable resources that can be sold and delivered at a field in production. An approved plan for development and operation by the Norwegian Government is a necessary condition for the resources to be in category 1 and 2. In category 2 the recoverable resources is on a field where the production has not started. Resources that the licensees has decided to extract and has not an approved PDO is in category 3. In category 4, there are contingent resources that have been proven and where there are ongoing activities regarding development that is expected to be approved by the licensees the next 4 years. Contingent resource where there production is likely, but not clarified belongs to category 5. This includes resources that are not in a present activity for development, but are likely to be in the future. Resources that are likely not to be produced are in category 6. This includes resources that are not evaluated to be valuable even with new technology on a long term view and fields that are too small to be developed. This is based on the evaluation from the licensees and the NPD. Resources where discovery has been proven, but the estimates are only a preliminary estimate are in category 7. In category 8 and 9 we find undiscovered resources. Estimated quantities of oil and gas that are probably present but that have not yet been proven by drilling.

According to NPD the Norwegian licensing system consists of two equally important types of licensing rounds. All areas that are open and therefore available for petroleum activities may be announced in these two types. This is to ensure that all parts in the NCS are adequately explored. Awards of predefined areas (APA) are licensing rounds for mature parts of the NCS. The APA system was introduced to ensure that profitable resources in mature areas are proven and recovered before existing infrastructure is shut down. The other system is the numbered licensing rounds for the least explored parts of the shelf, also called the frontier areas. The licenses are announced every other year. The oil companies are invited to nominate blocks for the round. The advantages of step by step exploration and assessment by the authorities lead to the licenses proposal.

2.5 Expected future production:

According to Rystad Energy, the expected future total production will be around 14.2 billion barrels oil equivalents per year until 2021. Then it is expected to slightly decrease in 2022. In 2023 it is expected to increase again due to the start-up of the Johan Sverdrup field until a top in 2025. After that it is expected that there will be a decreasing trend. Continued high exploration activity is required to be able to explore the undiscovered resources to maintain production from 2025 and create value for both the industry and the society in the long term.

The size of the undiscovered resources is a foundation for future oil and gas production in many decades to come.

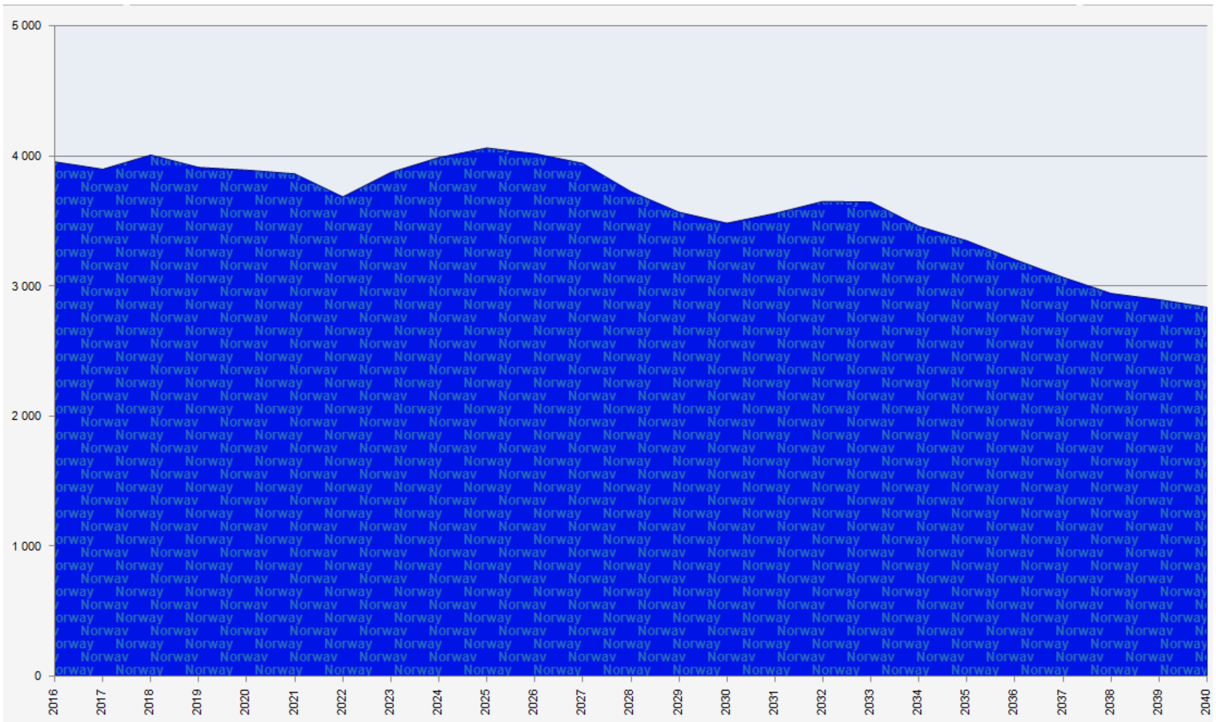

Figure 6 Expected future petroleum production in the NCS in 1000 barrels of oil equivalents per day (Rystad Energy, UCubeFree 2016)

3 Theory

Investment can, in a broad sense, be defined as the sacrifice of current money for future money (Sharpe, Alexander and Bailey 1999). Investment and capital growth have for many decades been seen as quite mysterious in the field of economic research (Mohn 2007). The main theoretical resources in this chapter are collected from the books “Energy Economics” by Bhattacharyya (2011) and “The Economics of Natural Resource Use, 2nd Ed” by Hartwick & Olewiler (1998). This chapter will first describe the distinction between investments in petroleum resources versus reproducible resources.

3.1 Petroleum resources

Oil and gas are typical non-renewable resources and have a huge need for investment. Oil and natural gas are formed by geological processes over millions of years. This means that it is a fixed amount of resources and when extracted, it cannot be renewed (Perman, Ma, Common, Maddison and McGilvray 2011). This is in opposite to reproducible goods such as fish and corn. One question is very important regarding non-renewable resources; what is the optimal extraction path over time for any particular non-renewable stock? Oil and gas is as other non-renewable resource, in practice not homogenous. This means that there are different quality and accessibility in addition to location and thus distance to the marked. These geological conditions will affect the cost of extracting the resources. Technology progress is important to be able to wield these geological conditions. However, in economic sense, the important issue is not only what is technically feasible, but what is available under certain conditions. This means that if it is technically feasible to extract the resources, but the cost is higher than the sales price, the resources are not available. The resource and potential resource supply is thus also dependent on market price and the cost of extraction. Oil is sold in a global market. Natural gas is more sold in three different regions, America, Europe and Asia, and the prices vary between them. This will then affect the economic value of oil and natural gas differently.

Energy projects are characterized by some important factors (Bhattacharyya 2011). They are big in size and very capital intensive, especially at the construction phase. Energy assets tend to have high degree of specificity, because the assets cannot easily be used in another industry. Oil and gas plants have a long life time and a long gestation period. These factors increase the risk in an energy project.

Oil and natural gas are natural resources that are extracted and consumed in a single period, this in opposite to resources such as gold and steel that can be used in many periods and even recycled. This makes oil and gas more an exhaustible resource.

An economic analysis of a project is aimed to analyse the projects welfare impact to be able to identify and select the best economical projects to ensure better allocation of resources (Bhattacharyya 2011). This is done by identifying projects and comparing the costs and benefits related to the investments to determine whether the project is economically acceptable or not.

The investment should be allocated in an optimal way to ensure stable development in the activities in the oil and gas industry and the main land. A country such as Norway that has a lot of petroleum resources must be aware of the effect this resource has on the economy in total and other industries. This can be divided in two main groups, the resource movement effect and the spending effect (Corden 1984). The resource movement effect is when domestic resources are allocated from traditional industries and sectors and into a (booming) resource –based industry. The spending effect means the spending of the (extra) income from the resource revenues, especially true Government budget, into the economy.

3.2 Exploration programme

Exploration programmes are used to go from prospects to resources. The objective is to maximize discoveries at a minimum effort to reduce exploration costs (Bhattacharyya 2011). The addition to reserves is the outcome of the exploration activities. Reserve additions will generally grow quickly at the early stages of the exploration, but then slow down as exploration continues. Mathematically exploration models can be written as this functional model (Bhattacharyya 2011).

$$Fn = \text{Fu}\,(1 - e^{-\gamma W}) \qquad 1)$$

In equation 1, Fn is the number of discovery, Fu is the total number of fields, W is exploration effort and γ is efficiency of the exploration. The size of the discovery is not accounted for in this model.

Exploration can be drilling within the limits of an existing reservoir, to extend a reservoir or be an unexplored ground (Bhattacharyya 2011). The exploration costs include rental of drilling rig, surveys and studies and cost of drilling. The marginal costs of exploring also tend to increase over time. This is because the most prospective areas are explored first and other, generally more difficult areas, is explored later. Location and the geo-physical conditions have a significant effect of the exploration costs. Exploration drilling of oil and gas offshore is more expensive than in flat and desert areas. Drilling costs follow an inverse relationship. A lot of money could easily be spent on exploration activities without commercially viable discoveries. Seismic costs are often lower offshore though. Net Present Value (NPV) can be written as in equation 2 (Bhattacharyya 2011).

$$NPV = \sum_{t=0}^{n} \frac{R_t - C_t}{(1+i)^t} - I_0 \qquad 2)$$

In equation 2, R is revenue, C is the cost, t is period t, i is the discount rate and I is initial investment.

There are by nature risks related to finding a dry hole even in very prospective areas. The normal NPV is thus extended to use the expected monetary value (Bhattacharyya 2011).

$$EMV = \mathrm{P} \times \mathrm{NPV} - \mathrm{E} \qquad 3)$$

Equation 3 shows the expected monetary value (EMV) where P is the probability of that a discovery is being made and E is the exploration costs.

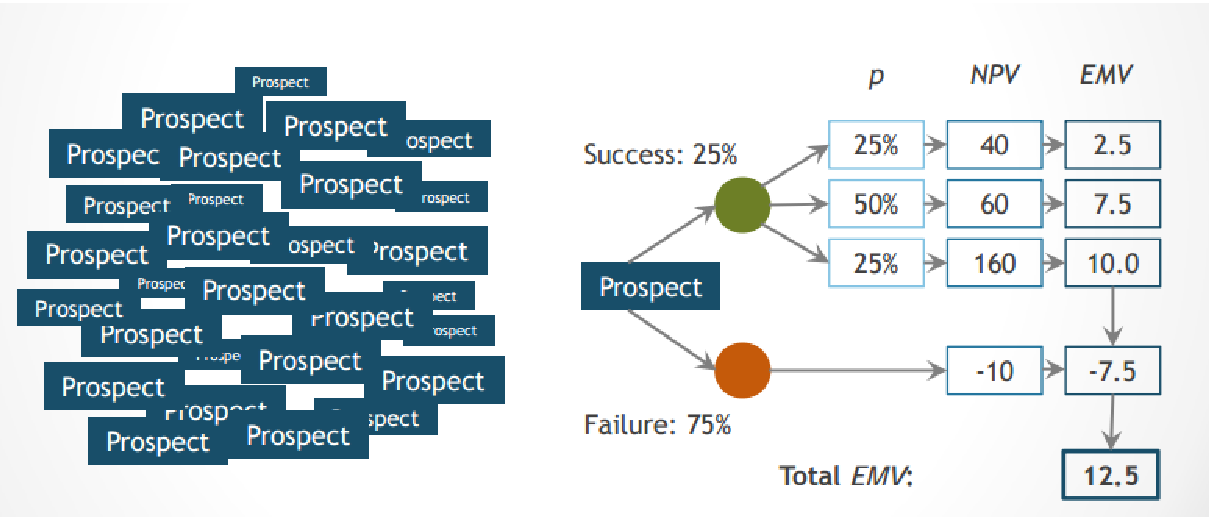

Figure 7 Exploration decision-making (Mohn 2015).

In figure 7 there are many prospects. A prospect is a field where, due to geological conditions, there is a possibility for being undiscovered resources. Each prospect is evaluated according to its likelihood of finding these resources. Equation 3 is used to evaluate each prospect. In the example given in figure 7, there is 25 % chance of finding resources and 75 % chance that there is nothing in the ground for a certain project. If there are resources, it is estimated that there is a 25 % chance of getting an EMV of 2.5, 50 % chance of getting an EMV of 7.5 and 25 % chance that the EMV is 10. The cost is 10 whether there are resources or not. This gives an expected monetary value at 12.5 thus giving a positive outcome that supports an exploration drilling. All prospects are then ranked according to each estimated total EMV result. The risks of failing to find recoverable resources and the unknown outcome in case of success clearly influence the overall decision-making process. Simulations are also used to get a better understanding of the entire range of possibilities.

The lack of infrastructure including public goods and oil and gas development might hinder further activities (Bhattacharyya 2011). There are a number of other factors that also may hinder exploration activities. Contractual risk might arise due to the fact that in most countries, the state is the owner of the underground resources and thus it is a risk for change in contracts when discoveries are made. For the resource owner (country), it might be tempting to increase their share of profit. This is likely, however, to reduce exploration over time and thus reduce the overall income. Thus, it is important for the country to establish a fiscal system and contractual arrangement that encourage investment from the industry and balance the benefits and income from the resources. In many countries, the government only participate in profit sharing, but does not take any risk of exploration. This is shown in equation 4 (Bhattacharyya 2011).

$$EMV = P \times NPV \times (1 - SP) - E \qquad 4)$$

In equation 4, SP is the level of state participation without taking part of the risk. The profitability of the investment is then affected. If the numbers in figure 7 is used, EMV will change to – 2.5. This means that the investment is unprofitable. However, if the state participates in both the profit sharing and the exploration risks, the situation change and the investment will again be profitable as shown in equation 5.

$$EMV = P \times NPV \times (1 - SP) - E(1 - SP) \qquad 5)$$

Commercial risks are another type of risk that is related to finding less favourable commercial prospects than expected. The reason for this can be poor geological conditions, smaller size than expected, poor quality of the oil and gas resource and similar issues that affects the profitability of the project.

Forecasting of the future supply of oil and gas is essential to be able to estimate the future need for investment to explore, develop and produce these resources. There are a number of methods for forecasting (Bhattacharyya 2011). A simple method is oil supply elasticity in relation to the price. This could then be used to estimate forecast supply as economic activities changes. This method is, though, not commonly used in practice. A more used method for forecasting supply of oil and gas fields is exponential decline where the decline is constant. Major concerns regarding this method is that it does not take into account the possibility for further discoveries and the effects of market or economic environment and government policies on future production. A more complex approach is the bottom-up field-by-field forecasting where the forecasting of each field is based on engineering studies of the production decline and which are then summed up. Expected additional reserves in the future might also be included. This kind of analysis is by nature very data intensive and has the potential to deliver accurate forecast. The International Energy Agency publishes results that use this approach through the World Energy Outlook. At last, there is also a top-down approach which is based on the estimates of ultimate reserves and historic production. This approach is relies on geophysical considerations rather than economics variables. However, this approach lack to take into account technological is also not considered to be accurate. Overall, these models employ an overall rate of depletion of the country, thus ignoring field-level information and might be give doubtful predicted results.

3.3 Development of resources

When a discovery is made, the next step in the process is to decide whether to develop it or not. The most important factor in this decision is the size of the discovery. Several estimations are taken place to evaluate the size. In the end, a decision of whether investment or not are taken after a carefully calculated analysis. At this stage, there are proven reserves, but still there are uncertainty regarding size and other characteristics of the field. An investment decision also depends on whether there is oil or natural gas that has been discovered (Bhattacharyya 2011). Oil discoveries tend to attract better industry attention due to easy access to the global market. Gas discoveries on the other hand is treated very differently and depends more on issues such as location and distance to a market with viable consumers.

The cost-benefit framework determines the investment decision. The costs related to develop the field and operating costs are the largest costs. These costs are influenced by factors such as national compliance requirements, potential relocation of settlement, geological conditions, development schedule, appraisal drilling, test requirements and infrastructure. The benefits are on the other hand dependent on factors such as the size of the reservoir, the production schedule, the future market price of the resource and the tax and fiscal regime in the country. In the end, each investor company has to decide whether to invest or not. This is often based on the company's own culture regarding decision-making. Large companies tend to restrain from investing if the oil price is too low, and for many of them this price is less than $20/barrels for project appraisal (Bhattacharyya 2011). Smaller companies tend to have a more risk willing approach to investments. If the oil price is low, it is only the largest projects with low production costs that will be started.

When the reserves are identified, it is classified into various types. The reserves physical and chemical properties decide which group the reserve belong to (Bhattacharyya 2011). This will then influence which price the resource will get in the marked. The expected price will then affect the willingness to invest in the resource and thus the need for investment. Crude oil is classified as light or heavy crude. Light crude are sold at a premium in the market compared to heavy crude since it yields more of lighter products. Crude oil is also classified based on its sulphur content. Crude oil with high content of sulphur is called sour crude, while crude oil with low content of sulphur is called sweet crude. Sweet crude is sold at a premium in the market because sour crude need special treatment before it can be used. Natural gas is classified whether it is found separately of oil or in association with oil. Another classification is dry and wet gas, where gas with large amounts of condensable hydrocarbon is called wet gas and dry gas when this has been removed. Gas is also classified according to the level of sulphur, such as crude oil, sour gas (high sulphur level) and sweet gas (low sulphur level) respectively.

3.4 Production of petroleum resources

Before the production phase starts after the field is developed, preparatory work and tests are carried out (Bhattacharyya 2011). Well preparation is where the well has to be cased, anchored and fitted with control mechanisms for flow control. To determine the flow rates and possible production profile testing is performed. Reservoir stimulation is used to improve flow paths and increase output with methods such as acidizing and hydraulic fracturing.

Initially the normal pressure difference between the well mouth and the reservoir makes oil and gas flow easily due to pressure from an underlying water aquifer, gas cap or dissolved gas. This natural pressure normally allows production of only 5 – 20 % of the oil in place (Bhattacharyya 2011). For gas not associated with oil, this recovery rate can be much higher due to better flow characteristics. For associated gas, however, the production depends on the oil production. Enhanced recovery techniques are used to improve production output in the range of 5 – 25 % of the remaining oil in the field. Water injection and gas re-injection is called secondary recovery methods. Tertiary methods include hot water injection, steam injection and injection of chemicals. This will increase the cost of oil production, where tertiary methods are more costly than secondary methods. There is thus a trade-off between cost and benefits of producing more petroleum resources have to be done. This important in respect to the level of investment that is needed to produce the remaining resources and the return of this investment. It also has to be taken into account that these methods might reduce the overall reserves, such as water injection can trap some oil resources. One single well cannot drain any reservoir (Bhattacharyya 2011). However, when more wells are being used, the pressure falls, thus there is a trade-off between wells and pressure declines. This is called rate sensitivity. Production of non-associated gas follows a similar pattern as with oil production. The initial output tend to be better than oil, on the other hand, once the peak is reached and the depletion starts, it is more difficult and thus costly, to improve production. Gas that is produced alongside of oil is even more complex since the oil is more valuable. The gas can be used by consumers if available or it can be re-injected to produce more oil or it can be flared. This waste creates unnecessary environmental damage.

3.5 Resource rent

Resource rent is an aspect that is an important issue for non-renewable resources. Resource rent can be divided in four types of differential rent (Bhattacharyya 2011). Fields that can be exploited cheap due to geological conditions can be seen as having a mining rent. Efficient technology lead to technology rent. Short distance to the marked gives a positional rent. Sweet crude oil attracts a premium over sour crude oil and this gives sweet oil a quality rent related to heavy crude oil. Rents might also rise due to non-competitive market structure and changes in the market conditions. An important factor of resource rent is the scarcity of the resource. The resource rent is an important factor when shearing the profit between the owner of the resource, the country and the producing company. It is important to make sure that both parts get a reasonable share of the resource rent. The instruments used by a country to collect this rent are the use of royalties and profit tax, and quasi-fiscal instruments such as state participation. Tax is easy to administer and involves low risk for the government. A royalty tax is an additional cost to the producer. This transfers the risk to the investor and protects the government when the price of oil is low. Overall, though, producer loose more than the state recovers from the producer's surplus due to the deadweight loss. It is especially difficult to decide the correct level of royalty for resources that have quite volatile prices, such as oil. Low royalty when the price is low, the government get even less revenue. High level of royalty makes the investment in the oil and gas resources less valuable, which then might also lead to less oil production which is not good for the country either. The revenue captured by the state can be seen as price paid by the investor to acquire access to the resource. This government "take" has changed accordingly to changes in the oil price (Bhattacharyya 2011). After the oil price shock in the 1970s this take increased, reversed in the 1980s where oil price where quite low and increased since 2003 when the oil prices increased again. The size of the government takes might also wary as much as between 40 – 99 % according to size and costs of the fields in addition to the risks involved (Bhattacharyya 2011). A state company is another method for oil-rich countries to capture the resource rent. If the state owned company is the only oil company in the country, thus get a monopoly, it gets a higher share of the producer surplus. The resource rent will then ultimately end up to the state. There are many concerns regarding this kind of state intervention and include lack of skills and expertise in oil production activities, political influence in decision-making, mixture between the company's and the state's finances and conflicts of interest between regulatory and ownership. This could then seriously affect the performance of the industry and their willingness to invest.

Due to the natural phases of a field's life, an oil producing country would normally have many fields at different stage. The total production output from the country is the sum of these fields. Overall production globally is the sum of the output from each oil-producing country. Reserve to production (R/P ratio) is a concept that is used at the national level. According to BP there are proven oil reserves left for 52,5 years of production and for natural gas there are 54,1 years left of the proven reserves (Bhattacharyya 2011). However, neither the level of production and confirmed reserves remains constant over time. To be able to have a constant R/P ratio, new reserves has to be added. The resource life (r) can be written as (Bhattacharyya 2011):

$$r = \frac{R_t}{P_t} \qquad 6)$$

$$R_{(t+1)} = R_t - P_t + D_t \qquad 7)$$

R stands for proven reserves, P is production, D is new discoveries and t is year t.

In order to maintain the same level of R/P, discoveries has to equals production even when there is no production growth. To be considered economically regenerated, the resource growth has to be larger than the production. Historically, the oil industry ensured economic regeneration until the late 1970s (Bhattacharyya 2011). In this period it was cheaper to find new fields instead of getting more out of existing fields. This changed in the 1980s when the industry faced an increasing cost of finding new oil in addition to an increasing long-run marginal cost of development. Whether this is a permanent situation now is not clear.

Every oil producer will try to maximize net present value of the oil. To ensure this, the quantity extracted must be chosen that maximize the differences between total revenues and the discounted value (Hartwick & Olewiler 1998). According to standard economic theory optimal production is where marginal benefit equals marginal cost. This is true for extraction of oil and other non-renewable resources. However, it modifies in three fundamental ways. The first is that the owner of the resource face an opportunity cost where the cost of using up the fixed stock at any point in time or being left with smaller remaining reserves. The operator must cover this opportunity cost to maximize profit. The operator measure this opportunity cost as the value of the unextracted resource, the resource rent. The second feature is the value of the resource rent over time. If the resource rent does not increase over time it is more profitable to extract all as fast as possible. On the other hand, if the resource rent is very high, it is more profitable to keep the resource in the ground because the value increases more than the opportunity rent, such as in a saving account. The last difference is that the extraction of the stock cannot exceed the total resource. This is called the stock constrain.

The marginal rent of each barrels extracted in period t equals the discounted rent of the marginal barrels extracted in the next period (Hartwick & Olewiler 1998). This is called the Hotelling rent. This rent exists because there is a fixed amount of oil in the field and the demand is higher than the total supply.

The firm must select a path $q_0, q_1, \dots, q_T$ to decide how to extract S_0 tons of petroleum resources to maximize the firm's profit (Hartwick & Olewiler 1998). The Net Present Value must be maximized since the extraction occurs over many periods. This involves getting the rate of extraction to be where marginal benefit equals marginal cost for all periods and satisfy the end condition, marginal profit of the quantity extracted in the final period must be as large as possible. The fundamental relation is that economic depreciation equals current rent according to current extraction in period t. Due to the extraction of the stocks, the value of the firm that extract it also declines. The market value is reflected in current rent on the amount currently extracted. To ensure neutrality in the taxation of the firm, this depletion must be accounted for by the tax system.

The oil market is global and thus each oil-producing firm is a price taker. The total oil-reserves in the world is declining due to extraction, thus the price should increase in the long run (Hartwick & Olewiler 1998). When a firm is a price taker, the price in each period will be a price schedule; $p_0, p_{1,\ldots,}p_T$. In equilibrium, each firm will use the same predicted future oil price to fulfill each manager's expectations. In a simple to period model, it can be shown that the price rise over time at a rate less than the rate of interest. The value of the undiscounted resource rent rises at the rate of the interest. The present value of resource rent is constant and quantity extracted per period falls over time.

Another relevant aspect is that the cost of extract the resource might be different the deeper in the ground the resource has to be taken out from (Hartwick & Olewiler 1998). It might be seen as a two stage extraction, where the cost in the first period is lower than the cost in the second period. To avoid that the consumers take the advantage of a jump in price, these two phases has to be linked to smooth the price between the phases. Future anticipated supplies of resources, included substitutes, influence the current exhaustible resource price.

3.7 Previous research

Development in the oil and gas industry suggests that investment behaviour change over time (Mohn 2008). Management mentality might be influenced by shifts and shocks in the prices, liquidity and uncertainty. The wave of mergers in the international oil and gas industry after the Asian economic crisis in the end of the 1990s is an example of this (Weston, Johnson and Siu, 1999). Empirical research of the role of uncertainty has increased (Carruth, Dickerson and Henley, 2000). The option value of waiting to invest is positively influenced by increased uncertainty, thus suggest a negative relation between investment and uncertainty (Dixit and Pindyck, 1994). In addition, investment leads to increased potential reward from the acquisition of future development and growth options. These perspectives related to modern theories of investment have been illustrated by Abel, Dixit, Eberly & Pindyck (1996).

Energy investment in general and particularly oil and gas investments have risks beyond geological uncertainty (below-ground risks). These above-ground risks include availability and access to remaining reserves, regulatory and market conditions. Due to the fact that most of the remaining oil and gas resources are in countries outside OECD, western oil companies face a range of new risks such as less market oriented systems, strong national oil companies and restrictions on foreign investment. Other risks include corruption, weak legal and control systems, political and military unrest, human rights issues and a variety of operational risk factors relating to local operations (Karl 1997). There is evidence that the paradox of plenty is a "soft" curse for resource rich countries. However, according to Dauvin and Guerreiro (2016) there is a positive link and statistically significant relation between resources and growth when a high quality institutional system is established.

Conventional oil such as crude oil, condensate and natural gas liquid, accounts for a substantial part of the global production. There are increasing concerns for a near-time peak and substantial decline in the production of oil where alternative sources remain unable to fulfil the gap (Aleklett, Höök, Jakobsson, Lardelli, Snowden & Söderbergh 2009). The UK Energy Research Centre conclude through their analysis that a peak before 2030 is likely and that it is even a risk for a peak before 2020 (Sorrell, Speirs, Bentley, Brandt & Miller 2010). However, other argues that rising prices will be able to stimulate new discoveries; enhanced recovery and development of unconventional oil (typically oil sand and oil shale) such that the global demand will be met well into the 21^{st} century (Odell 2004).

There have been many economic researches regarding oil and gas exploration and drilling, mainly in the US and the United Kingdom (Mohn 2008). The result in the study "The Prospects for Activity in the UK Continental Shelf to 2040: the 2009 Perspective (Kemp & Stephen, 2009) highlight a wide range of long term prospects for activity levels. With an estimated oil price of USD 45 and 30 pence per barrel of oil equivalents in real terms, investment and production felled sharply and most of the new fields and incremental projects were uneconomic. With an oil price at USD 60 and 50 pence per barrel of oil equivalents, a substantial number of new fields and incremental projects become viable. However, the investments levels where stable in the first years, but then declined noticeable thereafter. The third price scenarios where oil price of USD 80 and 70 pence per barrel of oil equivalents. At this level, the investment was evaluated to be buoyant for some years ahead and many new fields and projects become viable. The study also highlighted the effect of tougher capital rationing. In another study, Kemp and Stephen (2011) claimed that the most total resource availability is unlikely to be the key production constraint for some years ahead at the UK Continental Shelf. The resource price and investment hurdles are more important in addition to factors such as the tax system.

The battle between technology and resource scarcity is important for the costs in the future and thus the need for investments. Lindholt (2013) found significant effects of both depletion and technological change on oil finding costs from 1981 to 2009, except cyclical variations in finding costs that could come from changes in factor prices. Technology development more than mitigated the depletion effect until around the mid-1990s. However, this changed the last decade where depletion outweighed technological progress. According to Lindholt (2013) regional finding costs could stay at present level or even decline in the future. Future research and development activities are conditions for successful supporting cost-reducing technological growth.

4 Method

There has not been any other study that tries to estimate the need for investment for the remaining oil and gas resources in the NCS. This is in opposite to for example estimation of the value of a company, which has been done several times. This is thus quite unexplored territory. The main information regarding the size of the remaining petroleum resources are collected from the Norwegian Petroleum Directorate. Information regarding the costs is provided by Rystad Energy. This will be presented in this chapter.

4.1 Data collection

NPD (2016 a) has a database that contains information about discoveries, fields, companies, wells, production and reserves including historical data. Data from NPD has been the basis for the analytical estimation regarding the size of the remaining resources. To make things simpler, the classification system in figure 5 that is explained earlier in this thesis is divided in three categories of resources. This is undiscovered resources, resources to be developed and resources in production. Resources that are placed in the group of "Recovery not very likely" (6) in the classification system are not in the resource estimate. This is because NPD and the oil and gas companies expect these resources not to be economically valuable to produce without a substantial increase in future prices and technology development. Produced and sold resources are by nature not relevant.

NPD measure the remaining resources in million standard cubic metres of oil equivalents. Due to the fact that oil is sold in USD per barrel of oil equivalents, the standard cubic metres of oil equivalents are converted to barrels of oil equivalents.

The level of the future oil and gas price are an important factor. NPD (2016 b) estimates the oil price in the future to be USD 90 per barrel of oil equivalents from 2020 in constant 2014 prices on basis of information from the IEA's World Energy Outlook 2015. NPD (2016 b) estimate the price of gas to be NOK 2 per oil equivalents from 2020 in constant 2014 prices. This is USD 0.246 with an exchange rate of USD/NOK of 8.13 (Norges Bank 2016). This means that NPD expect prices to increase in the future. Commodity markets such as the oil market move in cycles. If the macroeconomic conditions normalize, global oil demand should rise annually by 1.1-1.2 million barrels of oil equivalents per day until 2020 (Statoil 2016). This is likely to increase the oil price. Thus the expected oil price of USD 90 per barrel of oil equivalents will be used in this paper.

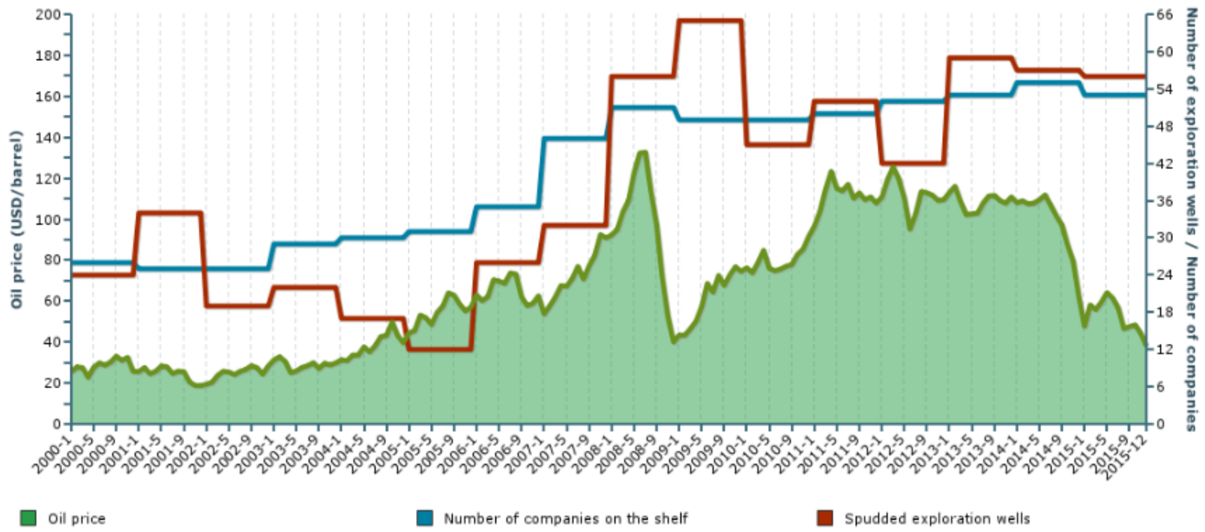

Figure 8 Oil price 2000 – 2015 (NPD 2016)

4.2 Cost estimate

Rystad Energy is an independent oil and gas consulting services and business intelligence data firm (Rystad Energy 2016). They have a database that contains information regarding oil and gas fields globally. This includes extensive information regarding costs and production per field in the NCS. This information has been used to estimate the average cost for different categories. According to Rystad Energy the average cost for 2011 – 2015 on the NCS was USD 8 per barrel of oil equivalents for exploring, USD 14 per barrel of oil equivalents for development and USD 9 per barrel of oil equivalents for producing the resources (e-mail from Oddmund Føre, analyst at Rystad Energy received 21.04.2016). These costs vary from field to field and area to area. Rystad Energy estimates the costs in the Barents Sea to be higher than in the Norwegian Sea and the North Sea. This is mainly due to higher costs related to the establishment of new infrastructure. This differences increase the uncertainty of the estimates of the investments needed to produce all of the resources on the NCS. The average cost of producing one barrel of oil equivalent on the NCS in 2015 was USD 7. However, according Rystad Energy, the cost are likely to increase with an expected oil price increase, thus USD 9 per barrel of oil equivalent is assessed to be a better estimate for producing the remaining resources. This thesis will use the estimation from Rystad Energy. These numbers are presented in table 2 and are referred to as scenario 1 or main estimate per barrel of oil equivalents. In order to describe the effect of changing costs, other cost scenarios are presented. In scenario 2, the average costs for NCS is the same as the main estimate based on each region part of the total remaining resources. However, each sea has been "given" a cost per barrel of oil equivalents that relates to each region expected cost level compared to the other regions. This means that since the North Sea is expected to have lower need for investment compared to the other two regions, the North Sea got lower unit costs per barrel of oil equivalents than the average while the other two regions got higher unit costs than average. See table 3 for the estimated unit costs per barrel of oil equivalents for each region. In the third cost scenario, all regions got the same percent cost increase, but the increase was dependent on the resources stage in the process. See table 4 for more details. The oil price scenario of USD 90 per barrel of oil equivalent and unit costs per barrel of oil equivalents referred to above, are all in real terms.

	Unit cost	Cumulated unit cost
Exploration cost	8,00	31,00
Development cost	14,00	23,00
Production cost	9,00	9,00

Table 2 Main unit cost scenario in USD per barrel of oil equivalents (Rystad Energy 2016)

		North Sea		Norwegian Sea		Barents Sea	
	Average unit cost	Percent change	Unit cost	Percent change	Unit cost	Percent change	Unit cost
Exploration cost	7,99	-20 %	6,40	10 %	8,80	30 %	-0,26
Development cost	13,99	-20 %	11,20	10 %	15,40	30 %	-0,26
Production cost	9,00	-15 %	7,65	5 %	9,45	25 %	-0,19

Table 3 Unit cost scenario 2 in USD per barrel of oil equivalents per region

Cost per stage	Main unit cost estimate	Percent increase	Unit cost scenario 3
Exploration cost	8,00	15 %	9,20
Development cost	14,00	10 %	15,40
Production cost	9,00	5 %	9,45

Table 4 Unit cost scenario 3 in USD per barrel of oil equivalents

Cost per stage	Main unit cost estimate	Percent increase scenario 4	Unit cost scenario 4	Percent increase scenario 5	Unit cost scenario 5	Percent increase scenario 6	Unit cost scenario 6
Exploration cost	8,00	10 %	8,80	20 %	9,60	30 %	10,40
Development cost	14,00	10 %	15,40	20 %	16,80	30 %	18,20
Production cost	9,00	10 %	9,90	20 %	10,80	30 %	11,70

Table 5 Unit cost scenario 4-6 in USD per barrel of oil equivalents

All collected information was added into a spreadsheet. Table 6 display the information regarding the remaining resources from the NPD. The numbers of the remaining resources are in million standard cubic metres of oil equivalents. This was then converted to barrels per oil equivalents with a rate of 1 million cubic metres of oil equivalents is 6 289 810 barrels of oil equivalents. The costs of moving the recourses from one category to the next and aggregated costs of moving each amount in each category is multiplied with the amount of oil in each category. This means that undiscovered resources adds use the total aggregated unit costs per barrel of oil equivalents when moving from each category to the next until it has been produced, while the cost of producing the resources in category 1 which ready for production, only use the unit cost of production per barrel of oil equivalents. This gave then the total costs of moving the resources from one category to the next. This was then aggregated to the overall costs. This was done with the different cost scenarios as well.

The estimated future production from 2016 to 2040 from Rystad Energy was entered in to the spreadsheet. The numbers from Rystad Energy was in 1000 barrels of oil equivalents per day. This was then converted into barrels of oil equivalents per year. The equation that gives the resource rent was then used in the spreadsheet together with the estimated price and production cost. This gave then the resource rent in figure 15.

The resource life was found by using NPDs data regarding resource growth since 1990 and yearly production since 1971. Due to lack of resource data before 1990, the period before 1990 was excluded. The numbers of the remaining resources are in million standard cubic metres of oil equivalents. This was then converted to barrels per oil equivalents. The changes in production from one year to the next are then calculated. The total remaining resources per 31.12.2015 in category 2-5 and 7 is then used as the “end point”. This end point minus yearly gross resource growth in 2015 plus yearly production in 2015 gives then the resources found per 31.12.2014. Yearly resource life is calculated by dividing the amount of resources on the production for each year.

Leads, unmapped resources and prospects (number 8 in the classification system) are naturally in the group of undiscovered resources. As explained earlier the oil companies can apply for awards in predefined areas (APA) and / or licenses in new unexplored areas. The resources have to be proven by exploration activities by the oil companies that are awarded the areas. When the oil prices are low, there is a likely to be more demand for exploring in mature fields. The costs of exploring in mature fields are likely to be lower due to good knowledge of the geological conditions. According to equation 1 shown earlier:

$$Fn = \text{Fu}\ (1 - e^{-\gamma W}) \qquad 1)$$

Fn is the number of discovery, Fu is the total number of fields, W is exploration effort and γ is efficiency of the exploration. Licenses in APA areas, the number of discoveries (F_n), is estimated to be higher than licenses in new unexplored areas (NPD 2016 a). This means that, ceteris paribus, W is higher for exploration in APA areas. To be able to discover as much in frontier areas the effort W and or the number of fields Fu must be higher than in the APA areas. However equation 1) does not take into account the size of the discovery, which is likely to be higher in new and unexplored areas, since the equation assume that the size of the field are the same for all fields.

5 Analysis

This chapter presents the results of the research. The total need for investment in the NCS is analysed with the use of the resource estimates and cost scenarios explained in the previous chapter.

5.1 Investment needed

The overall need for investments include exploration costs, development costs and production costs. The cost of moving the resources from undiscovered to discovered, discovered resources to resources ready for production and resources in production to produced and sold resources are based on different unit cost scenarios.

			Resource accounts per 31.12.2015	*Changes from 2014*
Class	*i*	Fields	Total million o.e	Total million o.e
Sold and delivered	0	Sold and delivered	6 630	229
Reserves	1	In production	2 127	-31
	2	Approved plan	612	196
	3	Decided by the licensees	388	2
		Sum reserves	3 128	167
Contingent resources	4	In the planning phase	237	53
	5	Recovery likely, but not clarified	338	-49
	7F	New discoveries tied to fields being evaluated	20	7
	7A	Possible future incr.recovery measures	215	-20
		Sum contingent resources in fields	809	-9
		Discoveries		
	4	In the planning phase	256	-415
	5	Recovery likely but not clarified	377	116
	7F	New discoveries being evaluated	106	-83
		Sum contingent resources in discoveries	739	-382
Undiscovered resources	8 and 9	Resources in prospects, leads and unmapped prospects	2 920	85
		Sum total resources	14 227	90
		Remaining resources	7 597	-139

Table 6 Recoverable petroleum resources at NCS in million standard cubic metres of oil equivalents, NPD (2016 a).

Table 6 present an overview of the total recoverable resources in the NCS. The numbers are uncertain except from the resources that have been sold and delivered (category 0), which is 6.6 billion standard cubic metres of oil equivalents. Estimated reserves that are ready to be produced (category 1) are 2.1 billion standard cubic metres of oil equivalents. This is equal to 13.38 billion barrels of oil equivalents. The categories from 2 to 5 in addition to 7 are resources that have to be developed before it can be produced. There are 2.6 billion standard cubic metres of oil equivalents in these categories which converted, are about 16.0 billion barrels of oil equivalents. Resources in prospects and leads are estimated to be 2.9 billion standard cubic metres of oil equivalents, equivalent to 18.4 billion barrels of oil equivalent.

Class	i	Fields	Million barrels of oil equivalents	Exploration cost in million USD	Development cost in million USD	Production cost in million USD	Total costs in million USD
Sold and delivered	0	*Sold and delivered*	41 705				
Reserves	1	*In production*	13 381			120 430	120 430
	2	*Approved plan*	3 852		53 928	34 668	88 596
	3	*Decided by the licensees*	2 443		34 202	21 987	56 189
		Sum reserves	19 676				
Contingent resources	4	*In the planning phase*	1 492		20 891	13 430	34 321
	5	*Recovery likely, but not clarified*	2 123		29 727	19 110	48 837
	7F	*New discoveries tied to fields being evaluated*	124		1 730	1 112	2 841
	7A	*Possible future incr.recovery measures*	1 352		18 932	12 171	31 103
		Sum contingent resources in fields	5 091				
		Discoveries	-				
	4	*In the planning phase*	1 612		22 565	14 506	37 071
	5	*Recovery likely but not clarified*	2 373		33 219	21 355	54 575
	7F	*New discoveries being evaluated*	664		9 294	5 975	15 268
		Sum contingent resources in discoveries	4 648				
Undiscovered resources	8 and 9	*Resources in prospects, leads and unmapped prospects*	18 366	146 930	257 127	165 296	569 354
		Sum total resources	89 487				
		Remaining resources	47 782	146 930	481 616	430 040	1 058 585

Table 7 Need for investments at NCS in million barrels of oil equivalents and million USD.

According to table 7, the total need for investment in the Norwegian Continental Shelf is USD 1 058.6 billion with unit costs as described in table 2. The need for investments at each stage is also presented in table 7. There is a need for USD 146.9 billion in exploration. The amounts of barrels per oil equivalents that have been explored are then added to the resources already discovered. These resources are then added to the resources already in production. From the results it can be seen that the development costs are highest with USD 481.6 billion. This is USD 51.6 billion larger than the production costs at USD 430.0 billion.

These results are influenced by the oil and gas price. If the price is between 23 and 31 USD per barrel, there are not likely to be any production of undiscovered resources. This is because the exploration costs make it too costly to invest. It is though important to remember that some explorations might have lower costs than USD 9 per barrel of oil equivalents due to higher likelihood for a discovery in more mature areas such as the Norwegian Sea and the North Sea compared to the Barents Sea. Then the total need for investment of producing the resources except undiscovered resources is USD 489.2 billion. With a price below USD 23 per barrel of oil equivalents, the cost of producing and development is higher, thus makes it unprofitable to develop resources that have been discovered, but not developed. With a price below USD 9 per barrel of oil equivalents, the costs exceed the income for all fields in the NCS. Thus only the largest and most efficient fields will be in production.

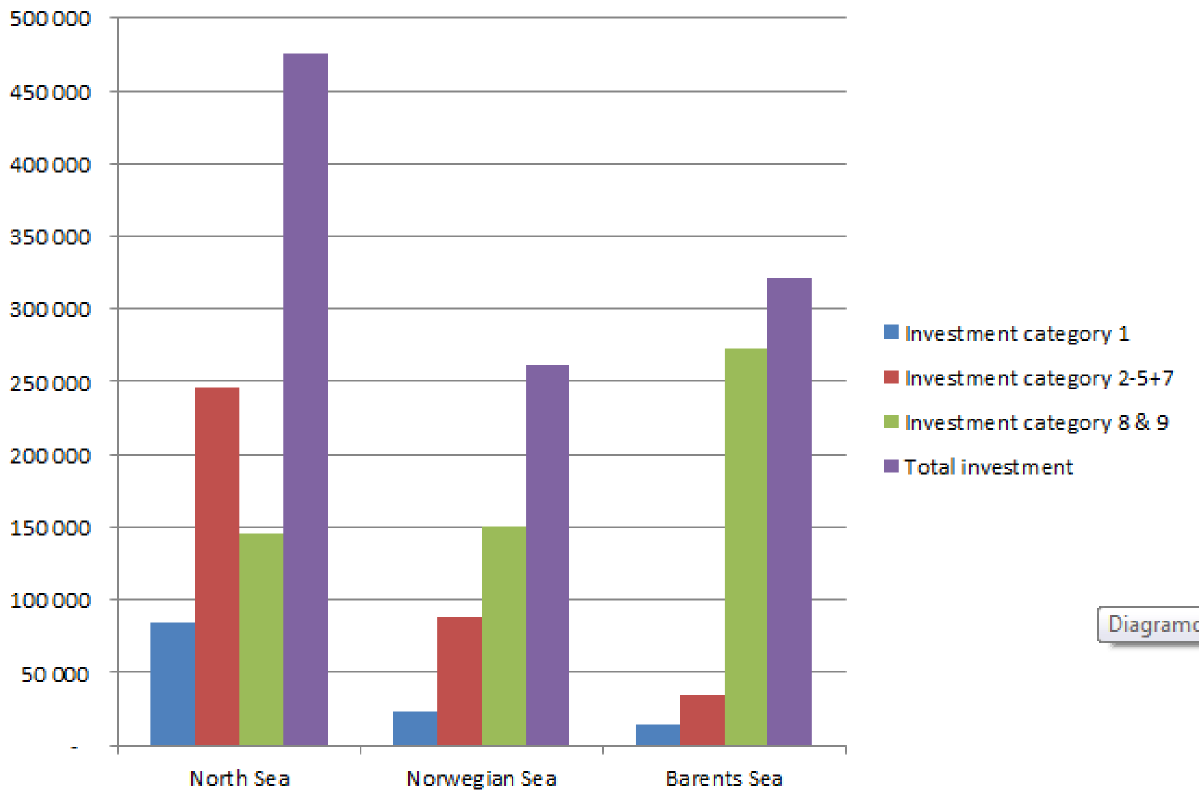

Figure 9 Investments per region in million USD

Investments per region are shown in figure 9. The total need for investment for all three regions is calculated to be USD 1 058.3 billion. Due to lack of data from NPD regarding reserves only in category 1 (reserves in production) for each region, possible actions for increased extraction per region and rounding off, these numbers are slightly different from the total need of investments presented in table 7. There are 8 fields that got a PDO approval, but where the production has not started. 6 of them are from the North Sea with the Johan

Sverdrup fields as the largest, two from the Norwegian Sea and none from the Barents Sea. Thus reserves that are in category 2 and 3 are placed mostly in the North Sea and the rest at the Norwegian Sea. Resources with possible actions for increased extraction are also placed mainly in the North Sea and the rest in the Norwegian Sea.

According to figure 9, the North Sea has the largest estimated need for investment with USD 475.3 billion. As mentioned earlier, the North Sea can be seen as a mature area. To produce reserves that are in production in the North Sea, there is an estimated need for investment of USD 84.0 billion. This is nearly four times as much as the Norwegian Sea and six times as much as the Barents Sea. The Norwegian Sea also has the largest estimated needs for investments to be able to produce resources that is discovered, but are not set in production. The Barents Sea has the largest estimated undiscovered resources and thus the largest estimated need for investments for this category of resources.

There are likely to be different unit costs per barrel of oil equivalents between the three regions. Table 3 outline cost scenario 2 with different estimates of unit costs per region and stage in the process. Out of the remaining resources at NCS, 51 % are at the North Sea, 23 % at the Norwegian Sea and 26 % at the Barents Sea. When the unit cost at the different region is included as a relative part of the remaining resources, the average cost is described as NCS in table 3.

In cost scenario 2, the unit costs in the North Sea are reduced with 20 % exploration and developing costs and 15 % for operation costs. The unit costs at the Norwegian Sea are increased with 10% for exploration costs, 10 % for development costs and 5 % for operation costs. The respectively percent for the Barents Sea are 30 %, 30 % and 25 %. These changes in the costs are because it can be argued that the cost level is lowest at the North Sea and that the Barents Sea got the highest costs. This is because the North Sea is a mature field and the Barents Sea is quite unexplored. There are only two fields that are producing at the Barents Sea. This makes it difficult to estimate the costs in this area.

To produce petroleum resources at existing fields might not be that different between the North Sea and the Barents Sea. There are likely that there will be larger differences when it comes to exploration and development activities. This is because of issues such as that exploration in unexplored areas is more unsecure and that development in new areas needs larger investments in infrastructure. These cost estimates are used in the table 8-10 to describe how this changes the need for investments for each region.

The total need for investments with the cost scenario 2 from table 3 is USD 28.3 billion larger than the investments with the costs scenario 1 from table 2. This difference is quite small and is not likely to have a significant impact of the changes between the regions. The total need for investments of producing resources that already is in production decrease with USD 8.0 billion. The total need for investments of developing and producing discovered resources decreased with USD 27.6 billion. However, the costs of producing undiscovered resources increase with USD 63.9 billion and result in the overall need for investments to be larger. Another interesting issue is that the total need for investments at the Barents Sea actually exceeds the North Sea with cost scenario 2. The largest part of this increase for the Barents Sea is the undiscovered resources with an increase of USD 91.2 billion. USD 44.4 billion of the decrease regarding the North Sea is resources that are discovered, but not developed. The relative small increase in the cost level for the Norwegian Sea does not influence this picture.

North Sea	Million barrels o.e.	Exploration cost in million USD	Development cost in million USD	Production cost in million USD	Total investment in million USD
Unit cost per barrel o. e.		8,00	14,00	9,00	31,00
Resources in production	9 336			84 024	**84 024**
Discovered resources	10 698		149 772	96 282	**246 054**
Undiscovered resources	4 686	37 487	65 603	42 173	**145 263**
Sum	**24 720**	**37 487**	**215 375**	**222 479**	**475 341**

North Sea	Million barrels o.e.	Exploration cost in million USD	Development cost in million USD	Production cost in million USD	Total investment in million USD
Unit cost per barrel o. e.		6,40	11,20	7,65	25,25
Resources in production	9 336			71 420	**71 420**
Discovered resources	10 698		119 817	81 840	**201 657**
Undiscovered resources	4 686	29 990	52 482	35 847	**118 319**
Sum	**24 720**	**29 990**	**172 300**	**189 107**	**391 396**

Table 8 Need for investments per stage with different unit costs per barrel of oil equivalents in the North Sea

The tables 8-10 present the need for investments for each region at each stage with different unit costs. The North Sea is presented in table 8. With cost scenario 1, the total need for investment is USD 475.3 billion. With cost scenario 2 the need for investment at the North Sea is reduced to USD 391.4 billion. This is lower than the adjusted costs for the Barents Sea in table 10 even though there is more than twice as much resources left in the North Sea. The cost of exploring, develop and produce the undiscovered resources is decreasing with 19 % for the North Sea. A reduction in the exploration costs for the North Sea might be likely due the relative good knowledge concerning the geological conditions. However, the undiscovered resources are only 19 % of the expected remaining resources. Thus this might not be the most important issue for the North Sea.

The existing infrastructure at the North Sea is of significant importance for the producing of the remaining petroleum resources. NPD (2016 b) highlighst this issue, especially whenit comes to small pockets of resources that will be economically unprofitable if they cannot use the existing infrastructure. 43 % of the remaing resources at the North Sea is discovered resources and includes several small pockets. The investment needed to develop and produce these resources counts 52 % of the total need for investment at the North Sea. Technology that increase the extraction and reduce the costs, especially at small pockets, is thus an important factor for the North Sea. In the scenario of reduced costs in the North Sea in relation to the other two region, development costs is an important factor. Half of the reduction in costs comes from the reduced development costs. Political constrains such as electification of the oil platforms might be an advantage for the North Sea comparred to the two other regions, especially the Barents Sea, due to the existing infrastructure.

Norwegian Sea	Million barrels o.e.	Exploration cost in million USD	Development cost in million USD	Production cost in million USD	Total investment in million USD
Unit cost per barrel o. e.		8,00	14,00	9,00	31,00
Resources in production	2 505			22 541	**22 541**
Discovered resources	3 806		53 290	34 258	**87 547**
Undiscovered resources	4 875	38 997	68 244	43 871	**151 113**
Sum	**11 186**	**38 997**	**121 534**	**100 670**	**261 201**

Norwegian Sea	Million barrels o.e.	Exploration cost in million USD	Development cost in million USD	Production cost in million USD	Total investment in million USD
Unit cost per barrel o. e.		8,80	15,40	9,45	33,65
Resources in production	2 505			23 668	**23 668**
Discovered resources	3 806		58 619	35 971	**94 589**
Undiscovered resources	4 875	42 897	75 069	46 065	**164 030**
Sum	**11 186**	**42 897**	**133 687**	**105 704**	**282 288**

Table 9 Need for investments per stage with different unit costs per barrel of oil equivalents in the Norwegian Sea

In the Norwegian Sea with unit cost 1, the investment needed is USD 261.2 billion and in the second unit cost scenario USD 282.3 billion. This is an increase of USD 21.1 billion. The largest increase applies to undiscovered resources, but cost increase for the discovered resources is significant too. Norwegian Sea contains 23 % of the total remaining resources in NCS. However, the Norwegian Sea has more undiscovered resources than the North Sea. This has implications regarding the cost level and cost changes between these two regions. The unit cost level at the Norwegian Sea is higher than the average in unit cost scenario 2. The costs of explore, develop and produce the undiscovered resources in the Norwegian Sea are 58 % of the total costs of the sea are. The total remaining resources at the Norwegian Sea are slightly less than the total remaining resources at the Barents Sea. The Barents Sea has much more undiscovered resources than the Norwegian Sea while the Norwegian Sea got more discovered resources and resources in production. This has an impact when the unit costs increase differently. The cost of exploring the undiscovered resources is lower than the cost of developing discovered resources. The development phase is the most expensive one for the North Sea. This indicates that this is the phase where the need for technology improvement is most important

Barents Sea	Million barrels o.e.	Exploration cost in million USD	Development cost in million USD	Production cost in million USD	Total investment in million USD
Unit cost per barrel o. e.		8,00	14,00	9,00	31,00
Resources in production	1 562			14 062	**14 062**
Discovered resources	1 510		21 134	13 586	**34 720**
Undiscovered resources	8 806	70 446	123 280	79 252	**272 978**
Sum	**11 878**	**70 446**	**144 414**	**106 899**	**321 759**

Barents Sea	Million barrels o.e.	Exploration cost in million USD	Development cost in million USD	Production cost in million USD	Total investment in million USD
Unit cost per barrel o. e.		10,40	18,20	11,25	**39,85**
Resources in production	1 562			17 577	**17 577**
Discovered resources	1 510		27 474	16 982	**44 456**
Undiscovered resources	8 806	91 580	160 264	99 065	**350 909**
Sum	**11 878**	**91 580**	**187 738**	**133 624**	**412 942**

Table 10 Need for investments per stage with different unit costs per barrel of oil equivalents in the Barents Sea

For the Barents Sea, the first cost scenario results in an investment at USD 321.8 billion and in the second cost scenario USD 412.9 billion. This is a cost increase of USD 91.2 billion. Most of the resources in the Barents Sea are undiscovered resources (74 %). This is the main reason for the total investment needed exceeds the North Sea in the second price scenario. It can be argued that there are several factors that make it likely that the cost per barrel of oil equivalent is higher in the Barents Sea than in the other two regions. The geological conditions at the Barents Sea are not as much examined, thus increase the risk of dry drilling. Other factors include long distance to the marked, development of new infrastructure and political concerns regarding pollutions in vulnerable areas. There are only two oil and gas fields in production, namely Goliat and Snøhvit (NPD 2016 a). This makes it difficult to estimate the average costs at the Barents Sea as a whole. Snøhvit produces gas, but not oil and Goliat is a quite small oil field. The Snøhvit field exceeded its estimated investments by NOK 46.4 million in 2014 numbers, an increase of 49.5 % (Skarskaune 2014). This makes it difficult to estimate the future need for investment at the Barents Sea and might hinder investments from oil and gas companies. There are likely that there is more gas than oil in the Barents Sea. This is also a distinction from the other two regions.

The announcement of the 23rd licensing round was announced 18.05.16 (Ministry of Petroleum and Energy 2016 a). This announcement awarded 40 blocks in the Barents Sea to 13 oil and gas companies. Many of the awarded companies are small and medium sized companies. This might be a signal that larger oil and gas companies do not find the Barents Sea to be economically attractive enough compared to other region in the world.

	Norwegian Continental Shelf			
	Cost increase in percent	Intital in million USD	Increased cost in million USD	Differences in million USD
Production	5 %	430 040	451 542	21 502
Development	10 %	481 616	529 777	48 162
Exploration	15 %	146 930	168 969	22 039
Total		**1 058 585**	**1 150 289**	**91 703**

Table 11 Increase in investments in NCS with different increase in unit cost per category

Table 11 presents the results from the third price scenario. The effect of an increase in the production costs of 5 %, 10 % increase in development costs and 15 % increase in exploration costs are described. This will increase the total need for investment in NCS by USD 91.7 billion to USD 1 150.3 billion. There are several factors that explain the different percent rate. Exploration cost is set at USD 8 per barrel of oil equivalent by Rystad Energy. An increase of 15 % gets a cost at 9.2 per barrel of oil equivalent. There is an issue regarding to set a per barrel of oil equivalent on extraction because the cost of wild cat drilling is the same independent of finding resources or not. With a success rate at 50 % the last 10 years in the NCS (NPD 2016 a) this means that for each barrel found at a cost of 4 USD there is a cost of USD 4 used at a wildcat drilling without any discovery of resource. A discovery rate of 50 % is high and it will be difficult to maintain this success rate in the future. Due to this uncertainty it might be more likely that exploration costs will increase more than production and development costs. Another factor is that highly prospective areas are explored first, thus the exploration has to move to less prospective areas which also tend to be more difficult to explore (Bhattacharyya 2011).

The plunge in the oil price has affected the exploration activities more than development and production activities. This is because the level of exploration activities have been reduced significantly, thus there have been fewer drillings. If the price reaches USD 90 per barrel of oil equivalent, the exploration activities and drillings will increase again. This might lead to less technology development to reduce costs while the oil price is low and then costs might increase more than other costs if the price increases. With the low oil price, more development activities will be performed in areas close to existing infrastructure instead of new areas. This will reduce the costs in the short run, but might increase the costs in the future. Production costs cannot easily be reduced in situations with low oil price. Technology, standardization and processes that reduce costs might thus be implemented to be effective in the future and not only when the resource price is low.

		North Sea		Norwegian Sea		Barents Sea	
	Cost increase in percent	Intital in million USD	Increased cost in million USD	Intital in million USD	Increased cost in million USD	Intital in million USD	Increased cost in million USD
Production	5 %	222 479	233 603	100 670	105 704	106 899	112 244
Development	10 %	215 375	236 912	121 534	133 687	144 414	158 855
Exploration	15 %	37 487	43 110	38 997	44 846	70 446	81 013
Total		**475 341**	**513 625**	**261 201**	**284 238**	**321 759**	**352 112**

Table 12 Increase in investments for each region with different increase in unit cost per category

Increase in the need for investments for each region according to cost scenario 3 is presented in table 12. In this scenario the North Sea got a need for investment at USD 513.6 billion. The Norwegian Sea got a need for investment at USD 284.2 billion and the Barents Sea a need for investment at USD 352.1 billion. The development cost increase more than the increase in production costs and exploration costs for each region. The cost increases have other effect on each region. The increase in the total need for investment is largest at the North Sea even though it is exploration costs that got the highest percent increase. This is because of the large amount of resources in production and discovered resources at the North Sea. The lowest increase in investment needed is for the Norwegian Sea. This can be seen as natural since the area has the least amount of resources left. However, it is worth mention that the Norwegian Sea got slightly more undiscovered resources than the North Sea, but this does not influence the overall result. Undiscovered resources first have to be explored and then developed and produced. Due to the fact that the Barents Sea has the largest amount of undiscovered resources, this also mostly influences the Barents Sea.

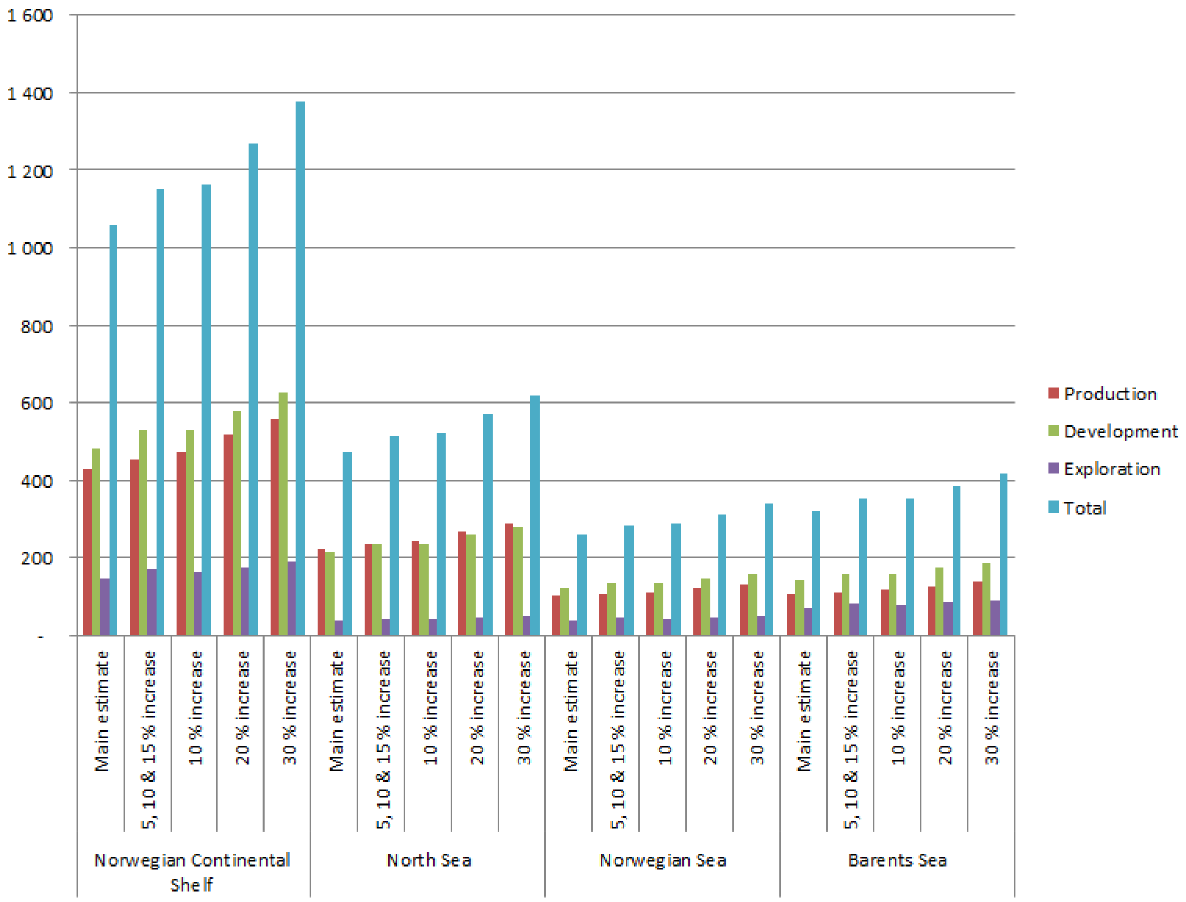

Figure 10 Increase in investments with five unit cost scenarios in billion USD

The graph in figure 10 presents the five different investment scenarios for NCS overall and for each of the three regions. The initial cost scenario and the 5-10 percent costs scenario are presented earlier. A cost increase of 10 percent per barrel of oil equivalent, will increase the total investment in the NCS to USD 1 164.4 billion. The numbers for 20 percent and 30 percent increase are USD 1 270.3 billion and USD 1 376.2 billion respectively. Future estimates of investment is by nature unsecure, thus it is applicable to describe exceeds in estimated costs. There are several examples of development of oil and gas fields costs that exceeded the initial budget. Between 2007 and 2012 the total investment exceeded NOK 49 billion (Lindeberg 2013). Three of the 24 projects accounted for the majority of this excess. This is a major concern for the oil and gas industry. The risk for exceeding development costs is important for the Norwegian Government as well due to the tax system where the investment is tax-deductible.

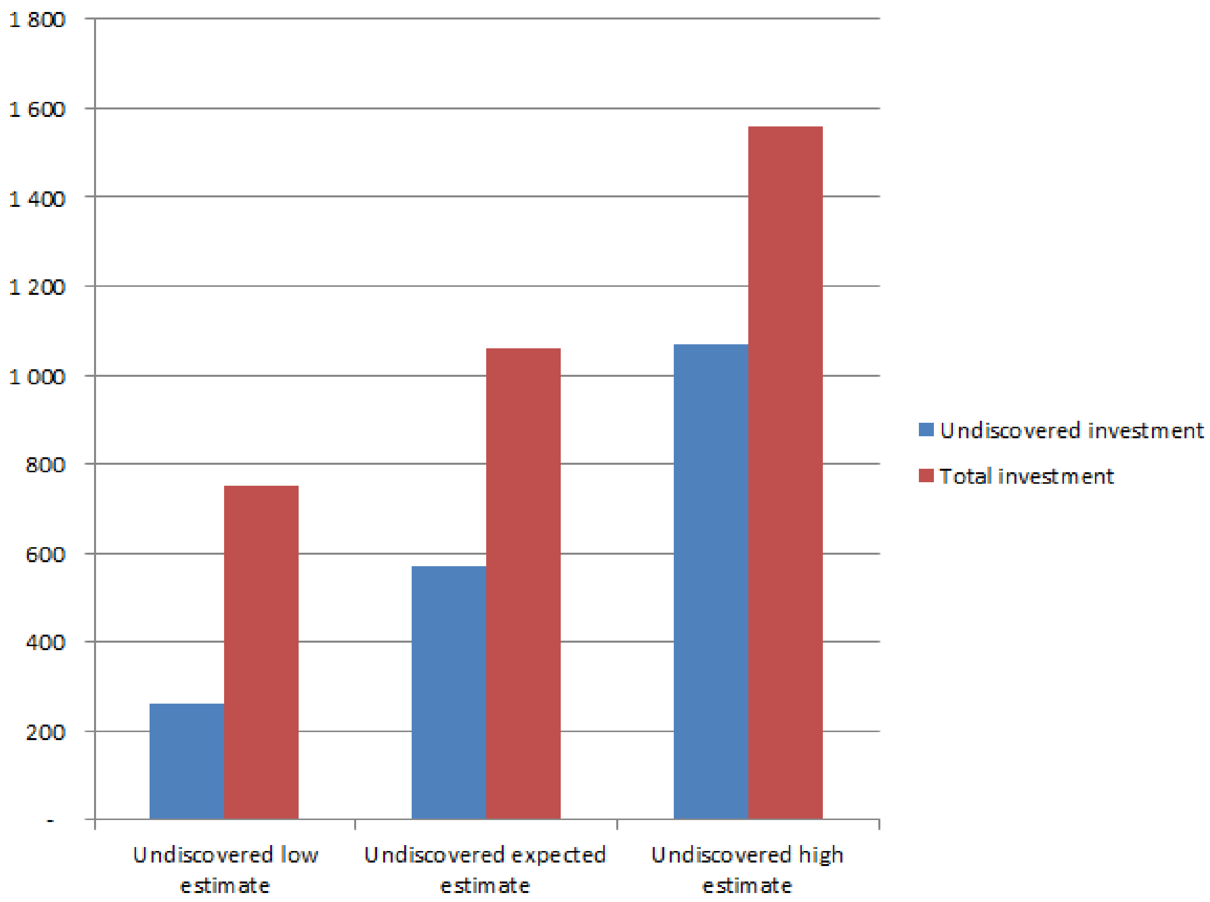

Figure 11 Need for investments according to main cost estimate for the three undiscovered resources estimates in billion USD

The undiscovered resources are very uncertain. According to NPD (2016 b), the estimates are between 1 350 (P95) and 5 490 (P95) millions standard cubic metres of oil equivalents. The final outcome of the size of the undiscovered resources will have a large impact for the total need for investment. The costs of explore, develop and produce these resources are then estimated to be between USD 263.2 billion and USD 1 070.5 billion. The expected estimate from the NPD is USD 569.4 billion. The total needs for investment of the remaining resources are between USD 752.5 billion and USD 1 559.7 billion. There are some obstructions for the industry in addition to the significant investment needed to be able to extract and produce all these resources. The drop in the oil price since 2014 is by nature an important factor. In their analysis, NPD (2016 b) has used an estimated future oil price at USD 90 per barrel of oil equivalent. This price can be perceived as far away when today's oil price is around USD 48 per barrel of oil equivalent, even though the price has increased from USD 30 per barrel of oil equivalent in the start of January 2016 (Nasdaq 2016). This uncertainty makes it more risky for the oil and gas companies to invest.

To explore, develop, and produce oil and gas resources are more expensive in the NCS than in many other areas. This is a challenge for the oil and gas industry and the Norwegian economy. Multinational oil companies will always try to maximize their expected profits and the high cost level in Norway might be a significant disadvantage. It is important for NPD to encourage new explorations. There are many different oil and gas companies in the NCS. The Norwegian tax system has been a part of the reason for the increase in oil and gas companies. Small companies are likely to accept higher risks when exploring, especially in new and uncertain areas such as the Barents Sea.

The future value of the remaining resources is significant dependent on the future oil prices. There are reasons to believe that NPD in their estimation of the remaining resources take too little account on the prices and too much a geological constrains. If the price is lower than the costs, the resources will stay in the ground regardless of how much there are left. There will be an increasing “battle” between technology and costs in the future. According to Lindholt (2013) the costs have exceeded the technology the last decade. However, there were indications the costs could stay at present level or even decrease in the future. Future will see if the cost-reduction technology will be enough to keep up with the increasing costs of producing resources in deeper and more difficult areas.

Another issue is that if most of the remaining resources are in many small pockets, the likelihood for an economically valuable development and production of these resources are small. The shift to more environmental friendly energy sources might as well be issue in the future.

The oil companies have a total tax of 78 % in Norway. 28 % is the normal company tax and an extra oil-tax of 50 %. Cost of exploring is deductible for the oil companies. According to NPD, exploration the 10 last years resulted in a 50 % discovery rate. This is high in an international perspective according to NPD. However, in the following estimate, it is estimated a future discovery rate at 50 %. According to previously estimate, there is about 18.4 billion barrels of oil equivalents resources that are not discovered in the NCS. With the future estimated oil price at USD 90 per barrel of oil equivalents, the total value of the undiscovered resources is USD 1 653.0 billion. It is important to mention that even gas is large part of the resources; to simplify the estimation the value is estimated by the use of the oil price only and not the gas price. With a cost of USD 23 per barrel of oil equivalents to develop and produce theses resources, gives a cost of USD 422.4 billion. This gives a NPV of

USD 1230.5 billion. The exploration cost is USD 9 per barrels of oil equivalents. Thus we can use equation 5 to get the expected monetary value (EMV).

$$EMV = \mathrm{P} \times \mathrm{NPV} - \mathrm{E} \qquad 3)$$

$$EMV = P \times NPV \times (1 - SP) - E(1 - SP) \qquad 5)$$

A total cost per barrel is estimated to 31 minus exploration cost at USD 9 per barrel will then give this EMV:

$$EMV = 0{,}5 * (18.4\ billion\ barrels * (USD\ 90 - 23) * (1 - 78\%) - 9 * 18.4\ billion * (1 - 78\%) \qquad 8)$$

$$EMV = USD\ 99.0\ billion \qquad 9)$$

In NPDs resource report 2016, NPD analysed the value of the discovered resources between 2000 and 2014 (NPD 2016 b). The overall resource estimate for the whole period was 8.62 billion barrels of oil equivalents. The exploration costs were estimated to be NOK 316.66 billion (2014 numbers). This is approximately USD 39 billion with a currency rate at 8.13 (Norges Bank 2016). The net present value was estimated to be NOK 1942.5 billion in the same period. This is USD 239.0 billion when converted. These results are interesting and relevant to the work in this thesis. This papers work estimates a net present value of USD 954 billion for the discovered resources (category 2-5 and 7). This means a difference in the two results at USD 715 billion. This is a large difference, but might be explained by the differences between the two. The main focus in this paper is the overall need for investment while in the NPDs report was the net present value in the specific period 2000 – 2014. The total costs are not mention in the report, only the exploration costs. This makes it difficult to compare the results directly. The cost level used in this thesis is estimated future unit cost per barrel of oil equivalent. Production and costs in the NPD report are estimates reported by the operators. An expected future oil price at USD 90 per barrel of oil equivalents is assumed in both analyses, however, this thesis had to simplify and have thus not used the gas price. This is relevant due to the fact that a large part of the resources are gas.

NPD (2016 a) have estimated the total investment for the years 2016 to 2020. Exploration, development and production costs are estimated to be NOK 204.4 billion (USD 25.2 billion) in average per year. This is significant less than in the top year of 2013 with around NOK 288 billion (USD 35.4 billion). With an overall need for investment at the NCS at USD 1 058.6 billion at a yearly investment at USD 25.2 billion, it will be 42 years of investments. With the expected decrease in production from figure 14, it might be difficult to maintain such a large yearly investment. On the other hand, there are also uncertainties regarding how many years it will take to produce and sell all of the oil and gas resources. With an average of 1 million barrel of oil equivalents produced per day, the resources will last for 67 years with the main resource estimate (Carstens 2014). If the maximum estimate of remaining resources is used, this increases the years of production to around 100. With 67 years of production this means a yearly investment of USD 15.8 billion which might seems more likely. 100 years of production reduce the yearly investment to USD 10.6 billion.

The petroleum production in the NCS in 1989 was at the same level as in 2013. However, in 1989 there were only 15 oil producing fields and in 2013 there were 72 oil producing fields (Carstens 2014). This trend with more, but smaller fields might result in the future need for investment to be larger than the estimate in this paper. On the other side, technology progress will decrease the costs. This includes new technology that improves residual potential in ageing fields. According to Statoil (2016), global GDP in 2040 will be more than twice that of the level in 2013 with an average global economic growth in the range of 2.6% to 2.9% per year. New energy sources are expected to be a large part of the increase in the future energy demand. However, Statoil (2016) expect an increase in the world's oil demand at 0.4 % and an increase in the world's gas demand at 1.1 % from 2013 to 2040 in their medium (reform) scenario. This results in a significant need for new investments globally, both in oil and gas, since production from existing reserves is not even close to keeping up with demand development (Statoil 2016). This highlights the need for technology development, the importance of willingness to invest and a stable political framework. Technology progress will be important not only to control the cost, but also to be able to trigger investment in fields that would be unprofitable otherwise. However, slow progress in the technology development might postpone and even stop investment in many fields.

5.2 Resource life and resource rent

New discoveries have to be equal or larger than the production to be economically sustainable. There where discoveries of 187 million barrels of oil equivalents and a production of 1 448 million barrels of oil equivalents in 2015. Thus, the production was higher than new discoveries in 2015. This means that the remaining resources shrink from 17 296 million barrels of oil equivalents in the end of 2014 to 16 035 million barrels of oil equivalents in the end of 2015. NPD (2016 b) states that it is important with increased exploration activities to be able to ensure enough new discoveries. Figure 12 shows that since 1990, there have been only five years where discoveries have excessed the production. Figure 13 shows that this has resulted in a downward sloping resource life curve.

$$R_{(t+1)} = R_t - P_t + D_t \qquad 7)$$

$$R_{2016} = R_{2015} - P_{2015} + D_{2015} \qquad 10)$$

$$R_{2015} = R_{2016} + P_{2015} - D_{2015} \qquad 11)$$

$$R_{2015} = 16\ 035 + 1448 - 187 = 17\ 296 \qquad 12)$$

$$r = \frac{R_t}{P_t} \qquad 6)$$

$$r_{2015} = \frac{R_{2015}}{P_{2015}} = \frac{17\ 296}{1\ 448} = 11.9\ years \qquad 13)$$

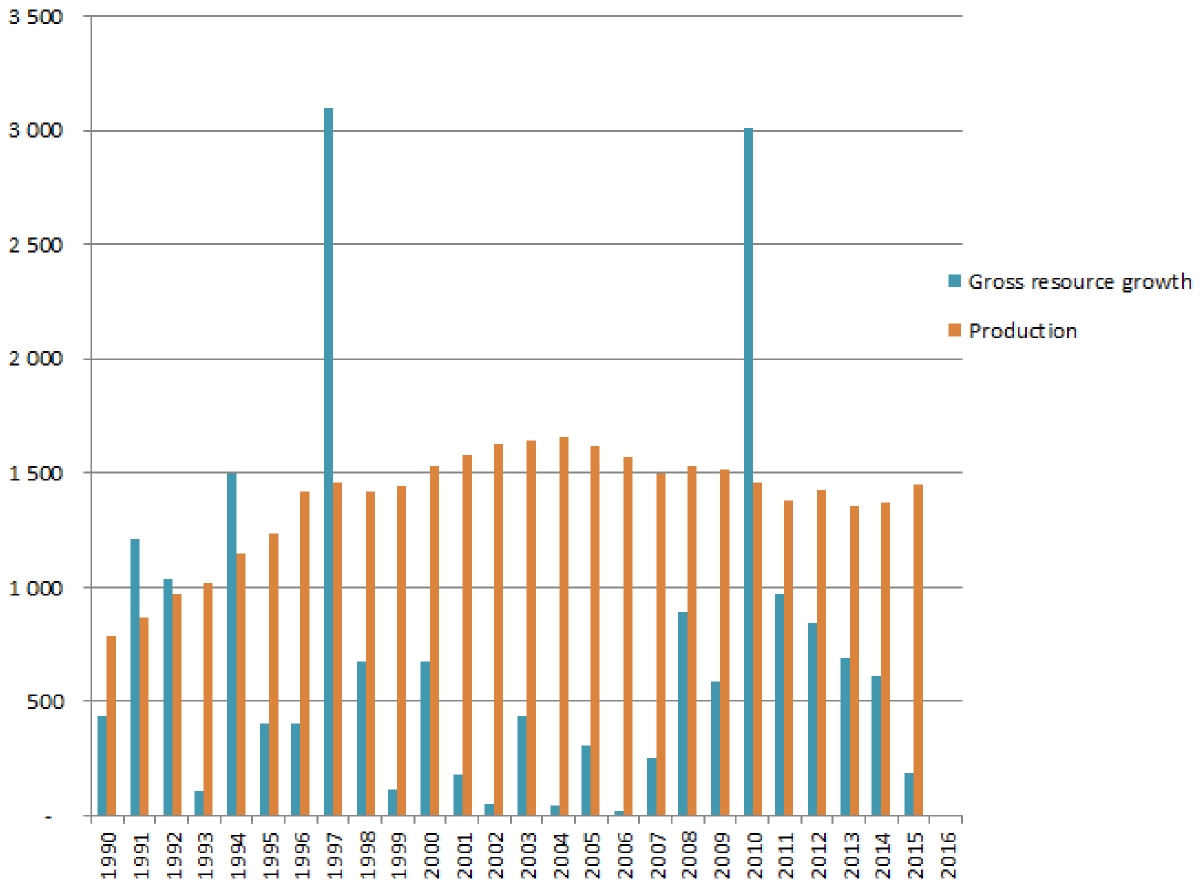

Figure 12 Resource growth versus production in million barrels of oil equivalents (NPD 2016 a)

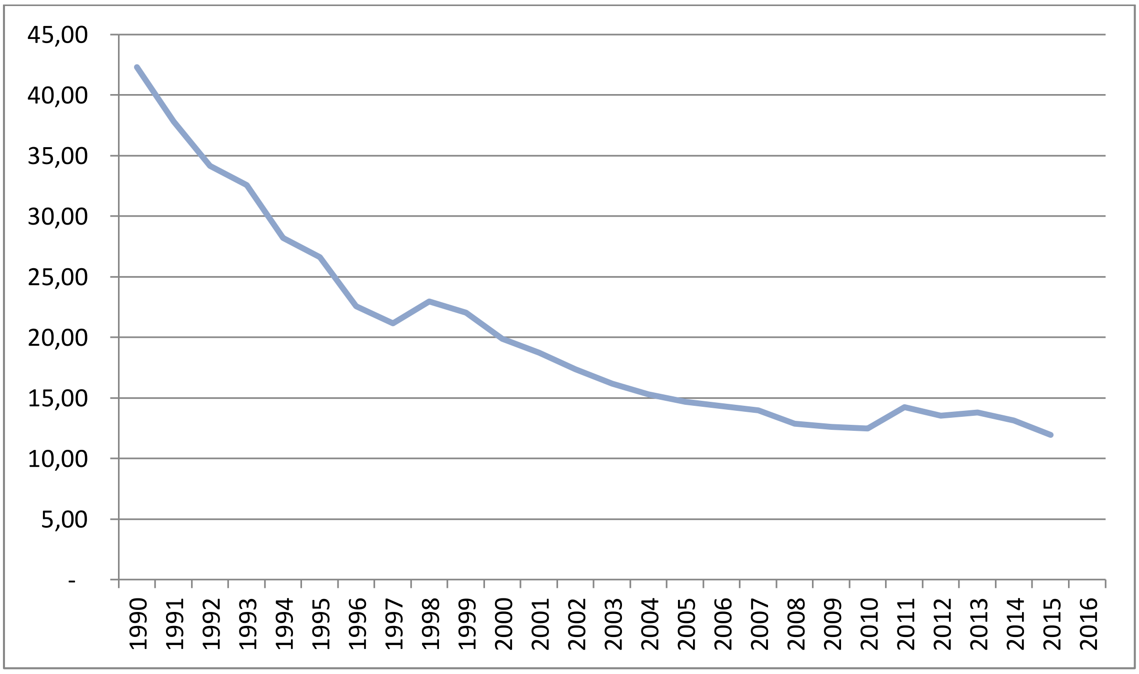

Figure 13 Resource life in years (NPD 2016)

The marginal rent of each barrels extracted in period t equals the discounted rent of the marginal barrels extracted in the next period. The differences between the remaining stock in 2016 and 2017 gives the stock produced in 2016. The estimated total resources left included estimated and undeveloped resource in the start of 2016 was 89.5 billion barrels of oil equivalents. The optimal extraction of production in 2016 reduces the resources left in 2017. This is executed from year to year. The optimal extraction from each year gives the optimal profit overall, see equation. This is because to ensure optimal profit, the marginal rent has to be equal in all periods.

The estimated future price that is used is USD 90 per barrel of oil equivalent. The gas price is not added to this estimation since it would make the estimation too complex. The costs used to get the results are divided in three. This is due to the different categories the resources are in. Resources that are in category 1 is set to have a cost of USD 9 per barrel of oil equivalents since these resources are already developed and ready to be produced. Resources in category 2-5 and 7 is set to have a cost of USD 23 per barrel of oil equivalents since these resources have to be developed before it can be produced. The estimated resources are set to have the cost of USD 31 per barrel of oil equivalents since it has to be explored, developed and produced. The resources are then set to be extracted with the cheapest (category 1) resources first followed by the next cheapest and in the end the most expensive resources. Rystad Energy has estimated the future oil and gas production in the Norwegian Continental Shelf until 2040. The estimated production until 2040 can be seen in figure 14.

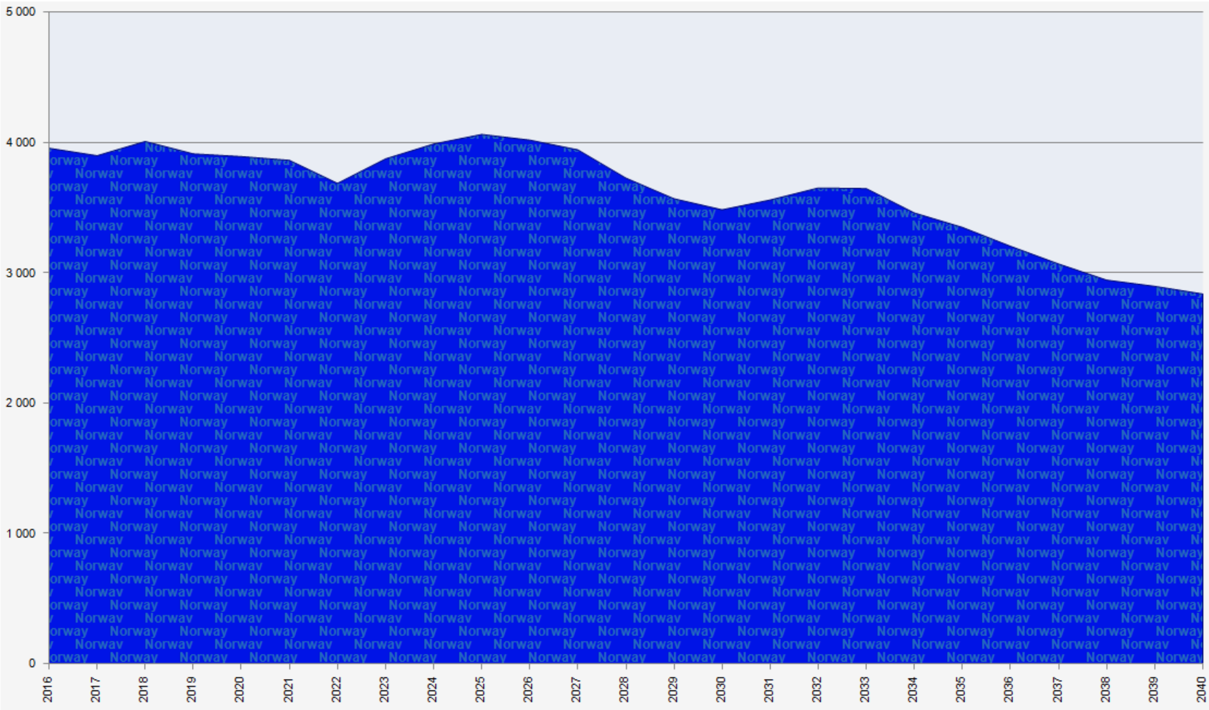

Figure 14 Petroleum production in 1000 barrels per day between 2016 – 2040 (Rystad Energy, UCubeFree 2016)

Figure 15 Resource rent at the NCS between 2016 – 2039 according to expected production from Rystad Energy

6 Conclusion

The main objective of this thesis work was to estimate the future investment requirement to extract the remaining oil and gas resources in in the NCS. The petroleum resources and the petroleum industries have been and are important for Norway. The income from the resources has been substantial and the industry has developed to be the largest industry in the country.

NCS consist of the North Sea, the Norwegian Sea and the Barents Sea. NPD (2016 b) estimate the remaining resources in the NCS to be 7.6 billion standard cubic metres of oil equivalents. This is converted to 47.8 billion barrels of oil equivalents due to the fact that oil is sold in barrels of oil equivalents. NPD's classification system has been used to split the remaining resources in three categories. Category 1 is oil and gas resources that are in fields that is producing and contains 13.4 billion barrels of oil equivalents. There is 16.0 billion barrels of oil equivalents that is discovered, but is not in production (categories 2-5 and 7). There are petroleum resources in the range between 8.5 and 34.5 billion barrels of oil equivalents that are still to be discovered according to estimates from NPD (2016 b). The expected estimate is 18.4 billion barrels of oil equivalents in category 8 and 9. NPD (2016 b) also estimated that about half of the remaining resources are gas. To be able to explore, develop and produce these remaining petroleum resources, there are significant needs for further investments.

Chapter 3 introduced the economic decision-making tools for supply of petroleum resources and presented some aspects that affect their supply. Decision making related to exploration and development faces considerable uncertainty related to issues such as the existence of the resources, the size, quality and the future of markets and resource prices. The petroleum industry is also concerned with depletion and the need for discoveries of new reserves to maintain a desired resource life. Non-renewable resources such as oil and gas differ from reproducible goods because there is a fixed stock of reserves that cannot be replaced if removed and used. Thus, one unit used today means one less unit available for extraction tomorrow. The economic theory of extraction explains the flow of production of resources over time and how quickly the resources stock is exhausted.

Chapter 4 described the method used to get the results in this thesis. Information of the remaining resources is collected from the NPD. The resources are converted to barrels of oil equivalents. The unit cost per barrel of oil equivalents for moving the resources from one stage in the process to the next is based on estimates from Rystad Energy. Different unit cost scenarios are described to get a better understanding of the need for investment.

The results from the work of the paper where presented in chapter 5. The main cost scenario from Rystad Energy gives the estimated total need of investment. Other cost scenarios where presented to show how different costs between the three region affected the overall investment, each of the region and the differences between them. The estimate regarding undiscovered resources is unsure. To show how this affected the need for investment at the NCS, the lowest and highest estimate where presented together with the expected estimate. Results regarding resource life ate the NCS and the resource rent was described in the end of this chapter.

The conclusion of this paper estimates the total need for further investment in the NCS to be USD 1 058.6 billion. The estimated need for investment at the North Sea is USD 475.3 billion. The Norwegian Sea is estimated to have a need for investment at USD 261.2 billion and the Barents Sea to have USD 321.8 billion. In unit cost scenario 2 where the unit costs in average is the same as the main estimate, but each region got different costs, these results change significantly. The Barents Sea will then have the largest need for investment with USD 412.9 billion. This is slightly higher than at the North Sea with USD 391.4 billion. The Norwegian Sea has the lowest estimate in this scenario too with USD 282.2 billion. One reason is due to the likelihood of the Barents Sea to have higher costs per barrel of oil equivalents related to the other two regions. Another important issue is the large part of undiscovered resources at the Barents Sea. In the third cost scenario, the unit costs per barrel of oil equivalents where increased at different level for each stage in the process. In the cost scenario three described how a different increase in the costs at different stages affected the total costs and the costs for each region. The increase was set to be 5 % in production costs, 10 % in development costs and 15 % in exploration costs. The total need for investment in the NCS then increased to USD 91.7 billion to USD 1 150.3 billion. In the cost scenarios 4-6, the unit costs were increased by 10 %, 20 % and 30 %. This increased the total need for investment at NCS to USD 1 164.4 billion, USD 1 270.3 billion and USD 1 376.1 billion respectively. Another important issue is the undiscovered resources. With the lowest estimate of undiscovered resources, the estimated needs for investment in NCS are USD 263.2 billion. With the use of the largest estimate of the undiscovered resources, the investment increases to USD 1 070.5 billion USD. This changed the overall need for investments in the NCS to be between USD 752.5 billion and USD 1 559.7 billion.

There are many uncertainties regarding this estimate. Undiscovered resources are by nature unknown. Resources that have been discovered are uncertain and cannot be known before it is produced and sold. The unit costs are estimated in USD per barrel of oil equivalent by Rystad Energy. These costs are estimates based on historical cost level from fields in the NCS and future costs are very uncertain. An addition, even a small variation at these estimates will result in a significant change in the need for investment. Further research and analysis of the need for investment might focus on getting more precise future estimated costs. The differences between each region might also be important for further research. Disposal and cessation costs are not taken explicit into this research and might be an issue for another study. There might be a distinction between the need for investment between oil and gas which neither has been accounted for in this research. In the work of this thesis, there were made a general and overall view. To get more accurate results, the costs of explore, develop and produce each of the fields have to be performed.

To provide a framework is the overall objective of Norway's petroleum policy (NPD 2016 a). This framework shall ensure a profitable production of oil and gas in the long term and that the value of the petroleum resources shall benefit the Norwegian society as a whole. The results from this paper have quantified the investment which makes the need for investment more tangible. To know how much investment that is needed to extract the remaining oil and gas resources is important to ensure stable investment in the future.

The results might be used by oil and gas companies to get a better understanding of the prospects of the industry. This includes the overall need for investment and how increase in the cost level affects the overall need for investment. Companies that consider the outlook of NCS might find these results interesting because it gives them more knowledge about the differences between the cost levels at the three regions. The results also highlight the costs of moving the resources from one category to another which should be important to the industry. Another aspect is how the cost sensitivity differs between the categories.

Investment in the oil and gas sector at NCS cannot be used to invest in another area, such as renewable industry. Thus, the results might be an input to a political discussion regarding how investment overall in the Norwegian economy should be distributed.

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