Universitetet
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FACULTY OF SCIENCE AND TECHNOLOGY

MASTER THESIS

Study programme/specialization: Industrial Economics. Finance and Risk Management	**Spring semester, 2018**
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Faculty supervisor:
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Title of master thesis:
Over Budget, Over Time, and Reduced Revenue, Over and Over Again – An Analysis of the Norwegian Petroleum Industry's Inability to Forecast Production

Credits: 30

Keywords: Estimates Overruns Production Bias Vale erosion Reference Class Forecasting	Number of pages: 110 +supplemental material/other: 0 Stavanger, 14.06.2018.

Acknowledgement

Working on this paper has been both interesting and rewarding. I have been challenged on an interdisciplinary level and pressured to use insight across subjects that I have studied throughout my five years in Stavanger, and abroad. I would like to thank professor Reidar B. Bratvold for the opportunity to take part in this study. His knowledge and insight in cognitive psychology and decision analysis have been especially rewarding. I addition, I would like to thank The Norwegian Petroleum Directory for providing data and insight along the way. I hope that my research can help the petroleum industry to realise their flaws, and that further research can help maximize the benefit from our petroleum reserves in the coming years.

This thesis sums up my five years at UiS. I would like to thank all fellow students and friends, both in Stavanger and elsewhere in the world. The international experience and friendships that I have gained though my stays in Adelaide and Milan will never be forgotten, and I sincerely hope that I will stay in touch with all of you, as well as my Norwegian classmates.

Abstract

It is a well-known fact that many projects on the Norwegian Continental Shelf (NCS) have been completed with cost overruns and schedule delays. Similar cost- and schedule deviations have been documented in other industries, leading professor Flyvbjerg of Oxford University to propose the following “iron law of megaprojects”: “Over budget, over time, over and over again”. Not surprisingly, such overruns are eroding the economic value of the investments.

As opposed to time- and cost slippages, production forecasts have yet to be the focus of a major study. Drawing from the Norwegian Petroleum Directorate’s (NPD) database, production forecasts given at project sanction (DG3) for 56 fields approved between 1995 and 2017 have been compared to actual production. NPD’s guideline specify that estimates should be given as P10-Mean-P90 numbers. The purpose of this study is to investigate whether the industry is better at forecasting production than they are at forecasting time and cost. Secondly, economic consequences and value erosion resulting from not reaching budgeted goals is examined. Finally, a proposed method for debiasing estimates will be presented.

To analyse estimates, overruns related to three parameters are addressed, and the results as follows:

- **Cost:** On average, the industry overrun their estimated development cost by 25 percent. For 68 fields where cost data has been collected, the total overrun is 213 billion 2017-NOK.
- **Schedule:** 42 development projects on the NCS have an average delay of 202 days, equal to overrunning estimated time schedule by 26 percent. The economic consequence of delayed startup in 56 fields is a value erosion of 61 billion 2017-NOK.
- **Production:** Data for 56 fields on the NCS show that they fail to live up to their production rates forecasted at project sanction. Less than 1/3rd of projects deliver rates inside their estimated 80 percent confidence interval, indicating a clear tendency to overestimate rates. The economic consequence of underproduction accrues to about 200 billion 2017-NOK, equal to a 17 percent loss of estimated revenue.

An estimate of the total value erosion from not delivering on budgeted performance accrues to *474 billion 2017-NOK*. Expanding the dataset to include *all fields* in- and outside the time span, would likely increase the lost value. For a field on the NCS that started production two months before schedule, and had average cost overrun and underproduction, profit was reduced by 23 percent.

Further, we discuss why the industry over the past 20 years, despite the introduction of large simulations and big data, has not improved its ability to predict outcomes. Research from international industries is introduced and related to this work. The most important bias that impact estimates are introduced and discussed. Human bias in this context can be grouped in two categories: delusion and deception. Based on earlier research, the effect of bias is evaluated, and examples from the NCS on how the industry delivers biased estimates is presented.

Books by Silver (2012) and Tetlock & Gardner (2015) reveal that superior understanding of probabilities and the ability to think probabilistically are common characteristics of well calibrated forecasters. This paper focuses on the historical performance of forecasters in the petroleum industry, and how we can use the outcome of their estimates to debias future predictions.

Based on the research of Kahneman and Tversky (1979a, b) Prof Flyvbjerg and his colleagues introduced Reference Class Forecasting (RCF), and how uplifts from probability distributions of outcomes can be used to adopt an outside view of a project (Flyvbjerg & COWI, 2004). Results show that using reference classes to adjust forecasts for projects on the NCS will increase the understanding of probabilities and risks and hence, also the ability to deliver debiased estimates.

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1 Introduction

1.1 Goal

This thesis is based on a hypothesis that falling short of expected production rates result in value erosion. To confirm or disconfirm the hypothesis, estimated production at project sanction for Norwegian oil and gas fields has been compared to actual production.

Cost- and schedule overruns on the Norwegian Continental Shelf (NCS) have been examined in earlier publications (NOU1999:11, 1999; Rystad Energy, 2013; NPD, 2013; EY, 2014; Taraldsen, 2015; Haukaas & Mohus, 2016). This paper wants to highlight the economic consequence of biased estimates, by addressing the total present value (PV) lost due to cost- and time overruns, as well as falling short of expected production rates. Based on the results, estimates that the plan for development and operations (PDO) approvals are based on will be addressed. We then turn focus over to why the industry fail to meet their budgets, and what factors that affect us when we try to estimate future outcomes. Further, a procedure for debiasing estimates is presented. The goal is to develop a standard procedure for the Norwegian petroleum sector that improves the understanding of risks related to estimates, and to maximize future benefit from the Shelf.

1.2 Background

Budget overruns on the NCS have been subject for several public and private research projects (NOU1999:11, 1999; Rystad Energy, 2013; NPD, 2013; EY, 2014; Taraldsen, 2015; Haukaas & Mohus, 2016). The conclusion has always been the same; Development projects on the NCS fail to live up to their estimated cost and time. Budget overruns passed 200 billion NOK in 2015 values (Taraldsen, 2015). For cost, both estimates and actual outcomes are publicly available. For production and time, outcomes are publicly available, while estimates are not. Drawing from the NPDs database, this thesis analyses production forecasts given at project sanction. The purpose is to investigate whether the industry is better at forecasting production than they are at forecasting time and cost, as well as to assess any economic consequence of poor forecasts.

1.2.1 Haukaas & Mohus

Haukaas & Mohus delivered in 2016 a bachelor thesis in Petroleum Economics at the University of Stavanger. Their paper analysed cost- and time overruns for projects sanctioned from 1992 to 2015 and looked for links between overruns and other factors that might influence projects. Their research was based on cost data for 78 fields, and reserves data from 66 fields. It showed that:

- The total overrun in the period was 231 billion 2015-NOK, corresponding to overspending budgets with 25 percent.
- There is no correlation between increased development costs and increased producible volume. In other words, budget overruns cannot be explained by increased estimated revenue.
- The relative cost overrun in megaprojects[1] is almost twice as big as in smaller projects. Bigger projects have a negative correlation between increased costs and increased producible reserves, which means that they have a larger exposure towards profit loss.
- Developments where the EPC-contract[2] for topside was given to Asian yards had a time overrun more than six times longer than those given to Norwegian yards. The relative cost overrun was more than doubled.
- 85 percent of the fields included in the analysis had cost overruns, indicating that estimates given in the PDO are biased. Overruns are present across the entire period, and although overruns have been subject of several reports and research projects, the operators on the NCS do not seem to have the ability, nor the will, to learn from their mistakes.

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[1] Megaprojects is by Ed Merrow defined as projects with costs higher than 10 billion NOK (2011a)

[2] EPC-contracts is an abbreviation for a contract that includes engineering, procurement and construction of an installation. It will be further discussed in chapter 2

1.2.2 Ferruh Demirmen

Ferruh Demirmen has published several papers discussing forecasts and how the industry fails to estimate producible reserves (2007; 2005). His papers look at total expected production over time, and the results, illustrated in Figure 1, show that estimators tend to increase expected total production volume as fields mature. Demirmens research include data for 15 Norwegian fields in the period 1974 through 2003. Another analysis, encompassing 38 oil and gas fields on the NCS, show that their estimated reserves had an average growth of 30 percent from 1997 to 2003. Although reserve forecasts seem to increase, Demirmen concluded that fluctuation in estimated reserves lead to reduced profit (2005, p. 8).

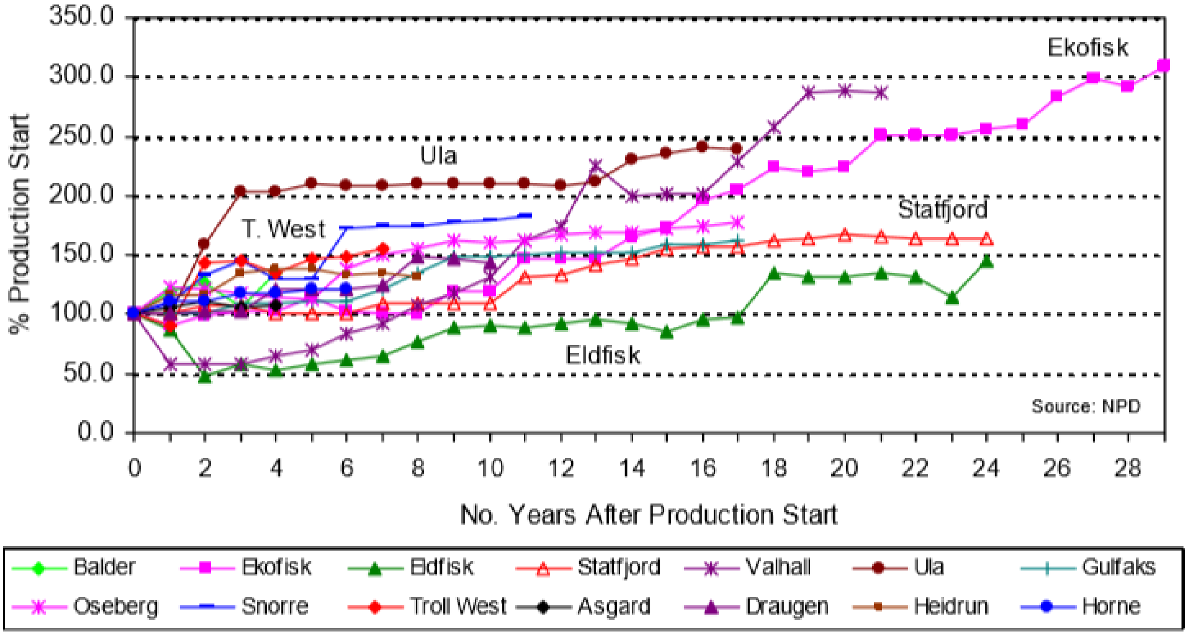

Figure 1: Development in production estimates on the NCS (Demirmen, 2008).

Demirmens research is interesting, but not directly comparable to the analyses presented in this paper. An average field on the NCS produces hydrocarbons for about 15 years before it is shut down. During this period, new technology, innovations and investments will affect the producible volume. The focus of this paper is to discuss the decision that is taken when approving the PDO for the initial development project, and the estimations and predictions that this approval is based on. Investments affecting production at a later point in time is therefore irrelevant, as it was not known or taken account for at the time of the initial PDO approval.

1.2.3 Nandurdikar & Wallace

In a study from 2011, Nandurdikar & Wallace used data developed and maintained by Independent Project Analysis (IPA) Inc. to show that in 1995, petroleum projects delivered on average 94 percent of planned production. When publishing the paper, they only delivered 75 barrels of oil for every 100 barrels promised at sanction. Their analysis, based on 147 projects, show that unreliable forecasts based on optimistic subsurface assumptions is one of the main reasons for the poor production attainment (Nandurdikar & Wallace, 2011). Furthermore, they show that historical experience is significantly different from expectations and skewed to overoptimism, as illustrated in Figure 2.

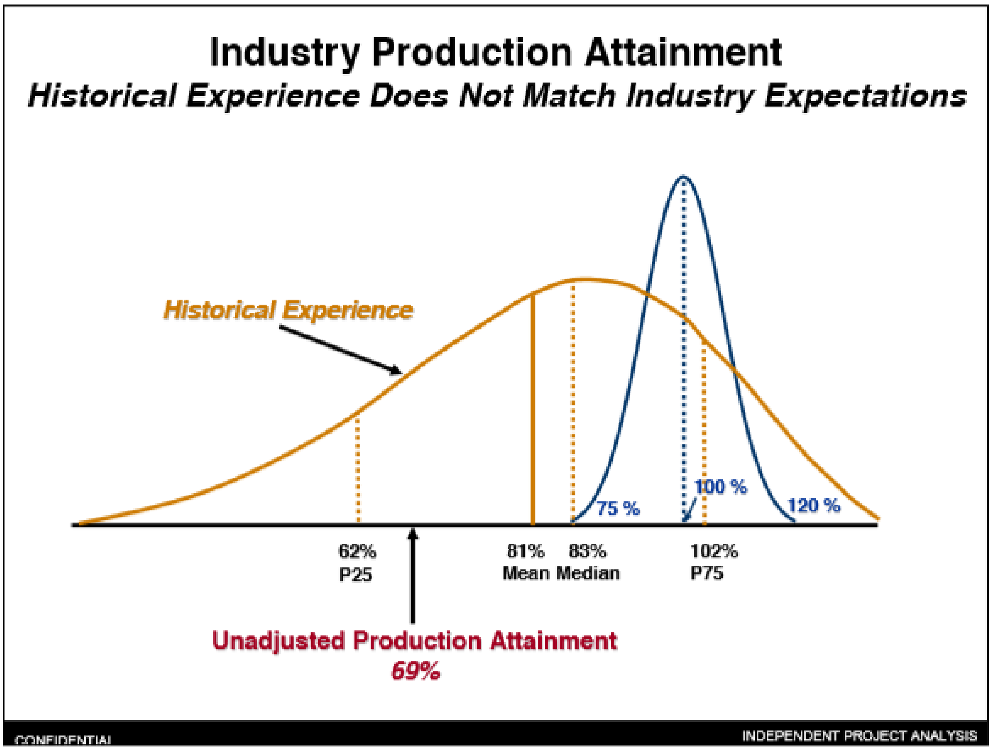

Figure 2: Historical and actual production attainment (Nandurdikar & Wallace, 2011).

They prove that the commonly held belief in the industry, which is that although projects underproduce in the first months after startup, production improves in out years, is wrong. Even four years after startup, average production is still only 80 percent of plan. This leads to a net present value (NPV) loss, and they argue that if it was not for high oil prices, companies would fail to return their costs of capital (Nandurdikar & Wallace, 2011, p. 4).

1.2.4 Flyvbjerg and RCF

Flyvbjerg and his colleagues have researched cost overruns and/or benefit shortfalls across several industries for decades, specializing in transportation- and infrastructure projects. Their research shows an inaccuracy of 20 to 45 percent in cost forecast for rails, bridges and road projects (Flyvbjerg, 2008, p. 5). Flyvbjerg et al. (2014, p. 7) argues that large capital investments completed within their budgets are the exception rather than the rule. He also argues that the deviations can be explained by biased estimates rather than by poor project leadership, and highlights *delusion* and *deception* as the two main sources of bias (Flybjerg, Garbuio, & Lovallo, 2009).

Flybjerg, in comparison with COWI (2004), argues that biased forecasts are due to estimators adopting an *inside view,* and that they fall short due to the *planning fallacy* (Kahneman & Tversky, 1979b). The planning fallacy is defined as the tendency to underestimate task-completion time and cost, even though managers know that similar tasks historically tend to run late and over budget (Flyvbjerg, Garbuio, & Lovallo, 2014). Taking on an inside view means that the decision maker considers problems as unique and focus on the particulars of the case rather than looking at the problem in a broader picture (Kahneman & Lovallo, 1993). Flyvbjerg argues that an outside view can be obtained by applying reference class forecasting (RCF) (2006, p. 6).

In comparison with COWI (2004), he introduces RCF and a guidance for the use of uplifts in transport infrastructure projects. Based on a study by Flyvbjerg, Holm & Buhl (2005a), RCF was in April 2005 endorsed by the American Planning Association (APA). Her Majesty's Treasury also recommends adjustment uplifts, based on data from past projects, to be applied to Great Britain infrastructure projects (Flyvbjerg & COWI, 2004, p. 7).

1.3 Procedure

Decision makers always aim to maximize benefits from a project. If estimates given when deciding how, when and whether to develop a field are biased, decision makers will not understand all risks related to the project. As a result, the decision on how, when, and if the project should be developed is unlikely to be optimal.

This thesis aims to investigate estimates given in the PDO. Based on- and inspired by the research Haukaas & Mohus (2016), Demirmen (2005; 2007), Nandurdikar & Wallace (2011) and Flyvbjerg et al. (2003; 2004; 2005a; 2005b; 2006; 2008; 2009; 2014) have published, deviations related to the following three estimates will be analysed:

- Development cost
- Time schedule
- Production rates

1.4 Structure

The paper is divided in eight chapters. Chapter one is dedicated to the background, purpose and procedure of the thesis. Further, chapter two will outline general reservoir theory and the chain of events in a petroleum development project. Chapter three will briefly explain how data is collected. It will further explain how it is sorted, and limitations that have affected the scope of the research. In chapter four, analyses on cost- and time overruns will be presented. These analyses are primarily based on earlier reports, as cost- and time overruns in development projects on the NCS are largely documented. Following these, a comprehensive analysis on estimated- and actual production rates will be presented. Finally, the PV erosion due to deviations from estimates will be addressed.

Based on the analyses, sources of bias and psychological factors that affect us when we estimate future values will be discussed. Research from other industries, and whether deviations from estimates are more present in the petroleum sector than other comparable industries, will also be discussed.

Chapter seven discusses possible adjustments and procedures on how to debias estimates. In chapter eight, multiplicators based on the method of RCF will be presented and tested to see whether they could help improve the industry's understanding of estimates and their related probability distributions.

1.5 Key contributions

Although overruns and benefit shortfalls in other industries are well documented, production shortfall and value erosion from not producing sanctioned volumes on the NCS has yet to be researched. Our research show that we are producing less than estimated the first years after initial oil, and the results is a value erosion where 17 percent of forecasted revenues are lost. Despite the increased use of uncertainty modelling and simulations, the industry has not shown any sign of improvement over the past 20 years. This indicates that it is human bias, and not the models themselves that is to blame.

This paper show that estimates can be debiased by using multiplicators from the probability distributions of historical outcomes to adjust predictions. The method is called RCF, and is based on the Nobel Prize winning work of Kahnemann & Tversky (1974; 1979a; 1979b), further developed by Lovallo & Kahnemann (2003) and introduced to practice use by Flyvbjerg et al. (2004; 2005a; 2005b; 2006).

2 Theory

2.1 Petroleum development projects on the NCS

According to the Norwegian Petroleum Act, the Norwegian State has the proprietary right to subsea petroleum deposits and the exclusive right to resource management on the Norwegian Shelf (NPD, 2018b).

Petroleum reserves on the NCS are primarily located offshore, sometimes hundreds of kilometres away from main land. Due to the complexity and difference between reserve deposits, development projects on the shelf are often highly uncertain, requiring technological developments and cooperation across several industries. Before initiating development of a field, a plan for both development and production must be approved. In the plan, all factors that can influence the project should be addressed.

Development costs in a new petroleum field can be in the tens of billions. The investment is irreversible, and it takes on average more than three years before production starts, and the field produces income (Haukaas & Mohus, 2016). The time aspect, and the investment costs required, are two factors that makes petroleum projects highly uncertain and risky. Not only does the revenue incur several years after the main part of the costs, it is also highly affected by the oil price, which could deviate as much as 50 percent in less than two years[3].

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[3] Brent Spot dropped by more than 50 percent from 2013 to 2015

2.2 Chain of events

As several deposits have been developed, produced, and terminated, a standard procedure in terms of applications and milestones has been created by the NPD.

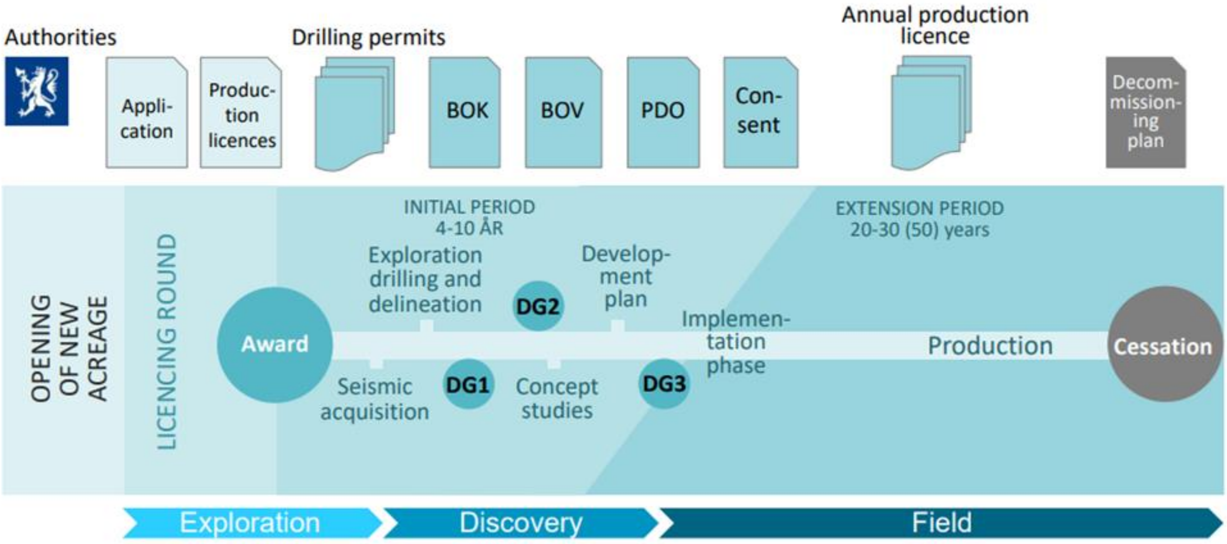


Figure 3: Milestones and phases of a petroleum project on the NCS (NPD, 2017b).

The illustration in Figure 3 can be viewed as the official classification of the phases of a petroleum development. It outlines the major milestones during exploration, development of concept, and production. In addition, it expresses which official documents and applications that needs to be delivered at each milestone. For the scope of this thesis, projects will be divided into five main phases:

- Concession and production license
- Determination of producible reserves
- Project development phase
- Production phase
- Decommissioning and abandonment

2.2.1 Concession and production license

Prior to the opening of new areas with a view to granting production licenses, an evaluation shall be undertaken of the various interests involved in the relevant area. In this evaluation, impact of the petroleum activities on trade, industry and environment, and of possible risks of pollution, as well as the economic and social effects that may be a result of petroleum activities, must be assessed (NPD, 2018b).

When new areas on the NCS are opened, companies can apply for either a survey- or a production license in predetermined geographical areas. If awarded with a survey license, the company is given the right to explore the determined block for petroleum but is not given exclusive right to survey activity in those areas that are mentioned, nor any preferential right when production licenses are awarded (NPD, 2018b)

If an area is opened for production of petroleum, companies can apply for a production license. A production license entails exclusive rights to surveys, exploration drilling and production of petroleum deposits in areas covered by the license (NPD, 2018b). When awarding a production license, an operator shall be appointed or approved by the Ministry. The operator will, on behalf of the licensee, oversee the daily operations. On the NCS, standard practice is that the Ministry awards several companies the production license in a joint venture, consequently creating licensee groups. The Ministry then decides what stake each company has in the license (Pettersson, 2011)

2.2.2 Determination of producible reserves

When awarded a survey- or production license, the company (licensee) will explore the area to determine the amount of producible reserves. In this phase, the economically recoverable hydrocarbons in a field, area or region are evaluated quantitatively (Demirmen, 2007).

The estimation itself is a technologically advanced procedure where information from well logs, core samples, seismic data and drilling is combined. All available data will be combined and used as basis for a reservoir model (Demirmen, 2007). The model is a detailed model where simulations can be run on the effects of production, pressure changes, etc. The estimation of producible reserves is critical, and perhaps the most important phase of a petroleum development (Meddaugh & McCray, 2017). It determines the future expected production of the field, thereby also the expected cash inflow.

Type of installation and solution for development is based on the estimation of producible reserves. Over- or underestimating reserves can have a significant effect on the overall profitability of the project, and it is essentially important that the data gathering, and reservoir models are well calibrated. To determine the producible reserves, a standard classification system is used (NPD, 2018a).

2.2.3 Project development phase

After determining the amount of producible reserves, a field will enter the development process. In this phase, possible installations and constructions for producing hydrocarbon will be examined. The potential income from production, as well as costs of developing, operating and decommissioning the construction will be examined, and the profitability of different solutions further analysed to obtain the optimal development, i.e. the installation that gives the highest utility.

NPD divides this stage into five main milestones, illustrated below:

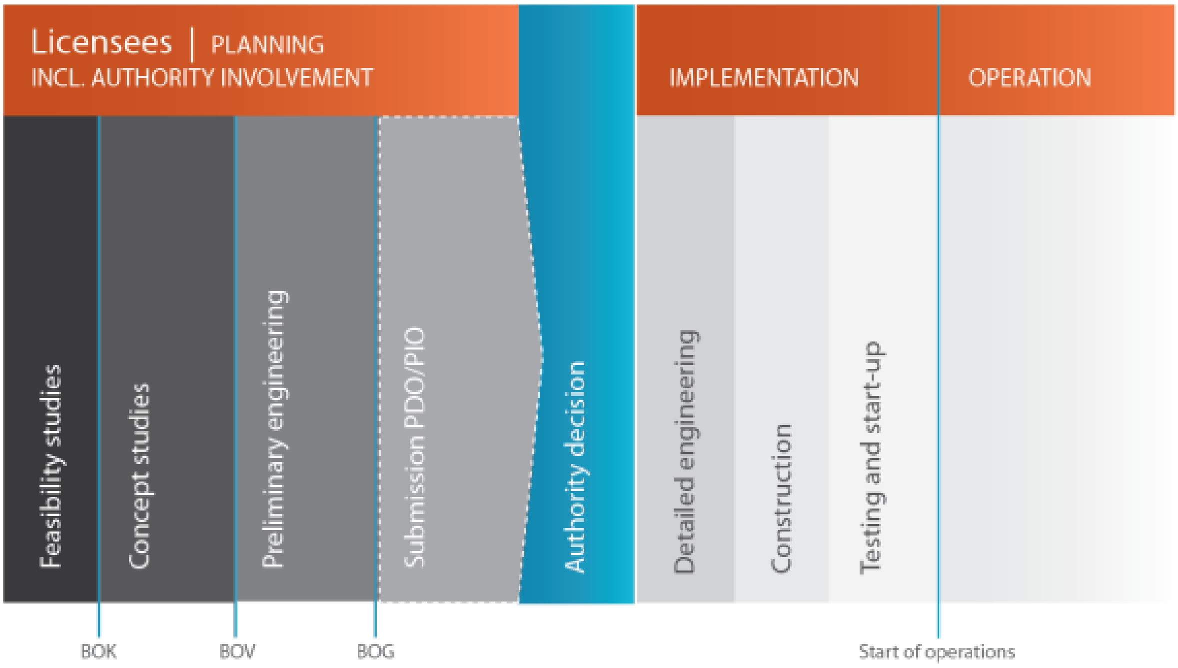


Figure 4: Phases of a petroleum development project (MPE, 2017).

The five main milestones are:

DG0 - Start of the feasibility studies

DG1 - Concretization decision (BOK)

DG2 - Decision to continue (BOV)

DG3 - Decision to implement (BOG)

DG4 - Start of production/operations

PDO

An important milestone for a project is the PDO application delivered to the authorities. Submission of PDO is noted as BOG, or DG3. The plan needs to be approved by the authorities before detailed engineering and construction of facilities can be initiated (MPE, 2010).

The Ministry of Petroleum and Energy (MPE) has developed a PDO/PIO guideline which purpose is to provide advice on how a PDO and a plan for installation and operation (PIO) can be prepared in a manner which fulfils the authorities' requirements. The guideline also a tool for understanding the administrative processes and contribute to efficient cooperation between the licensees and the authorities (MPE, 2010, p. 6). It states what information that must be included across all sections of project development and production. The specific requirements important for this thesis will be outlined when relevant.

In the PDO, estimates for cost, time and production must be given (MPE, 2017). These estimates are important elements in the profitability forecasts that PDO approvals are based on.

2.2.4 Production phase

Sale of hydrocarbon is the main source of revenue for a petroleum installation. Thus, the revenue does not incur before the field starts to produce and sell hydrocarbons. Once production is initiated, a field will produce hydrocarbons for several years, until production is no longer profitable.

When production from a field declines and closes in on the point where it is no longer profitable, enhanced oil recovery (EOR) methods can be applied to increase production and the lifetime of the field. Some installations also work as processing facilities for other surrounding subsea fields. In these cases, topside and platform might be held open for several years, although the field is not producing from its own reservoir, but rather working as a processing facility for fields nearby (NPD, 2017a).

The Shelf is continuously screened, and new discoveries are often found close to already existing infrastructure. In some cases, new areas are linked directly to producing fields, and incorporated in the production volumes. An example of such a field is given on page 59 (Balder).

2.2.5 Decommissioning and abandonment

When a field has produced its producible volume and further production is no longer profitable, the operator can apply for shut down and decommissioning of the field and its installations. As the NCS grows older, more and more fields shut down, and the frequency of undiscovered reservoirs decline. As a result, decommissioning becomes more and more relevant.

Shutdown, decommissioning, and abandonment cannot be initiated without approval of the cessation plan. As the NPD aims to maximize the utility from the shelf, a field and its installations need to be proven no longer profitable for production to be shut down and installations removed. Even after removal, innovative technology can be developed and again make production from the reservoir profitable. Examples of re-opened fields on the NCS are Odin and Yme. Decommissioning of platforms and installations, as well as the plans for permanent plugging of the well and related cost estimates should be discussed in the PDO (MPE, 2010, p. 50)

2.3 Producible reserves

Holding other factors constant, the production rate determines the revenue from a field. It is therefore essential to determine the amount of producible reserves, and fully understand how production will affect future and current production rate. As expressed by the NPD:

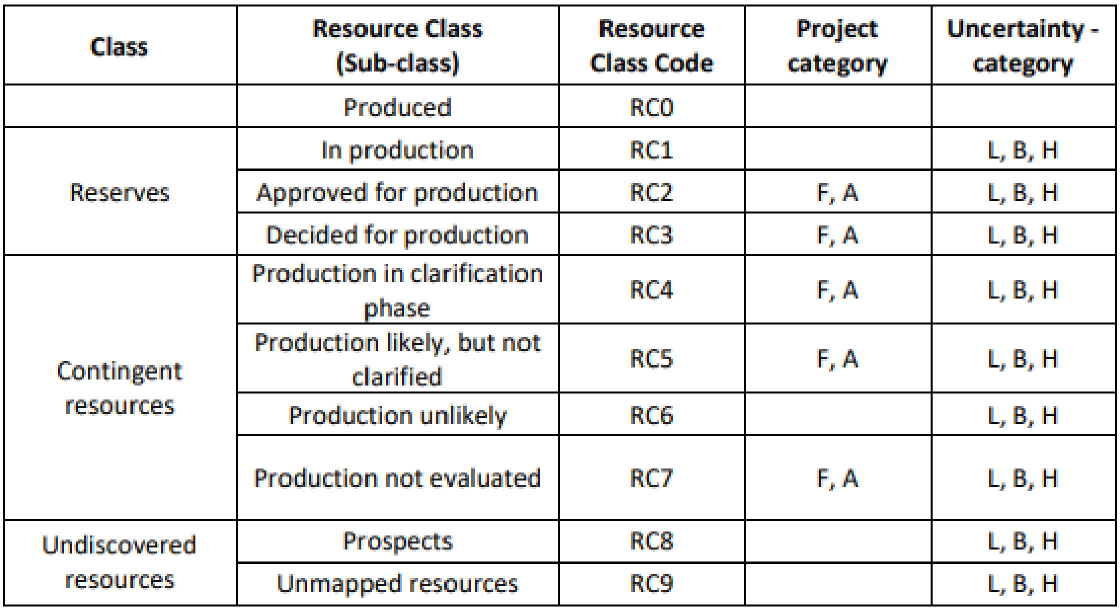
“One of NPD’s primary objectives is to maintain an overview of the overall petroleum resources so that the authorities have the best possible basis for planning measures to ensure good resource management and for forecasting future production and activity” (NPD, 2018a, p. 1)

2.3.1 Definitions and classifications

To maintain this overview, NPD is dependent on a clear classification structure for all reserves, both producible and unproducible. Reservoir classification systems have been subject to several changes and is under constant development. The current classification system for the NCS, defined by the NPD, was developed in 2001 in cooperation with the oil companies (NPD, 2018a). Although the NPD has developed their own classification system, it is closely aligned with the Petroleum Resource Management System (PRMS), which is explicit based on project maturity (NPD, 2018a, pp. 1-2)

Petroleum resources on the NCS are divided into classes which reflects the knowledge related to the volume and the maturity of the development. The classes are closely correlated with those used in international classification systems, such as PRMS 2007 and United Nations Framework System (UNFC) 2009. An overview of the defined classes and sub-classes are illustrated in Table 1 and Figure 5 (NPD, 2018a, pp. 5-6).

Table 1: Classes and sub-classes for production estimates on the NCS (NPD, 2018).



Class	Resource Class (Sub-class)	Resource Class Code	Project category	Uncertainty - category
	Produced	RC0		
Reserves	In production	RC1		L, B, H
	Approved for production	RC2	F, A	L, B, H
	Decided for production	RC3	F, A	L, B, H
Contingent resources	Production in clarification phase	RC4	F, A	L, B, H
	Production likely, but not clarified	RC5	F, A	L, B, H
	Production unlikely	RC6		L, B, H
	Production not evaluated	RC7	F, A	L, B, H
Undiscovered resources	Prospects	RC8		L, B, H
	Unmapped resources	RC9		L, B, H

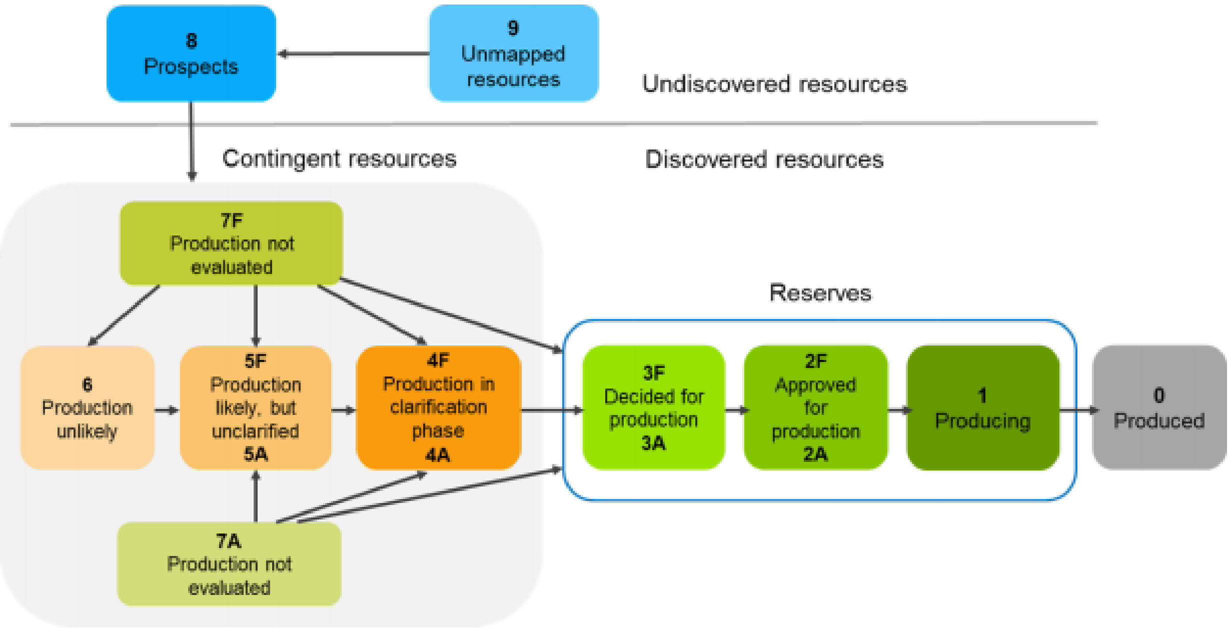


Figure 5: Illustration of resource classifications for the NCS (NPD, 2018).

Project categories in Table 1 is the distinction between first development and a project to optimize. Projects in category F are first developments for a deposit, while category A are projects which aims to optimise production from deposits which have been produced earlier or is currently under production.

When discussing "reserves", it is referred to the definition given in the table. I.e. resources that are in production, approved for production, or decided for production. In other words, resources that have been defined in a PDO and/or approved for production by the MPE.

An overview of the connection between project maturation and resource classes is given in Figure 6 (NPD, 2018a).

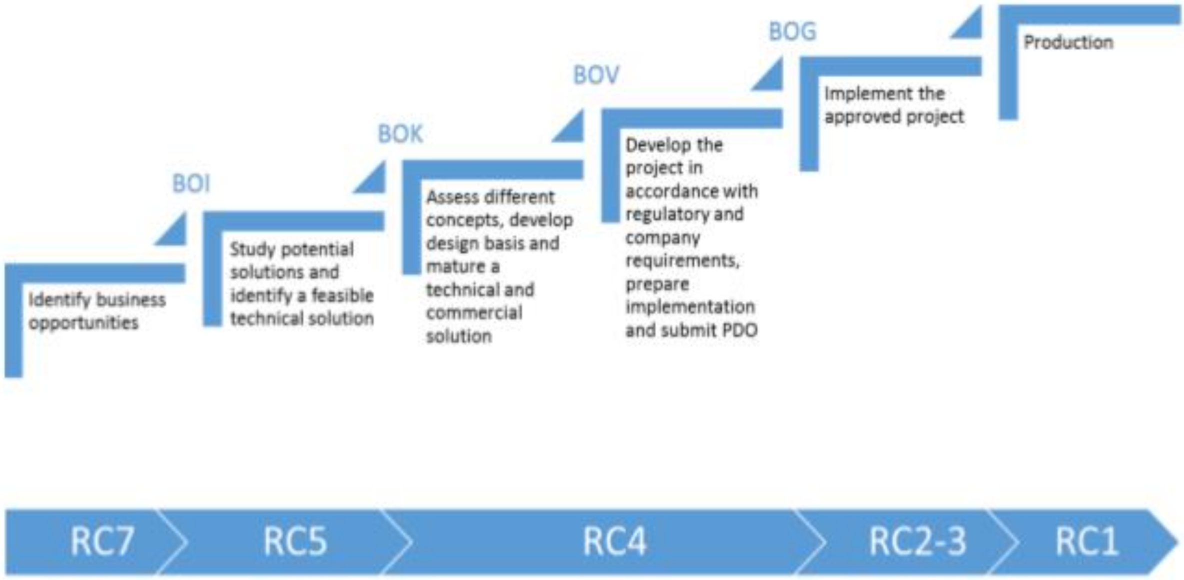


Figure 6: Connection between project maturation and resource classes (NPD, 2018a).

2.3.2 Uncertainty

Accurate reserve estimates and production forecasts is a necessity when it comes to field development decisions. Reserve estimation requires a comprehensive understanding of the reservoir and all variables that affects both the volume in place, and the total producible volume. Due to the high uncertainty and complexity in hydrocarbon production, one can never expect to perfectly estimate the producible volume. Therefore, more important than estimating the exact producible volume, is it to understand uncertainties and probabilities related to the given estimates.

NPD's resource classification system states that "all petroleum resources shall to the extent possible be designated by P10 – Expected value - P90" (NPD, 2018a, p. 1). These uncertainty categories are not used to define classes, but to express probabilities related to volumes (NPD, 2018a, p. 5).

A P10 estimate, in this paper defined as a low estimate, is an estimate that the estimator believe has a 10 percent chance of being lower than the actual production. A P90 estimate (high) is an estimate that the estimator believes will be higher than the actual value with a 90 percent probability. In other words, if the P10 and P90 estimates are accurate, there is an 80 percent chance that the actual production rate lies between these two values. An illustration is given in Figure 7.

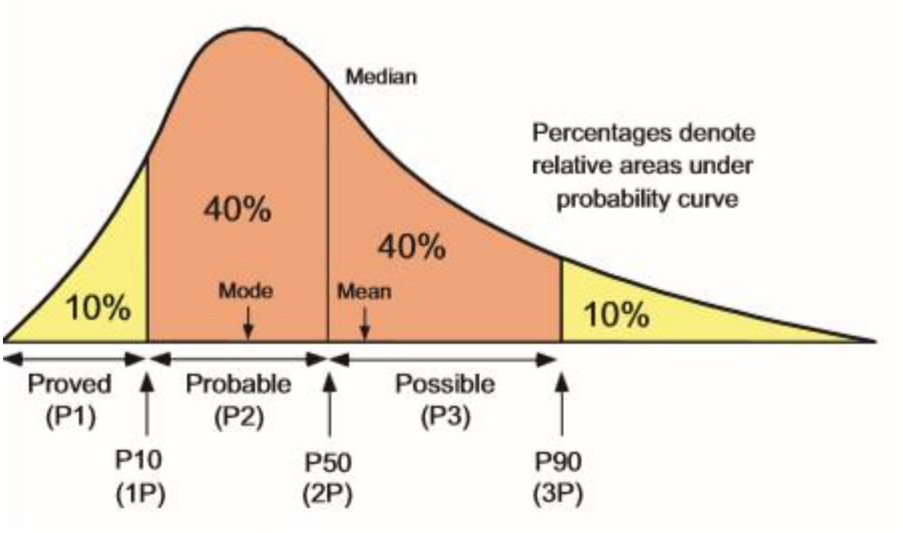


Figure 7: Reserves definition (Demirmen, 2007, p. 81).

In the petroleum industry, P10 and P90 are often denoted opposite, with P10 being high-, and P90 being the low estimate. We have chosen to use the standard in other industries, as an attempt to not cause misunderstandings.

The best estimate (B) is defined as the "best estimate of petroleum volumes that are expected to be recovered from a project" (NPD, 2018a, p. 10). If the best estimate is determined by a stochastic method, the best estimate shall be considered as the expected value (NPD, 2018a, p. 10). The estimate is referred to as the best-, mean-, and base estimate as well as the expected value by the authorities (MPE, 2017; NPD, 2018a). In this paper, it will be referred to as the mean estimate. It is not defined as a P50 estimate[4], but this paper will discuss the benefits of using a P50 estimate rather than an expected value. Although the updated PDO guideline now specifies that P10- and P90 estimates must be given (MPE, 2017), earlier PDO guidelines did not specify what probability the low- and high estimate should reflect (MPE, 2010; NPD, 2000). It is therefore possible that forecasters before 2017 have used other probabilities than P10/P90 in their estimates. This information is not included in the available data, and all estimates are therefore assumed to reflect P10 - Mean value - P90.

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[4] The P50 estimate is the same as the median

As geologists and reservoir engineers conduct more analyses, wells are drilled, and the development closes in on production start, more and more information about the reservoir becomes available. When more information is available, uncertainty in the reservoir models and 3D-simulations decrease. In other words, uncertainty decreases over time, and it is at its lowest when a field is shut down and abandoned.

An actual example of the uncertainty reduction is given in Figure 8. The figure illustrates total estimated gas production for a field on the NCS that is expected to be decommissioned in near future. Because of missing data, the figure only illustrates estimates given the last seven years, but the trend is clear. Deviation from high- and low estimate to mean increase the longer back in time you go and is reduced with increasing information[5].

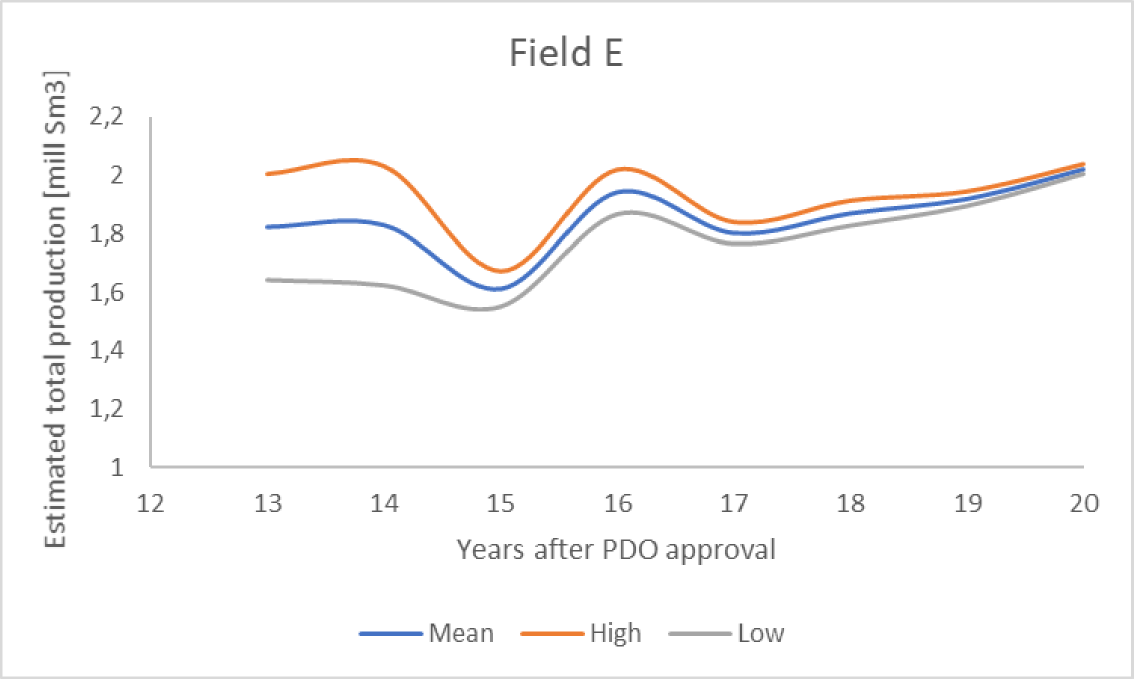

Figure 8: Estimated high-, mean- and low gas production for a standard field on the NCS. Sorted by years after PDO approval.

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[5] In this case, actual production for all years up until each estimate is known. Which means that in year 15 after PDO approval, you *know* the *actual* production in years 0-14, and *forecast* production for the remaining life of the field. These values are then summed up.

2.4 Profitability of projects

Petroleum developments projects are, as other projects, evaluated based on their costs, revenues, cash flows, and profitability. Profitability of a project is the accrued discounted revenues minus the accrued discounted costs. For a field development, the main source of revenue is the sale of hydrocarbons. While oil is usually produced and sold in the spot market, gas is typically used as pressure stabiliser in the reservoir and then sold as fields mature.

2.4.1 Cost allocation

Costs of a field can be divided into three main categories: development, operational and decommissioning. Figure 9 illustrates the cost allocation for two field developments on the NCS. Both projects were found and developed in the 90's and started producing hydrocarbons around the millennia. They were shut down a few years ago and are set to be plugged and removed in the coming years.

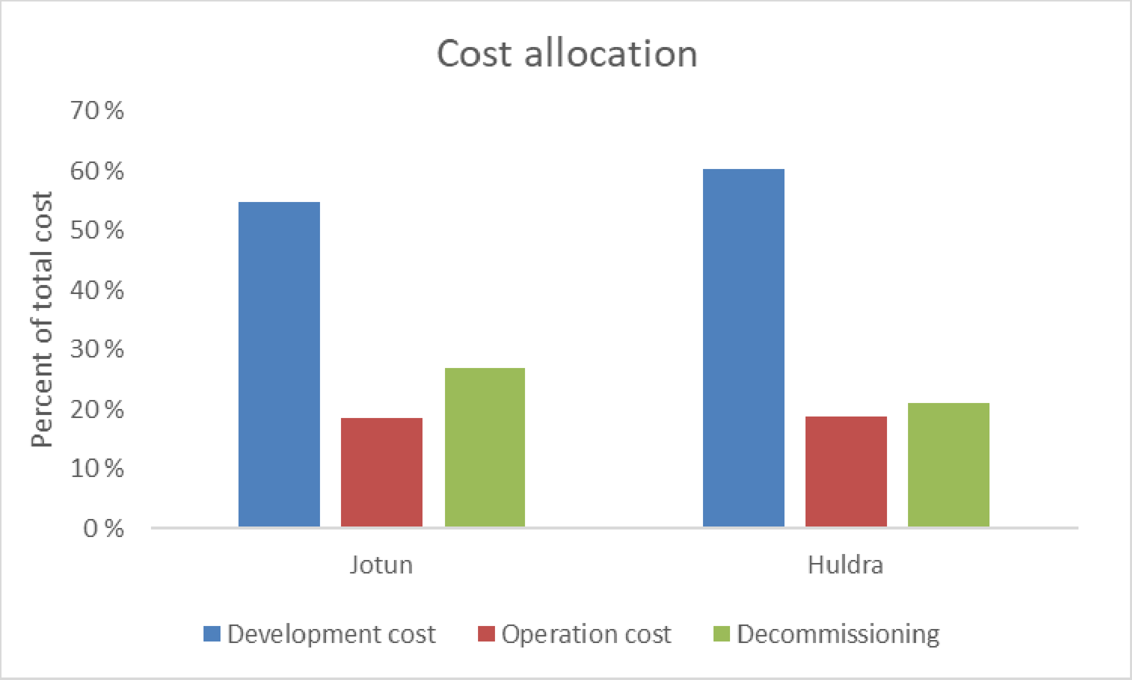

Figure 9: Cost allocation for two fields on the NCS.

Development costs have comprised between 50 and 60 percent of total costs for both projects, although they both produced and had operational costs for about 20 years. Development costs are related to engineering, procurement, construction (EPC) and installation of facilities. The major part of development costs run from approval of PDO (DG3) until the complete facility is installed and production starts (DG4). According to the PDO guideline, contractual obligations cannot be entered into, or construction work commenced before the PDO is approved, unless the MPE issues an agreement that says otherwise (MPE, 2010, p. 13)

Cessation costs are based on the cessation plan for each field, delivered to the NPD (ExxonMobil E&P, 2015; Statoil, 2012). Cessation involves plug and abandonment of wells, removal of topside, pipelines and other facilities, as well as onshore recycling of installations and all related material. As removal of the facilities is not yet finished, the decommissioning costs are still an estimate, and can be subject to over- or underspending.

2.4.2 Production of hydrocarbons

Oil fields on the NCS and elsewhere have a distinct production profile. In the years after first oil, when pressure in the reservoir is at its highest, the rate of production is expected to be at its maximum. These years are commonly referred to as the plateau phase. After the plateau phase, fields enter a period of tail production, where the yearly producible volume is expected to decline until all producible reserves are taken out. Figure 10 (Apanel et al., 2013, p. 9) is an illustration of a typical expected production profile for a petroleum field.

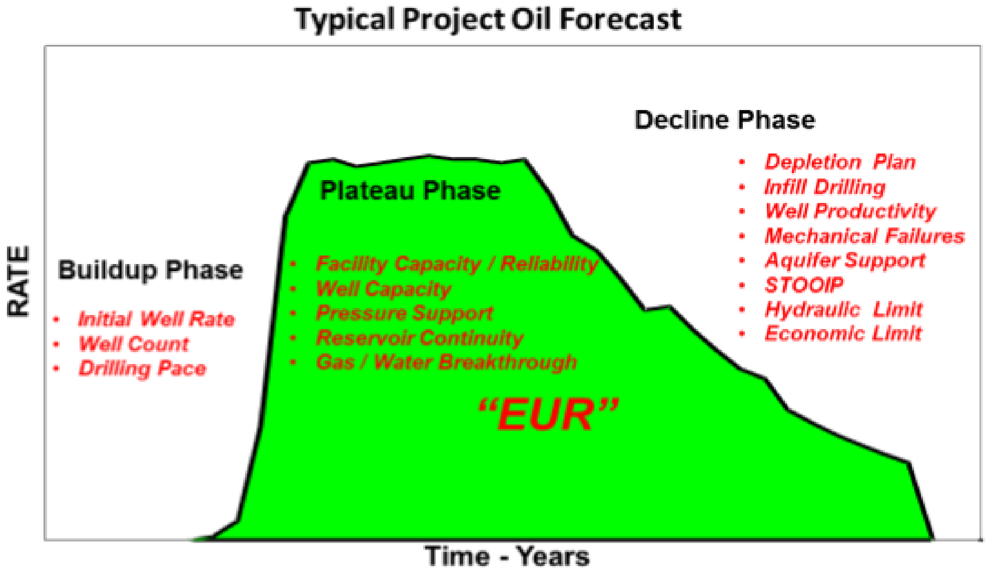

Figure 10: Illustration of a typical production forecast for a petroleum field (Apanel et al., 2013).

Actual oil production profile for Draugen, a field on the NCS, is given in

Figure 11.

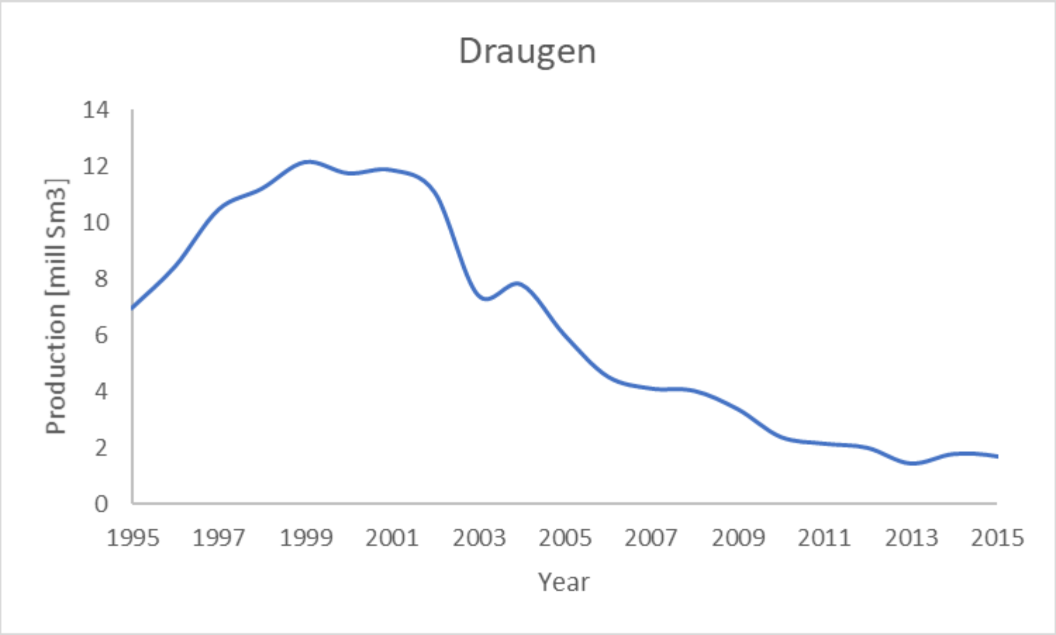

Figure 11: Actual oil production profile for Draugen.

A major part of production occurs in the plateau stage, which usually begins 1-2 years after production start. In addition to be the period with the largest annual production, the plateau period is also the one that affects the PV of the project the most. To evaluate the economic benefit at the time of PDO approval, expected revenues from sale of hydrocarbons must be discounted back to the PV at the time of evaluation. As the discounting factor is raised by the power of years after evaluation, revenues become less and less worth the later production occurs.

2.4.3 Discounting cash flows

Figure 12 is an illustration of the PV of a $1 yearly revenue, when using a discount factor of 10 percent. A $1 income in year five after evaluation is only worth $0.62 in present terms. This means that although a field produces its expected total volume of hydrocarbons, the timing of production affects the revenue from the field. Spot price of oil, exchange rates and other factors such as interest rates will also affect revenues.

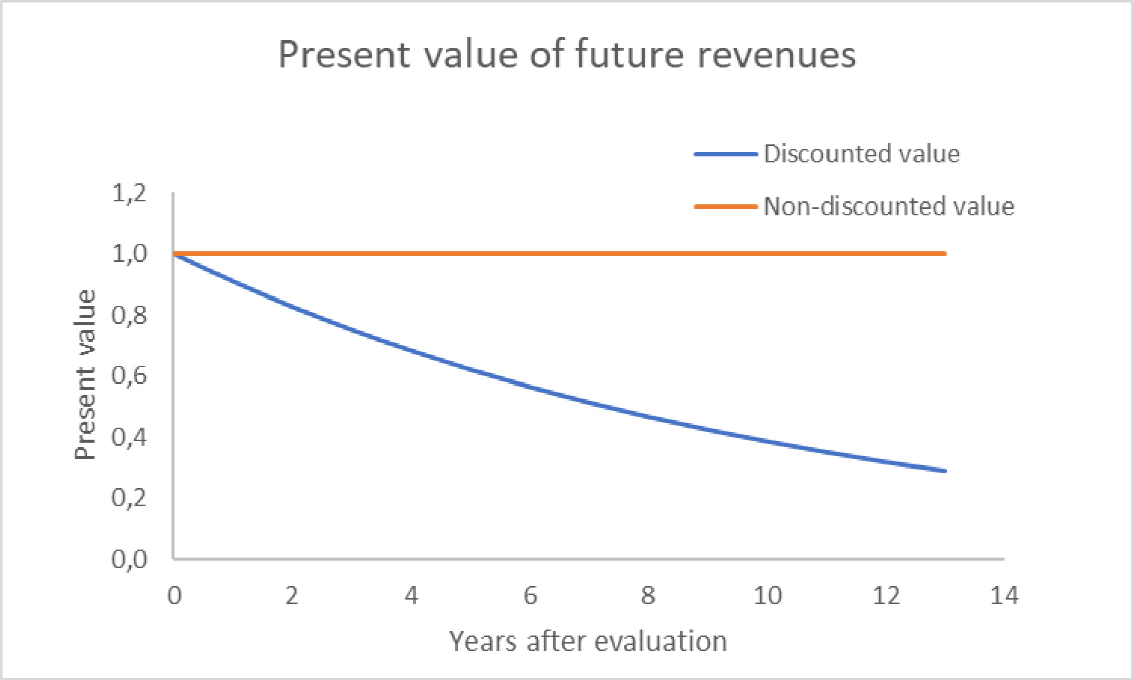

Figure 12: Illustration of the effect discounting has on revenues.

2.5 Estimation of costs

Cost of development and operations given in the PDO is based on estimates conducted by the operator in comparison with the licensees. An estimate must account for uncertainty and should therefore be related to statistical distributions or confidence intervals (Haukaas & Mohus, 2016). The PDO guideline (MPE, 2010) says that “the project should be developed so far that all investment elements can be estimated with reasonable certainty”. It also says that cost estimates must be stated as an expected value, and that 10/90 and 90/10 confidence levels must be presented. A 10/90 confidence level, in this paper referred to as a P10-value, is a value that the estimator believe has a 10 percent chance of being lower than the actual outcome. Underestimating the likelihood of overspending budgets leads to an unknown exposure to risk and could result in unoptimized capital allocation.

2.6 Contract theory

2.6.1 Divided contracts

Offshore development projects are complex and unique in the sense that the different reservoirs, seafloors, and depths sets the requirements for technological and geophysical adaptions and solutions. In a development project, several contractors and suppliers are involved, and a clear form of contracts is crucial to succeed with the project. Earlier, contracts for developments on the NCS was structured as illustrated below. The operator gave a specific assignment to a specific supplier, and the supplier was then responsible for that part of the development. The abbreviations are described in Table 2

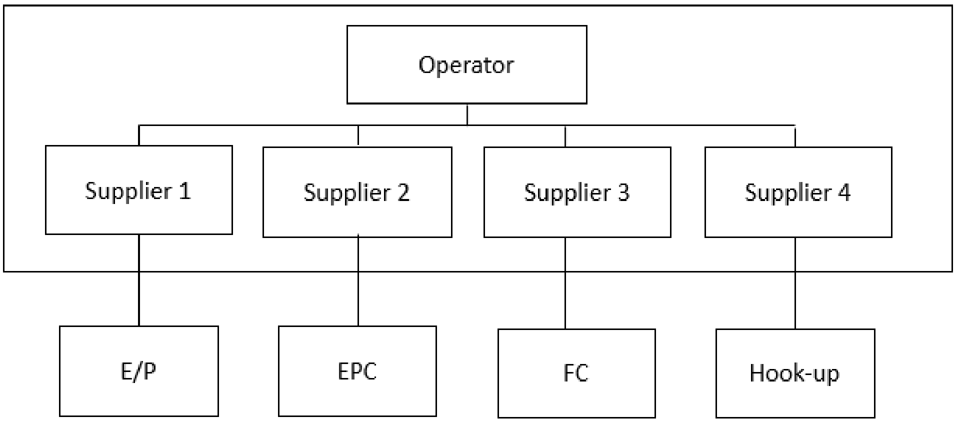

Figure 13: Overview of contract structure before for divided contracts.

Table 2: List of abbreviations commonly used in petroleum development projects.

Activity	Abbreviation
Engineering	E
Procurement	P
Constriction	C
Installation	I
Commissioning	C
Hook up	H
Fabrication	F

2.6.2 NORSOK

After a period of major cost and time overruns, NORSOK was implemented in 1994. NORSOK-standard was introduced with the aim of reducing cost and time related to development and operation of petroleum installations on the NCS with 40 to 50 percent by 1998, compared to 1993. While at the same time keeping the standards of health, environment and safety (NOU1999:11, 1999). The NORSOK-standard also marked a change in the industry toward the use of total contracts in field developments on the Shelf.

2.6.3 Total contracts

Today, the most common contract structure is total contracts for distinct parts of development. An example of this can be an EPC-contract for topside, which in the recent decade often was awarded to Asian shipyards. In an EPC-contract, the supplier takes responsibility for engineering, procurement, and construction of the installation, with the operator acting as supervisor. Figure 14 illustrates a typical setup for an EPC-contract, where the operator expects a finished set of constructions to be delivered at site, without the need for major engineering before installation. Installation can also be included in these contracts, forming an EPCI-contract.

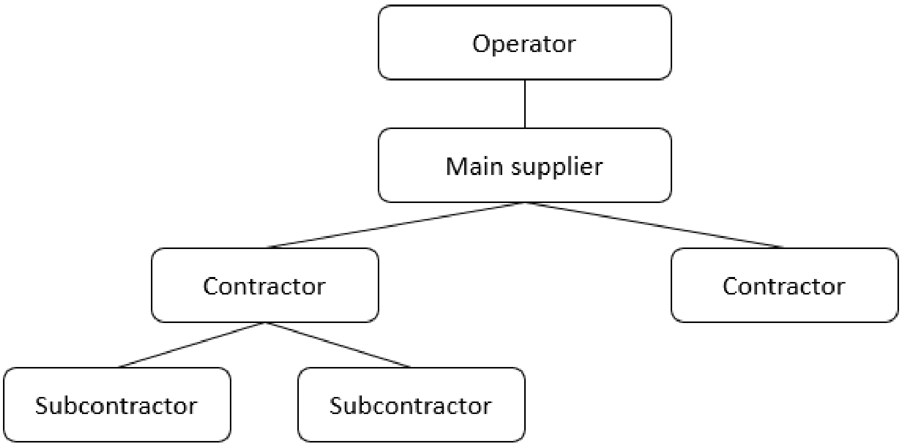

Figure 14: Illustration of contract structure when applying total contracts.

2.7 Project follow – up

On the NCS, the operator is the one that, on behalf of the licensees, holds the overall responsibility for the planning, execution, and day to day operations of the project (Pettersson, 2011). It is therefore crucial that the operator has a deep understanding of both the project at hand, earlier projects completed on the shelf, and comparable projects in other parts of the world

Some contractors require close supervision, while other previously used companies may require less attention, as they have a deeper understanding and competence in the NORSOK-requirements. In the case of new suppliers, closer supervision may be crucial to make sure that the development is proceeding according to plan. According to the Office of Audit General of Norway, the MPE has limited influence on project management after approval of the PDO. It is therefore the operator that, on behalf on the licensees, holds the main responsibility for project follow-up in the development phase (2004-2005).

2.8 Decisions

In decision analysis, a good decision is defined as a decision that is logically consistent with the decision makers preferences, alternatives and information (Bratvold & Begg, 2010). These arguments are called decision basis, and can also be formulated by three questions: What do we wish to accomplish, what can we do, and what do we know?

In the petroleum industry, decisions that does not involve any form of uncertainty are almost impossible to find. Due to uncertainty, a good decision may result in a bad outcome. Similarly, a bad decision can result in a positive outcome (Bratvold & Begg, 2010, p. 6). It is essential to distinguish the quality of a decision from the results of the outcome, because the decision maker often has minimal impact of the outcome of his or her decision. An example is outlined in a paper published by MPP (1980, pp. 243-244). The paper says that the development of Statfjord A and B had cost overruns of 117 percent. Despite this, due to an increased oil price in the producing lifetime of the field[6], the profit turned out to be higher than estimated. If the

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[6] Oil price here defined as an outside factor that the decision maker (instance that approved the PDO) does not have any control over.

oil price had not increased and remained higher than expected, the field would have been less profitable than expected. The managers of the Statfjord development, and the government officials that approved the PDO, have no real influence on the oil price. Thus, an argument can be made that approving the PDO was a bad decision, as costs more than doubled compared to what they estimated.

Bratvold & Begg (2010, p. 7) uses the following points to describe why decisions in the petroleum industry are difficult:

- Uncertainty: Decisions in the petroleum industry are based on estimates and models that are created to mirror reality. There will always be uncertainty in these estimates and models.
- Complexity: A development project can involve several decisions, where each one has factors that needs to be evaluated. One factor can also be affected by decisions regarding others, hence increasing the complexity.
- Obscurity in which goals that are most important: There are several different stakeholders that want their saying on how to develop the shelf. An example could be the ongoing discussion on whether we should open Lofoten for oil production (Skarvøy & Johnsen, 2016).
- Conflicting objectives: A petroleum field development is a huge project, and has ramifications on a local, national and international level. In a decision, all objectives need to be weighted and compared.
- Fear of consequences: Big decisions are important and can influence the decision maker, the organization, society and the environment. In many cases, the decision is irreversible and the consequences permanent.

3 Data and method

This chapter gives a brief description on how data is gathered, as well as describing the method used for analysing the obtained data.

3.1 Data

A substantial portion of the work related to this thesis has been to sort and systemize available data. The analyses are based on two separate databases, one related to development cost and time, the other related to production.

Data on development cost and time was gathered by Haukaas & Mohus (2016). Their comprehensive base of data is based on publicly available information. It has been made available and further used as basis for an expanded dataset used in this paper.

Yearly updated production estimates for all fields on the NCS has been made available by the NPD[7]. Although the database is rich and comprehensive, a lot of data is missing. As a result, some fields are not included due to unreliable or missing estimates. Estimates given in the year of PDO approval are matched with actual production, downloaded from npd.no.

3.2 Method

The analysis is divided in four main parts. Part one examines costs and budget overruns related to development of installations. As this topic is well covered by Haukaas & Mohus (2016), only a brief analysis that substantiate their findings is presented. The second part looks at schedule delays and analyses average delay in developments on the NCS. These analyses are also based on the dataset from Haukaas & Mohus.

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[7] The data was made available under a non-disclosure agreement so none of the actual field names for which we have production estimates will be used. If a field name is used in the thesis, it is to show public data; e.g., estimated and actual costs, estimated and actual development time, or actual production. Axes-values are removed when showing their value can reveal which fields that are being discussed.

In part two, we look closer at production estimates and the industry's ability to deliver on their forecasts. Production rate forecasts on the NCS have not yet been the subject of a rigorous study and is therefore the focus of this work. We look at actual production, and the historical ability to deliver on estimates. The total difference between budgeted and actual production is found and used as a basis for calculating the economic effect of deviations from forecasts. Finally, part four summarizes the three analyses, and gives the total PV erosion from not delivering as budgeted.

3.3 Limitations

Limitations of the paper are mainly set by the amount of available data. For production estimates, a significant amount of information is either missing, or clearly wrongfully reported. As a result, the paper has been restricted to only include oil production, and exclude gas, NGL and condensate. Some fields have also been removed from the analysis, as no, or incomplete estimates are given in- or close to the year of PDO approval.

Getting access to historical P10- and P90 values for costs would provide insight that could help improve future cost estimates even more. More data; on cost, schedule and production, would improve the quality of this research. If monthly production data was available, the effect on schedule delays on both production shortfall and revenues would be possible to find. The author highly recommends the Norwegian petroleum industry, and the NPD specifically, to continue providing data and resources to further research.

The paper is limited to only include field developments on the NCS. A broader analysis including fields from other parts of the world would be useful, both to expand the dataset, and to look at differences between countries, regions and type of installations.

4 Analysis of estimated- and actual outcomes

In this chapter, analyses on forecasted and actual cost, scheduled time and production on the Norwegian Shelf will be presented.

4.1 Development cost

Cost overruns on the NCS have been subject to several public and private reports over the last decades, summarized by Haukaas & Mohus (2016, pp. 1-3). Generally, it can be concluded that cost overruns are very common and a well-known phenomenon. The investigations, conducted at different points in time, have come up with similar explanations for the overruns. Project management, incomplete and unsatisfactory pre-engineering, poor cost control, and not understanding uncertainties associated with estimates are listed as some of them (Styringsgruppen, 1980; NOU1999:11, 1999;Office of the Audit General of Norway, 2001; Rystad Energy, 2013; NPD, 2013).

The dataset in this paper is restricted to fields with PDO approval in the period 1995-2017. The dataset from Haukaas & Mohus (2016) is used as background, and additional information added. Development costs are updated to 2017-values. The dataset includes data for 68 developed fields.

Figure 15 gives an illustration of the average PDO cost in blue and average cost overrun in orange. The sum of the two bars equals the average total cost for projects approved that year. The line illustrates the relative overrun, given on the secondary vertical axis.

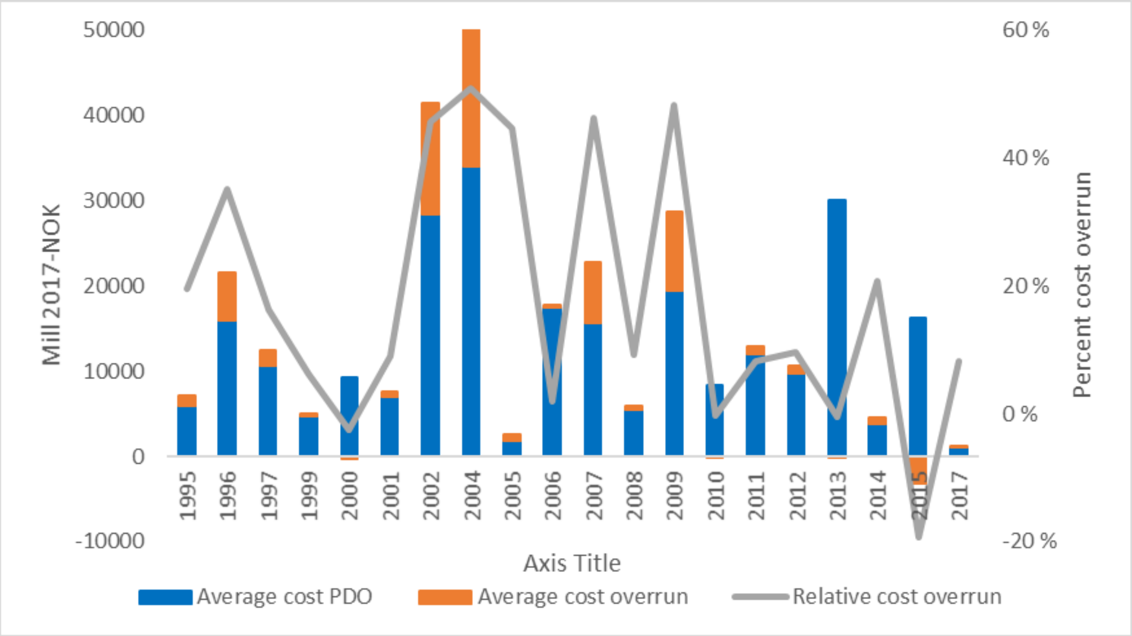

Figure 15: Average cost, average cost overrun, and relative cost overrun for fields on the NCS. Sorted by year of PDO approval.

All projects included in the figure are completed and have started producing[8]. Fields currently under development that are not a part of the illustration includes Johan Sverdrup I, Martin Linge and Aasta Hansteen. Including these fields, will affect results in the years they were approved. Although some may argue that Johan Sverdrup shows that the industry has reduced costs, this does not mean that the quality of forecasts is improved. All three fields have ended more than 10 percent over/under budgeted cost. Costs in the Johan Sverdrup development are reduced by almost 20 percent, while Martin Linge is about to be installed with costs more than 40 percent higher than estimated.

The relative overruns seem to decrease after 2010, and a significant cost reduction of almost 20 percent has been observed for projects with PDO approved in 2015. This does not indicate that cost overruns on the NCS is a thing of the past. Historically, the industry has not learned from their mistakes, nor improvements. As Figure 15 show, projects approved in 1999-2001 had final costs less than 10 percent above estimated, an improvement compared to the 1995-

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[8] As of 01.01.2018

1997 period. Despite this, projects approved in 2002-2005 had relative overruns of more than 40 percent. No PDO's were approved in 2003 and 1998.

Total cost overrun for the 68 fields is 213 billion 2017-NOK. It corresponds to overrunning budgets with 26 percent. 82 percent of the fields were completed above budgeted costs, and 37 percent finished with costs more than 20 percent above estimated.

Due to the thorough cost analysis presented by Haukaas & Mohus, this thesis is restricted to conclude that cost overruns are evident. The overruns have occurred for more than two decades, and there is no trend that indicates that the last years cost reductions are the start of a new era of delivering debiased forecasts for development projects on the NCS.

4.2 Development schedule

In the PDO, an estimated date, or a time interval for production start, is given. For a project to finish on time, production of hydrocarbons must start inside this time interval. As PDO's are classified, data regarding estimated production startup are hard to find. Haukaas & Mohus dataset is therefore used and updated with fields that have started producing since 2015. The dataset comprises estimated and actual production start for 42 field developments on the NCS, PDO's are approved from 1998-2013.

Average expected development time[9] for a project on the NCS is 2.7 years. Developments have an average delay of 202 days, or 25 percent. Of the 42 fields, 17 percent started producing before schedule and 69 percent later than scheduled. 13 fields were more than half a year delayed, and 17 outran their time schedule with more than 20 percent.

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[9] Development time is defined as the number of days from PDO approval to production start

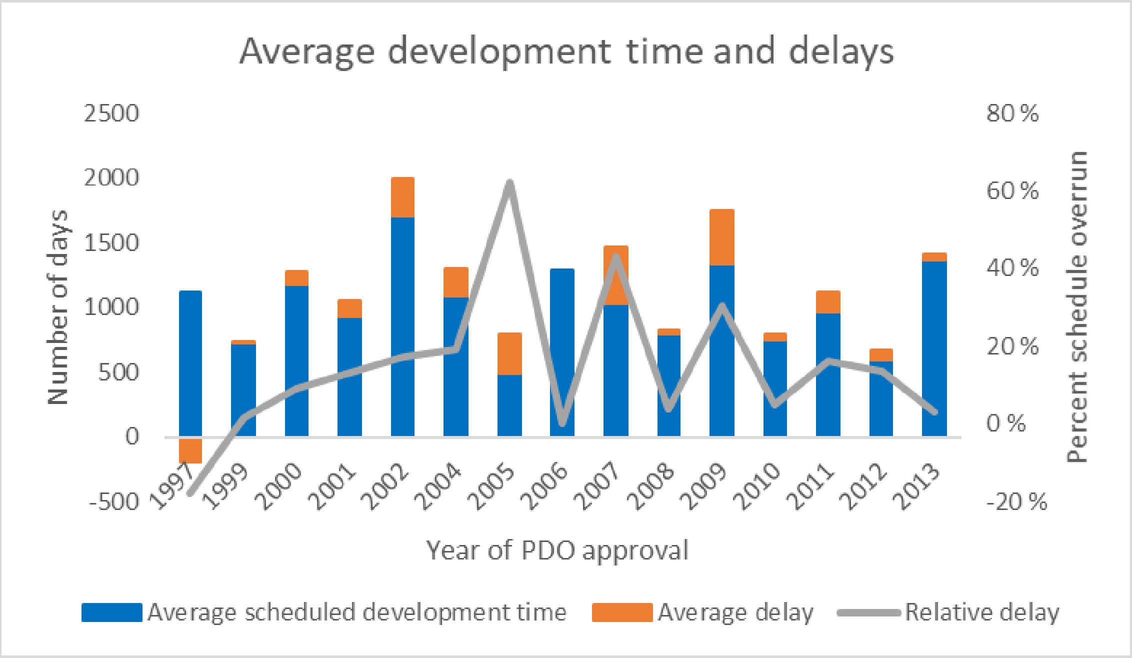

Figure 16: Average forecasted development time, schedule overrun, and relative delay for fields on the NCS. Sorted by year of PDO approval.

Figure 16 gives an overview of development time and schedule overrun for all fields where sufficient data has been collected. It is constructed as Figure 15, showing average forecasted development time in blue and delay for projects with PDO approved the same year in orange. Relative schedule overrun is given on the secondary axis. Delays are evident almost every year, and the industry seem to overrun estimated development time by about 10-20 percent across the period. Oseberg Sør is the only field that has finished significantly before schedule, while there are several fields where the schedule overruns are larger than a year.

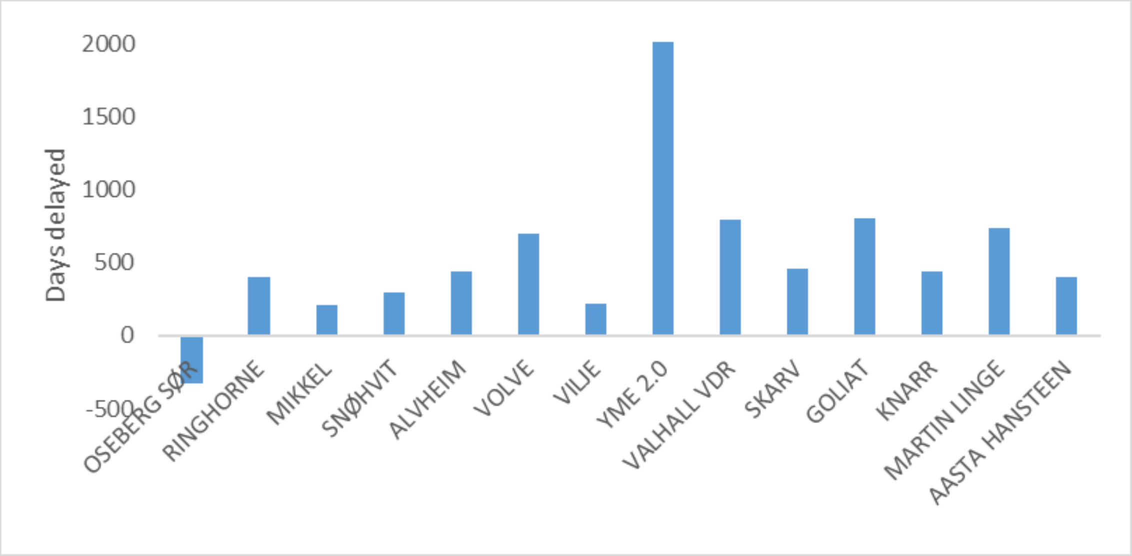

Figure 17: Overview of projects with more than six month schedule overrun.

In Figure 17 , fields with schedule deviations of more than six months are sorted ascending by the date of PDO approval. Three fields had their PDO approved after 2010, and two of them have yet to opened for production. The re-opening of Yme was cancelled in 2012, after overruns both in terms of cost and time (NPD, 2013). Martin Linge and Aasta Hansteen are included in this figure, although they have not yet started production. They are not included in other analyses.

Due to the thorough schedule overrun analysis by Haukaas & Mohus, this thesis will restrict itself to conclude that time overruns are evident. Overruns have occurred for more than two decades and there is no trend that indicates that the industry has learned from their past mistakes, nor any trend indicating that schedule overruns are decreasing.

4.3 Production attainment

Haukaas & Mohus (2016) showed that there is no direct correlation between increased development costs and changes in forecasted producible reserves. In this paper, production estimates at PDO approval will be compared to actual production

Reserves estimates on the NCS have been researched by Demirmen (2005; 2007). His analyses are based on 15 field developments on the NCS in the period 1974-2003. The papers show that estimated total production fluctuates during the lifecycle of a field. The fields have an average growth in the estimated total production of 16 percent (2005, p. 3). This trend is also evident in data for this thesis, and can be seen in the example in Figure 8 (estimated production for Field E)

An increase in forecasted production at a later stage of a fields lifecycle can have different explanations. Technological innovation, new methods for production, and additional wells, which requires further investments not accounted for in the PDO, will all affect production. Often, fields are expanded with additional PDO's, or by incorporating new discoveries as a part of the development. Connecting a new reservoir that is not mentioned in the PDO, will affect the producible volume and required investments. These are all factors and events that are unknown, or not accounted for in the estimates given in the PDO. This thesis aims to analyse the decision to implement (DG3), and the estimates approved by the ministry.

Nandurdikar and Wallace presented in 2011 analyses on production attainment based on a dataset of 147 projects, developed by IPA. Their results show that four years after startup, fields produce 80 percent of what they are planned to. On average, the industry delivers 81 barrels for every 100 promised. Further, 75 percent of industry projects never deliver to plan (Nandurdikar & Wallace, 2011). An overview of the first four year production attainment is given in Figure 18.

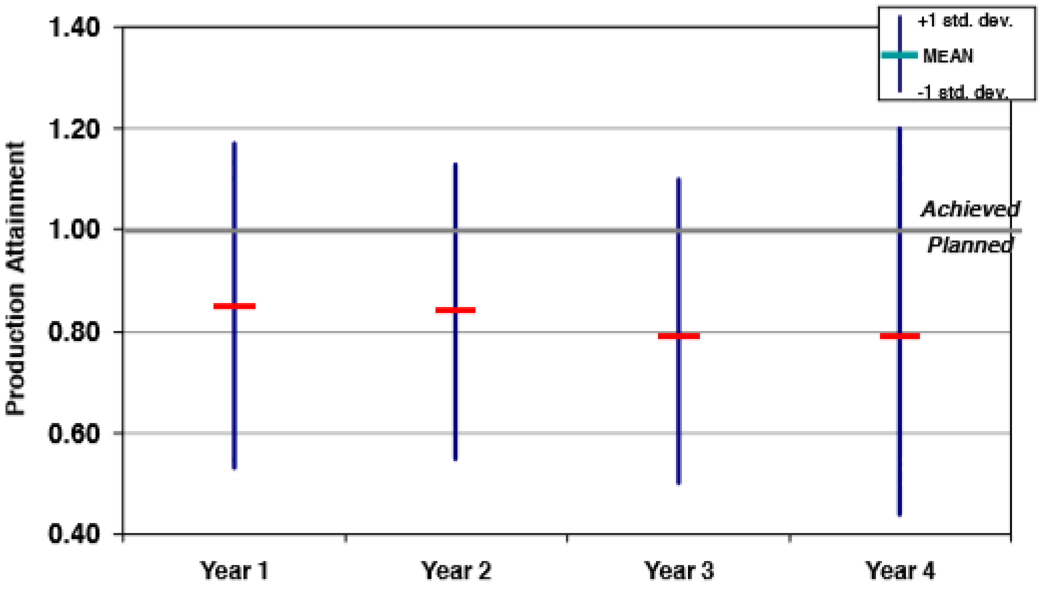

Figure 18: Production attainment for the first four year of production (Nandurdikar & Wallace, 2011, p. 4).

4.3.1 Production estimates for 56 fields

Production estimate data provided by the NPD includes yearly estimates for the complete lifetime of each field, updated each year. All analyses presented in this paper will, unless otherwise stated, be based on the estimate given at the year of initial PDO approval[10].

To discuss the industry's ability to estimate, forecasts must be compared with actual production data. As a result, only fields that have expected- or actual production start before 31.12.2017 is included in the analyses. After this delimitation, the dataset comprises 56 fields. The fields are relatively equally spread out across the period.

Estimated yearly mean production for the 56 fields is given in Figure 19. Production was estimated to start in 1997, and steadily increase as more fields were forecasted to start producing in 1998 and 1999. Total mean production was higher around the millennia. As illustrated in Figure 11 a major part of a fields production is expected to occur in the plateau stage, which starts approximately 1-2 years after first oil.

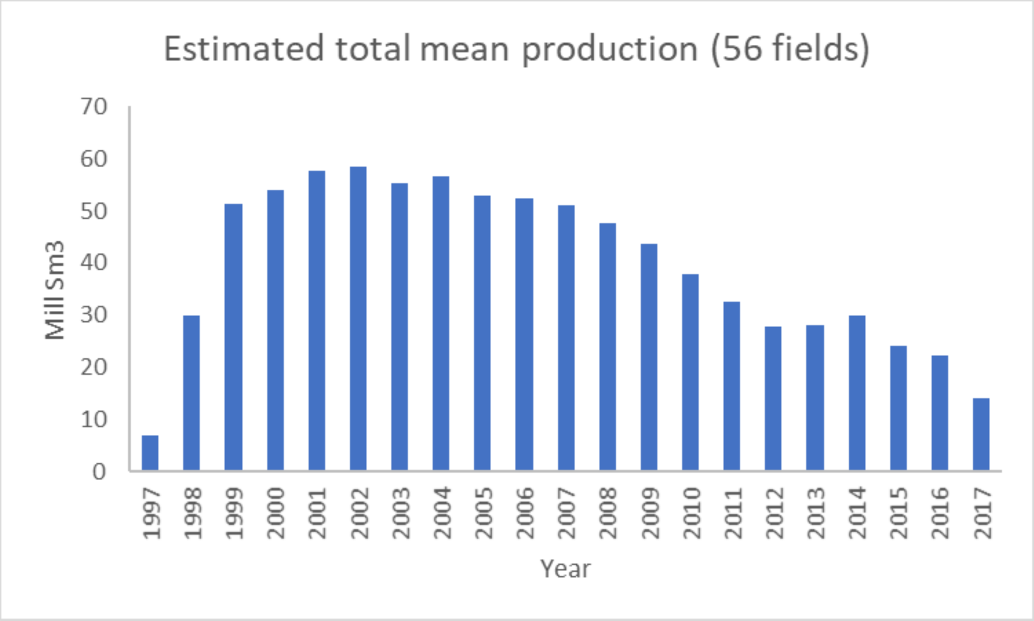

Figure 19: Estimated yearly mean production, when only including the 56 fields and production until 31.12.2017.

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[10] Due to missing, or unreliable data. Estimated production is given +/- 3 years of PDO approval for some fields

4.3.2 Estimated production profile

To be able to compare the timing of production for fields across the period, data has been sorted by the number of years after expected, or actual production start. Figure 20 is an illustration of the data in Figure 19, when normalized to zero at estimated production start.

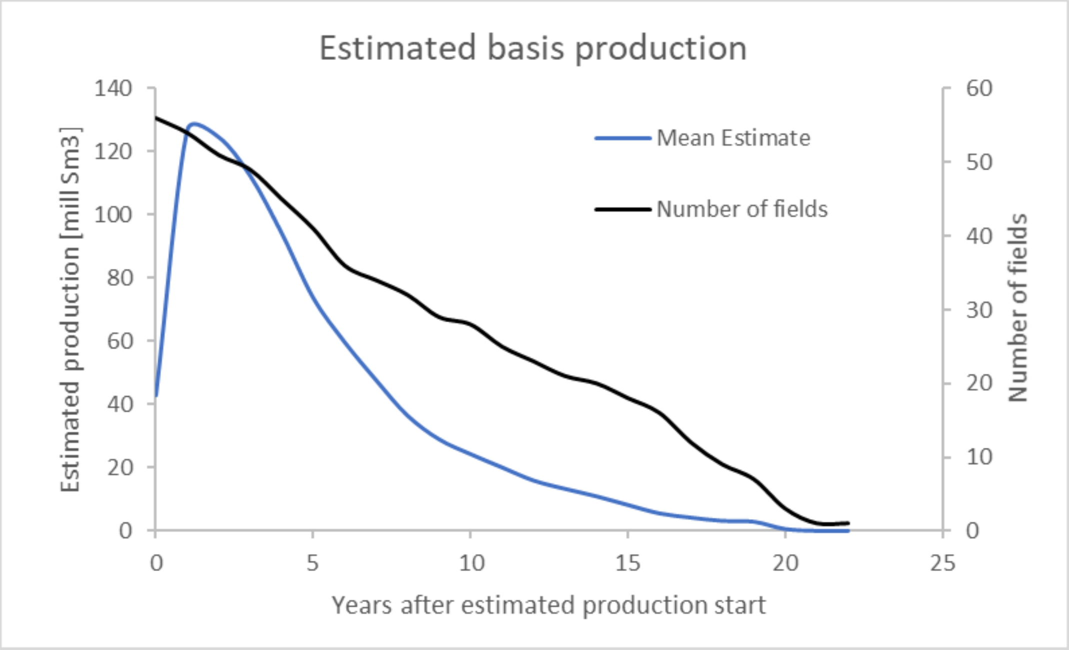

Figure 20: Estimated yearly mean production, sorted by the number of years after estimated production start.

When sorting yearly production by number of years after estimated first oil, the production profile becomes clear. The black line is added to illustrate the number of fields that is included in the total estimated production each year. When studying this graph, remember that estimated production is cut off after 2017. This means that a field that was estimated to start production in 2014, only has estimated production for year 0-3 after estimated production start. Tail production is therefore lower than if all production years were included.

4.3.3 High and low estimates

NPD's database includes high- and low estimates for all fields. According to the MPE guideline, low- and high estimates should reflect P10- and P90 estimates (MPE, 2017). Figure 21 illustrates yearly forecasted production for a field on the NCS.

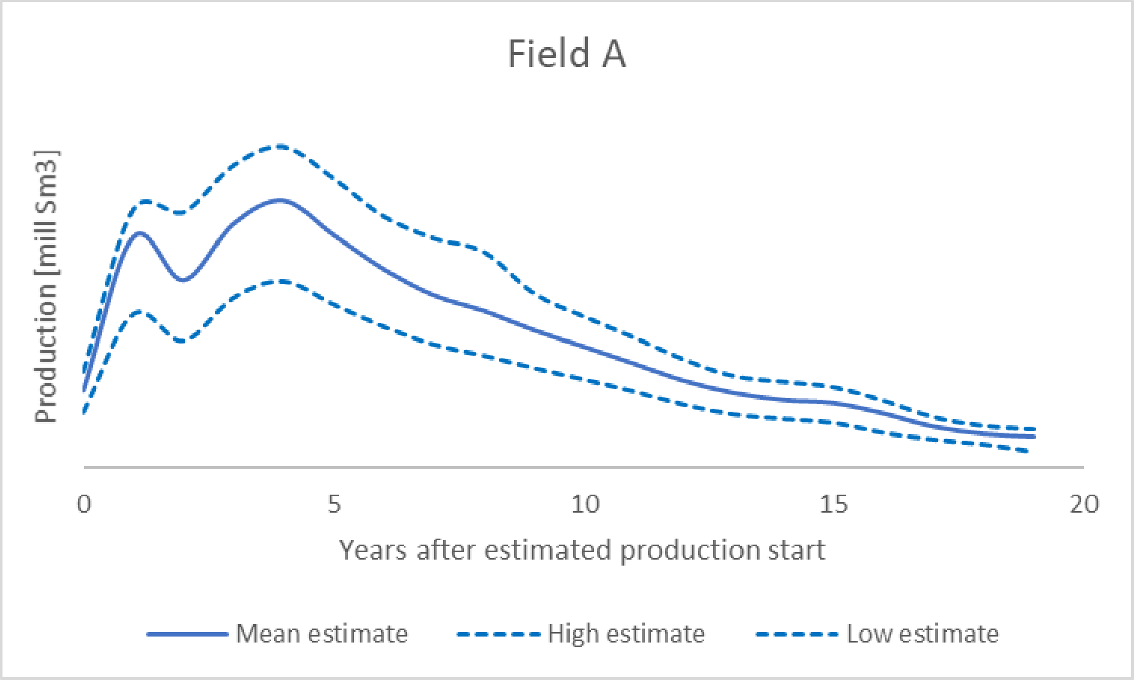

Figure 21: Illustration of difference between high-, low- and mean estimates for a field on the NCS.

The figure shows the difference between the three estimates. The high estimate is higher than the mean, and the low estimate lower. The absolute difference is higher in the plateau stage than the tail stage. Despite this, Figure 22 show that the relative deviation from the mean seem to remain quite stable throughout the lifetime of the field.

Note that, if the operator of field A follows the NPS's recommendation, a probability distribution for the production each year must somehow be generated, as the P10-Mean-P90 values can only be identified or calculated if such a distribution exists.

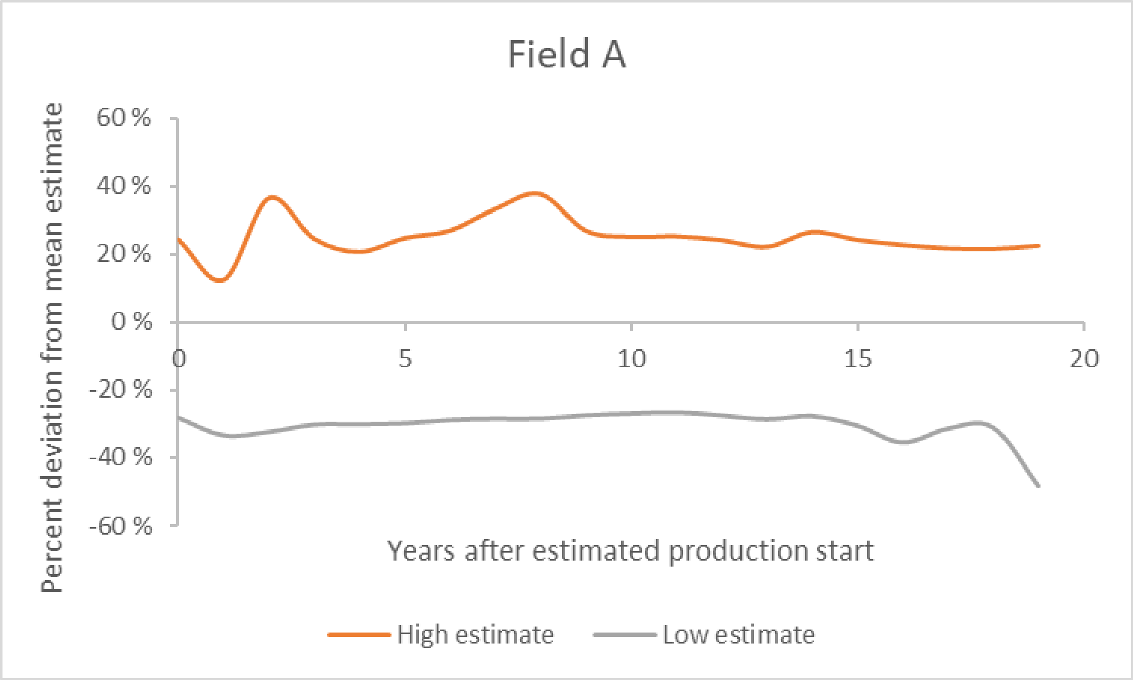

Figure 22: Relative difference from mean to high- and low estimates.

4.3.4 Actual production

Actual production for fields on the NCS is publicly available information, downloaded 02.03.2018 from www.npd.no. In this paper, only fields where actual production can be compared to estimated production are included. Total annual actual production for the 56 included fields is illustrated in Figure 23.

Oil production was at its maximum in year 2000, and has remained quite stable throughout the period, fluctuating between 40 and 50 mill Sm3 per year. It is interesting to note that it seems like production has remained more stable than forecasted. In 2013, fields were estimated to produce approximately 30 mill Sm3, while they produced close to 40 mill Sm3. This can have three explanations; either older fields have increased their tail production, newer fields have increased their plateau production, or, a combination of the two.

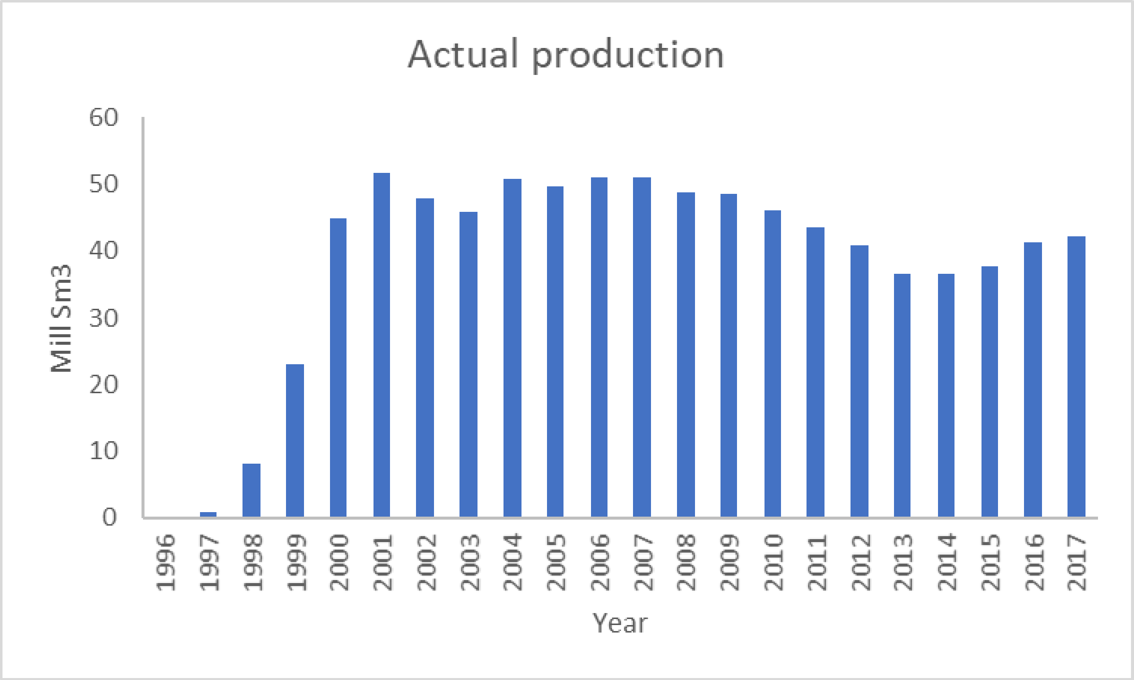

Figure 23: Actual oil production from 1995-2017 for the 56 fields that are included in the analysis.

4.3.5 How to compare production

4.3.5.1 Two methods for normalizing data

It is used two different methods when comparing estimated- and actual production. This sub-chapter is dedicated to describing the two, and the differences between them.

Normalized to estimated production start

In the first method, data is normalized to estimated production start. To illustrate the effect, imagine a field that in its PDO was expected to start production in 2010. Then, development was delayed, and production started in 2012. When estimated startup is set as time zero, forecasted production in 2010 and 2011 will be compared to a non-existent actual production, as the field is still in its development phase. This means that the effect of schedule overruns is included in production shortfalls.

Time shifted to actual production start

In the second method, estimates are time shifted so that *actual production start* is set as time zero. Using the same example as earlier, estimated production for 2010 and 2011 will now be shifted so that it is compared to actual production in 2012 and 2013. This method reduces the effect of schedule overruns in the development phase. Although the effect of delays is reduced, it is not fully removed. Fields with delays inside a calendar year will still come out with actual startup the same year as estimated startup, although they might have been up to 12 months delayed. Fields might also start up earlier than estimated, which gives the opposite effect.

The difference between the two methods will give an estimate of the consequence of schedule overruns.

4.3.5.2 Example

For a field on the NCS, field A, estimated- and actual production profile using both method one and two is illustrated in Figure 24 and 24 respectively.

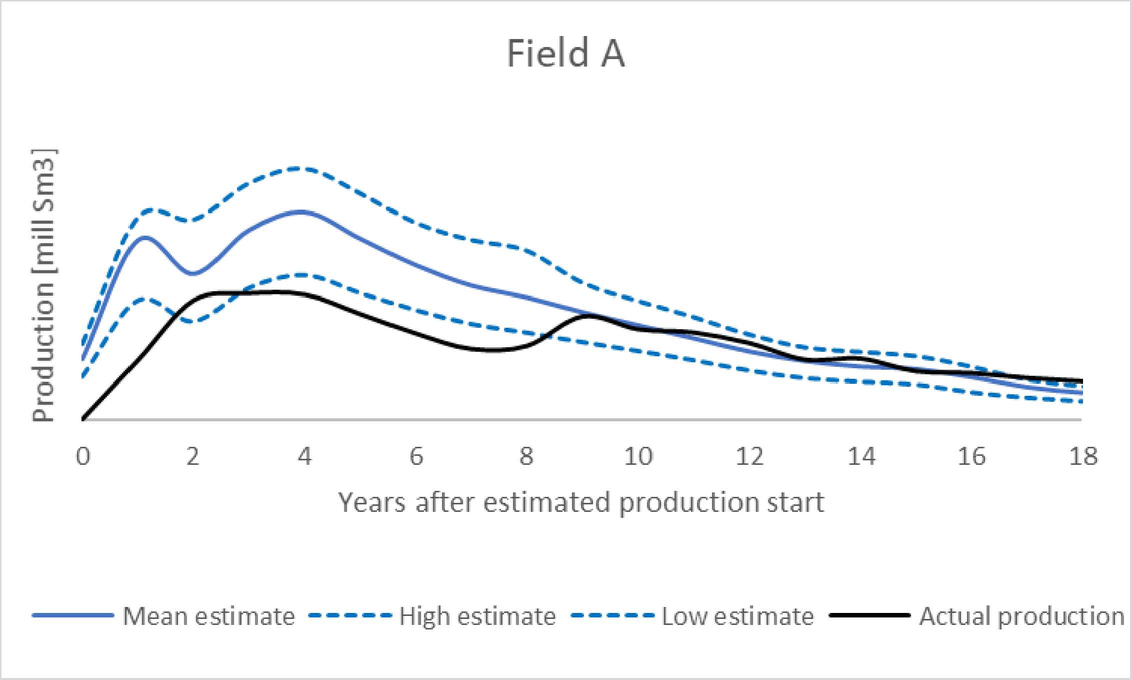

Figure 24: Actual and estimated production profile for a field, when normalized to estimated production start.

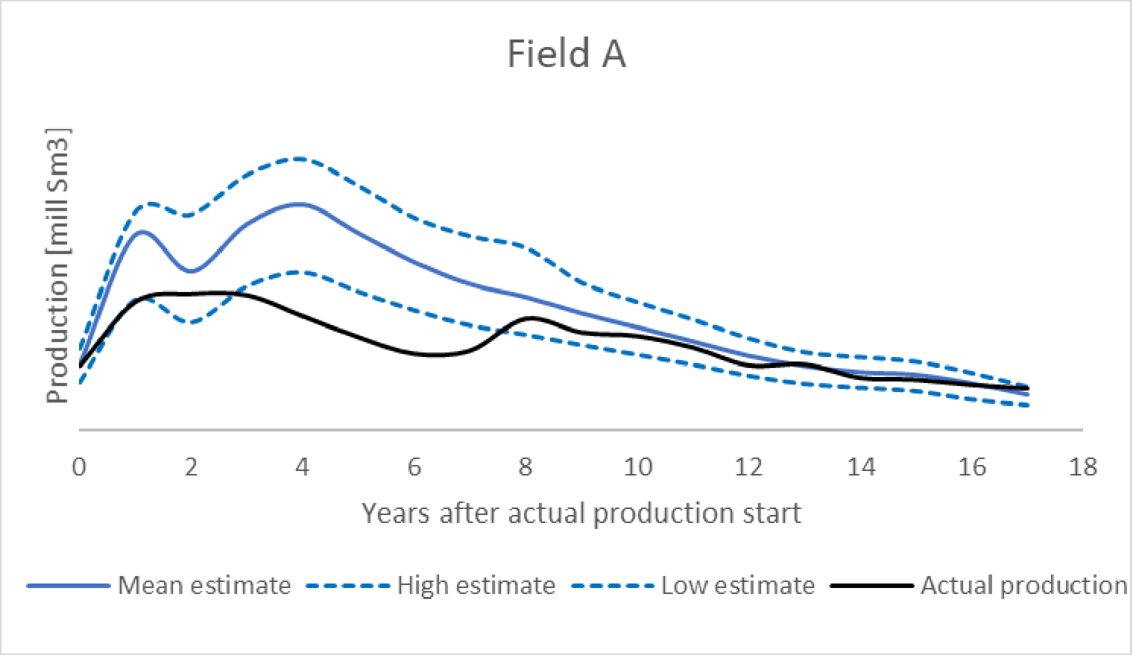

Figure 25: Actual and estimated production profile for a field, when shifted to actual production start.

The field started producing about one year later than estimated, which shifts the production line one unit to the left in the second illustration. After startup, the field produced less than estimated for ten years, and has since then produced approximately as estimated. In the figure below, production profile using the two methods is taken out to illustrate the effect of the two sorting methods. The orange line gives production when sorting by number of years after estimated startup, and is therefore shifted one unit to the right, as startup was one year delayed. Although sum of production will be equal for the two methods, method 2 will give higher revenue because of the discounting effect.

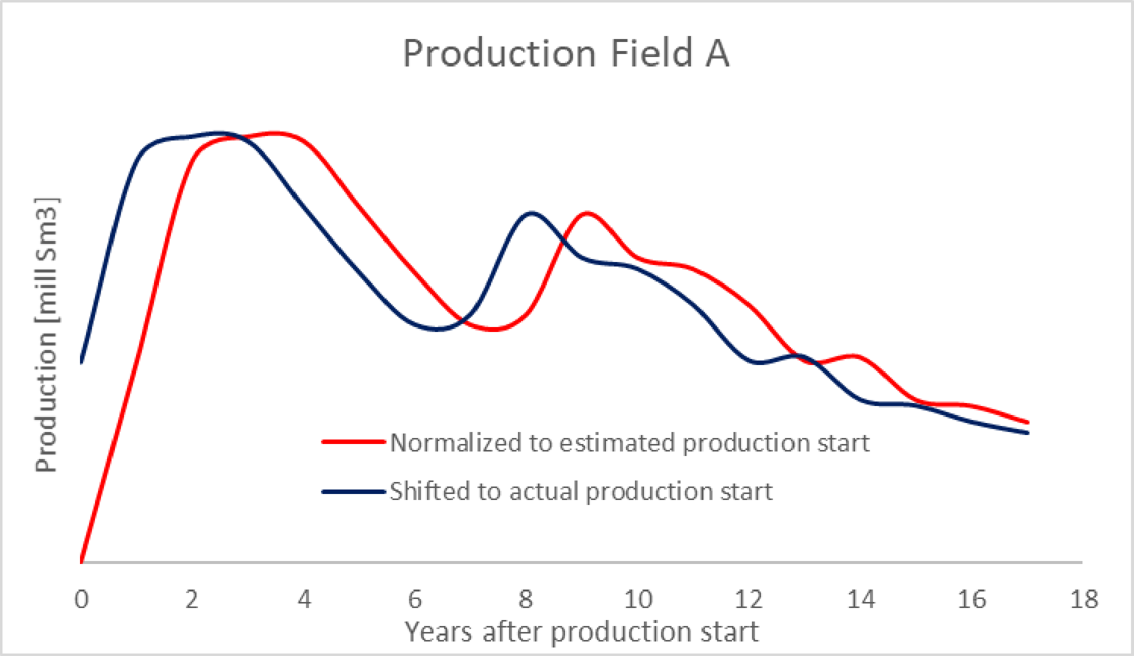

Figure 26: Difference when normalizing data to actual- and estimated production start

In addition to showing the effect of the two ways to normalize data, Figure 26 shows the effect of further investments after production start. The increased production in year 8/9 after first oil is due to an investment that was not accounted for in the PDO. Comparing production from this year onwards is therefore irrelevant when looking at the industry's ability to deliver on production forecasted at project sanction.

Production for the first four years (year 0-3), with actual production start as time zero, will be the focus in the next part of chapter four. This is the most important period of the production lifecycle. In these years, fields are expected to produce more than 50 percent of their volumes, and the discounting effect is at its smallest. The period is also small enough for fields not to be affected by further investments and PDO's, which, as illustrated in Figure 26, can affect production.

4.4 Statistical distribution of outcomes

The only way to become better at predicting future events is by keeping track of past predictions and results. Accepting the uncertain nature of future events, any predictions that might have a significant impact on values and decision making should be probabilistic.

Following the NPD guidelines, predictions of future production from fields operating in Norway should include expected production as well as P10/P90 confidence intervals. However, actual production values will be time series with specific values for each year. We can compare the estimates and actual results by using a graph like the one shown below (note that this graph is a generic example and is not based on actual production data).

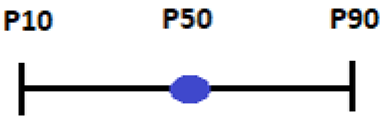

Figure 27: Illustration of data points used in figure 27.

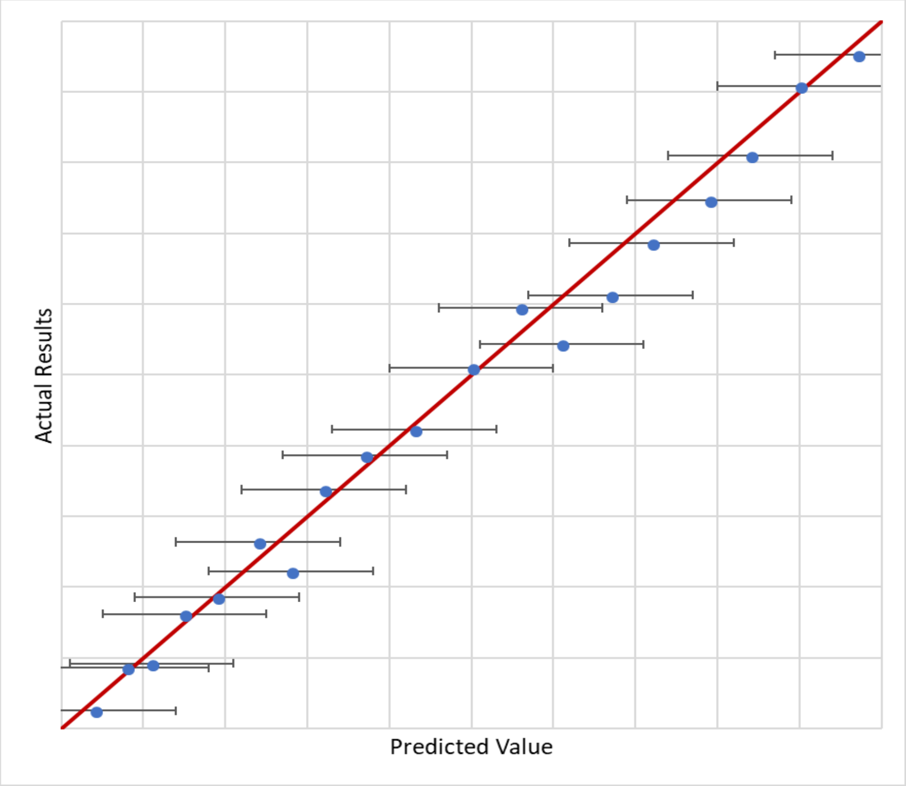

Figure 28: Illustration of an ideal distribution of debiased estimates and outcomes

The graph shows predicted median (P50) values in blue and the low and high estimates as error bars (wing tips off the P50). The y-axis position is determined by actual results. To illustrate an ideal distribution of outcomes, all numbers in the illustration are made up.

The companies give a mean, or estimated value (EV) when forecasting. If the production distribution for a given year is symmetric, perfect prediction would result in everything lining up along the 45-degree line where actual outcome always equals the EV. This, however, will, in general, not be the case when using probabilistic forecasting. When forecasting uncertain quantities, as is the case for all forecasts, we should use distributions to estimate P50-values, and look for two characteristics:

1. Approximately half of the P50-markers are to the left of the 45-degree line and half are to the right. The actual value is greater than the estimated P50 half of the time, and less than the estimated P50 half of the time (this is the definition of the P50). This assumes that the estimated distribution is symmetric as it is strictly true for the P50 only.
2. Approximately 80 percent of the error bars touch the red, 45-degree, line. That is, the actual value falls within the estimated P10/P90 range 80 percent of the time.

In the following we will look at closer at production attainment in the first four years of field life. The purpose is to investigate whether oil & gas companies operating in Norway are well calibrated when they estimate production for a new development. To do so, we include the P10/P90 estimates in our analysis. By “well calibrated” we mean that the production predictions should be debiased and satisfy the following requirements:

- The range of actual production outcomes fall within the range of predicted production rates.
  - ➢ If the actual outcomes fall outside the range of predicted possible outcomes, the estimator is overconfident (Kahneman & Tversky, Judging under Uncertainty: Heurustics and Biases, 1974)
- The average of the predicted production rates should be close to the average of the actual production rates.
  - ➢ If this is not the case, the estimator is optimistic or pessimistic in his or her predictions.

Although in this case, actual outcome for a given field consists of a single value for each year, the operators are asked by the NPD to provide three values for each period: expected production and the P10/P90 percent confidence interval.

To identify the tree values requested by the NPD, the estimator needs to assess the probability distribution over the production for each period. The expected production, $E(q_t)$ for any year is given by the probability weighted sum of the possible production rates.

Equation 1: Expected production for a given year

$$E(q_t) = \sum_{i=1}^{n} x_i p_i$$

where x_i represent the possible rates and p_i the associated probabilities[11]. Similarly, the P10/P90 percentiles cannot be identified without first having assessed the probability distribution over the production for each period.

In general, means or expected values are additive; i.e., the mean of the total production in the first four years is given by simply summing the mean of the production for each year, 0 through 3. However, percentiles cannot be added in the same way to get the P10-, P90-, or P50 values for the four-year production. Rather, a Monte Carlo simulation approach can be used for this purpose. Furthermore, it is to be expected that there is some dependence (autocorrelation) between the production for each year. As this dependency will impact the four-year percentiles, an autoregression analysis is required.

In this work we go through the following steps to identify the P10/P90 percentiles for the four-year production estimates:

1. Each year has three estimated production numbers which, according to NPD guidelines, should represent the P10, best estimate, and P90 estimates. We start fitting a beta distribution by setting the low- and high values as P10 and P90 respectively. Further, min is set to 0, and

---

[11] Although the probability distributions used often are continuous, computer implementation generally requires that the distributions are discretized.

max at approximately 2*high. The result is that each of the first four time periods now have a continuous distribution representing the estimated production for that year, based on the estimates provided by the companies.

2. The next step is to include the year-on-year autocorrelation production. This is done by autocorrelating the actual production in years 0-2 with the actual production in years 1-3; i.e., an autocorrelation with a lag of one. This gives a correlation coefficient (and covariance) for the year-on-year dependency which is used to rank correlate the distributions for estimated production for the first four years.

3. Finally, we sum production for each field in years 0–3 and conduct a Monte Carlo simulation with 5000 iterations to aggregate this into the total production for the first four years. The result of this is a probability distribution over the four-year production from which we can identify the mean-, P10-, P50-, and P90 values.

Using this procedure, we have correctly identified the means and percentiles required to compare estimated production with actual production in a probabilistic sense. The mean from the distribution, deviates less than 3 percent from the sum of the annual means for all fields. We start by looking at a scatterplot of the actual four-year production versus the P50 estimate of the first four years as shown in the graph below.

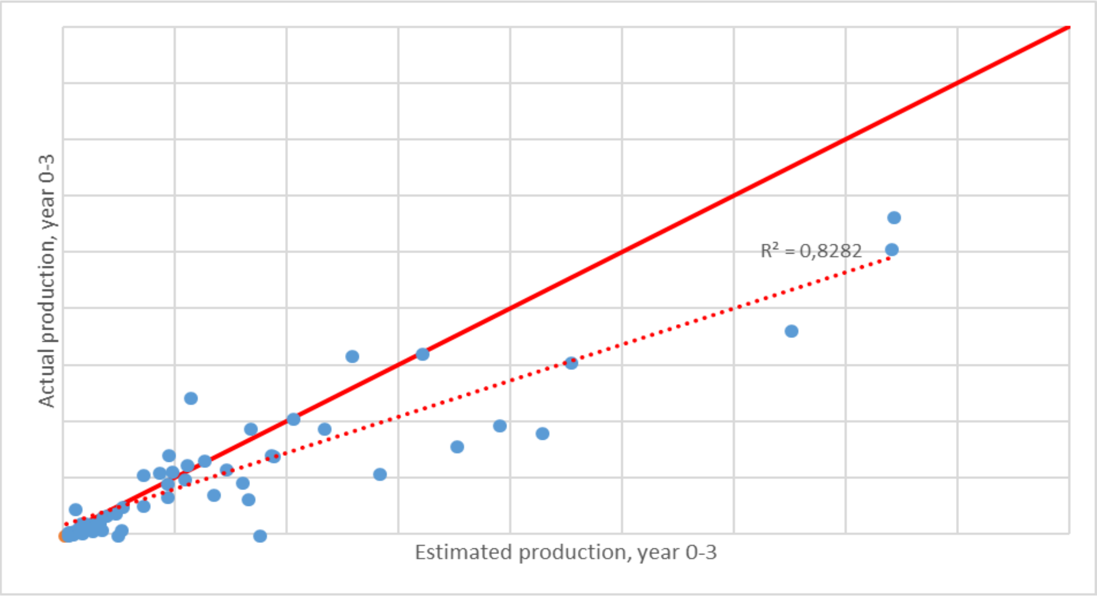

Figure 29: Distribution of results for 56 fields on the NCS. only production in year 0-3 is included, sorted according to actual production start

If estimates were debiased, about half of the blue dots would lie above the red line, and half below. 67 percent of the dots lie below the line, illustrating overconfidence and overestimated production for the first four years. The dotted line is the approximated linear regression to the scatter plot that the blue dots make up. It is significantly steeper than the solid one, with an R^2 of 0.8282, which can be interpreted as; 82 percent of the actual production can be explained by the estimate. Based on the illustration, it is reasonable to conclude that production forecasts for the first four years are biased, and that measures should be taken to improve the quality of forecasts.

4.5 High- and low estimates

In the next figure P10- and P90 error bars are included to see whether and how often production falls within the 80-percent prediction interval that the two estimates make up. The blue dots illustrate the P50-estimate, while the error bar is given by the low- and high outliers. If debiased, half of the dots should lie on each side of the solid red line, and 80 percent of the error bars should touch it.

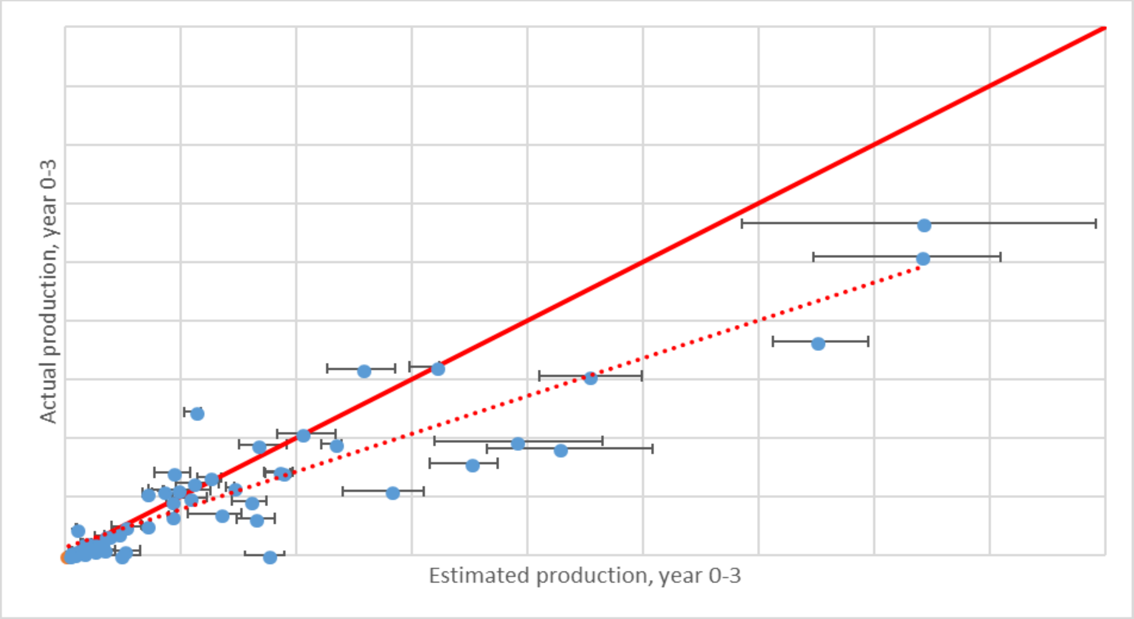

Figure 30: Distribution of results for 56 fields on the NCS, with error bars illustrating the 80 percent confidence interval for each estimate

On first sight, it seems that more than 80 percent of the outcomes are outside their 80-percent confidence interval. But the figure only clearly illustrates results for bigger fields. To get a better understanding of the results in smaller fields, Figure 31 shows the same illustration with smaller values on the axes. The results are similar; fields are producing less than estimated in the first four years. The trend is the same in all levels of field size.

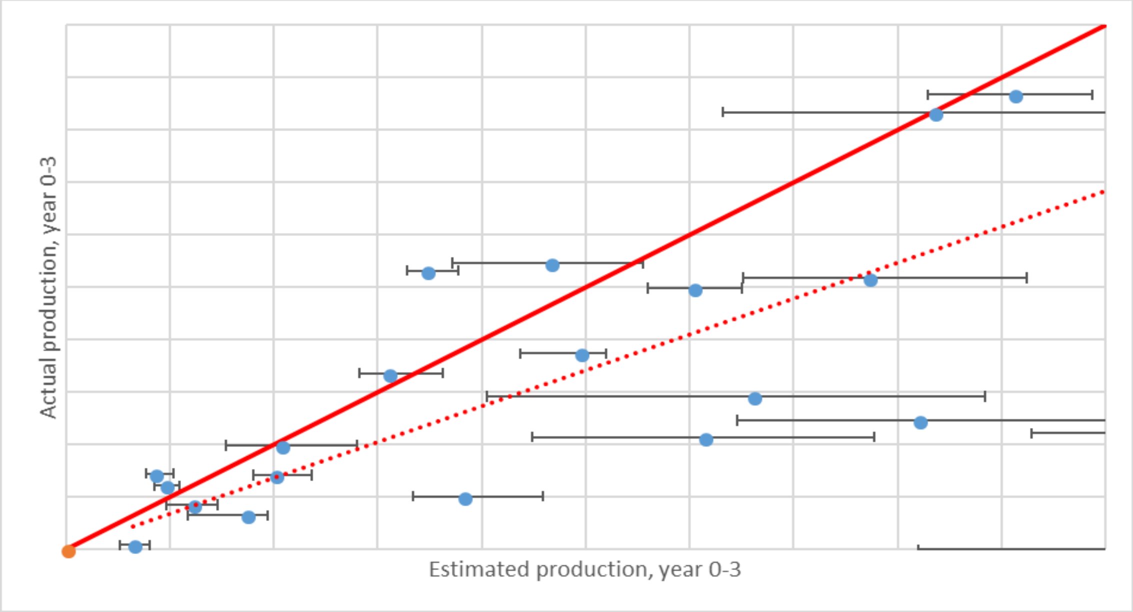

Figure 31: Distribution of results for fields on the NCS, with error bars illustrating the 80 percent confidence interval for each estimate. Zoomed in on minor fields

The illustrations are summarized in the table below. 58 percent of fields produce less than the low estimate in the first four years. Of the 56 fields, only 25 percent produced inside the given 80 percent confidence interval. 33 percent had production higher than the P50 value from the distribution. Results from a perfectly calibrated forecaster is shown in the second line.

Table 3: Summary of the industry's ability to forecast production in year 0-3

	Inside P10/P90	**Under P10**	**Over P90**	**Over P50**
The industry's forecasts	23 %	64 %	13 %	25 %
Perfectly calibrated forecasts	80 %	10 %	10 %	50 %

4.6 Have the industry learned from their past mistakes?

In the analysis of time- and cost overruns, the conclusion was that overruns have occurred over a period, and that the industry do not seem to learn from their mistakes. To see whether this is the case for production forecasts, the evolution of forecasted versus actual results over time has been investigated.

Over the past decades, uncertainty quantification has increased in the oil and gas industry. One would believe (hope) that these improvements, and the use of simulations and big data, would have a positive effect on forecasts, and that this is reflected in the results.

The first four years (0-3) of production is included, and data is normalized to estimated production start. To look for a trend, simple moving average (SMA), using both five and ten years, has been applied. Simple moving average is found by taking the average of the yearly normalized production over the past 5- or 10 year periods. Figure 32 illustrates the results. The blue line gives the results for fields with PDO approval in the given year. It fluctuates, from a low of 0.09, to a max of 1.24. Despite this, the SMA's are quite stable, indicating that the quality of forecasts has not improved over time. In fact, forecasters seem to quite stably overestimate production by 20 percent.

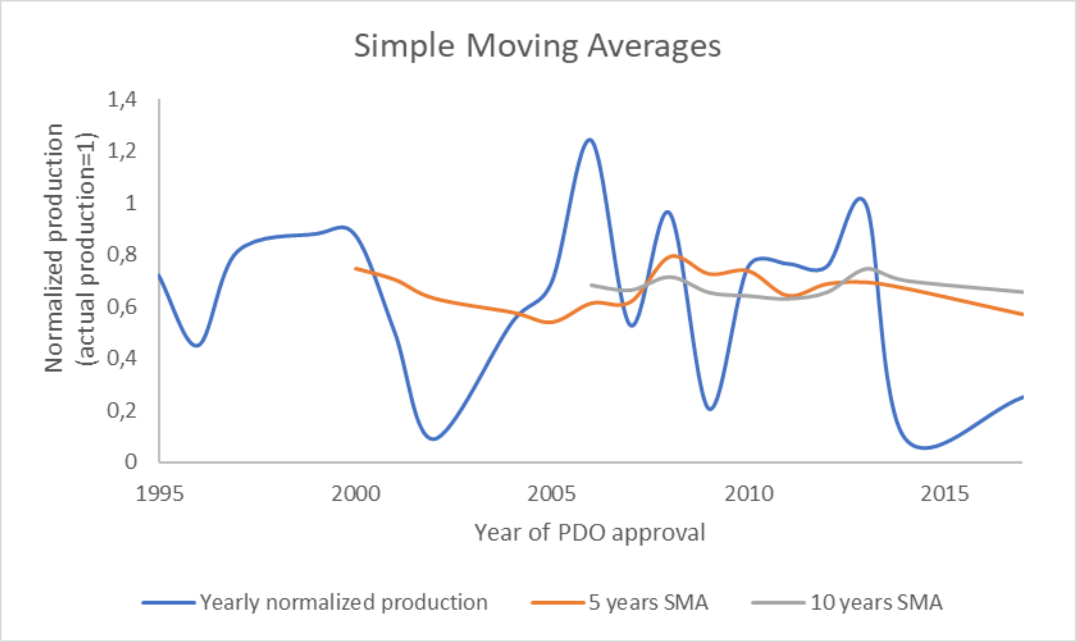

Figure 32: 5- and 10 years simple moving average for production forecasts. Only production in year 0-3 included. Sorted by number of years after actual production start

Forecasters in companies operating on the Norwegian Shelf are biased. Their estimates are overconfident, have been so over a period, and there is no sign indicating that they are getting any better. Even though companies are not just giving an expected value, but also P10/P90 estimates, they do not seem to understand the risk and probabilities related to the estimates. If they did, they would have learned from past mistakes and developed and used methods that improved both estimates, and their understanding of outcomes.

In chapter five, the economic consequence of underproduction will be addressed, and an estimated total value erosion from not meeting budgets presented.

5 Economic consequence of delays and underproduction

The following chapter will outline the economic effects of underproduction. As an introduction, total production profile for the 56 fields will be presented and discussed.

5.1 Production profile – normalized to estimated production start

When normalizing data to estimated production start, and including actual production, the obtained production profiles are illustrated in Figure 33. Here, only mean estimate is included, as P10/P90 values are not additive.

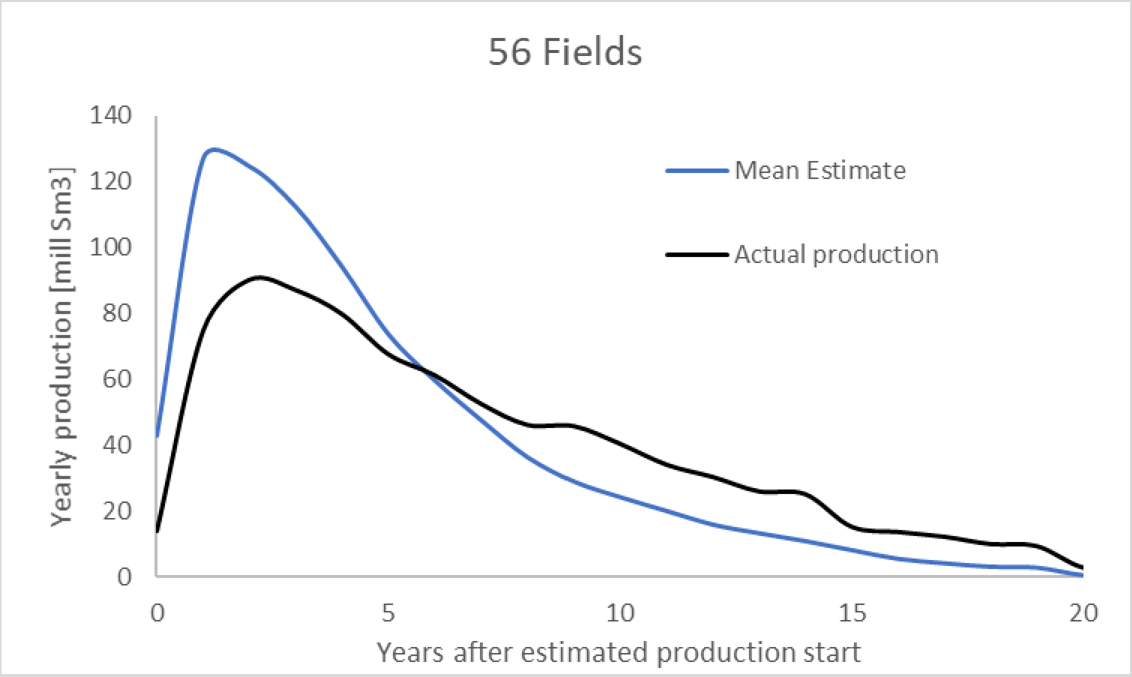

Figure 33: Yearly estimated- and actual production for all fields, normalized to estimated production start

Actual total production, illustrated in black, is significantly less than forecasted for the first years of estimated production. In the sixth year after estimated production start, total actual production grows larger than the mean estimate, and stays higher from that point on and throughout the lifetime. In the year of forecasted production start, the mean estimate is as much as 202 percent, or more than three times, higher than actual production. In the first year after forecasted production start, the mean estimate is 70 percent higher than actual production.

The black line, which illustrates actual production, has some spikes. The spikes are due to new investments/developments in already existing fields. An overview of these investments is given below. For example, the spikes in year 7-9 after estimated production start is due to projects for expanding Fram, Balder, Gullfaks Sør, etc.

Table 4: Overview of additional investments in already producing fields.

Field	PDO Approved	Investment	Years after PDO
VALE	2001	2005	4
FRAM	2001	2007	6
VEGA	2007	2013	6
BALDER	1996	2003	7
GLITNE	2000	2007	7
OSEBERG SØR	1997	2004	7
TAMBAR	2000	2007	7
URD	2004	2011	7
VILJE	2005	2012	7
GULLFAKS SØR	1996	2004	8
VOLVE	2005	2013	8
ALVE	2007	2016	9
VARG	1996	2005	9
NORNE	1995	2005	10
KVITEBJØRN	2000	2013	13
OSEBERG ØST	1996	2011	15
SYGNA	1999	2015	16
VISUND	1996	2012	16
ÅSGARD	1996	2012	16

Production in the plateau stage is significantly lower than forecasted. For the first years of production, less than 25 percent of fields are producing the estimated mean volume. For more than 60 percent, actual production is lower than the low estimate. As explained, the low estimate is defined as a number in which the estimator believes it is a 10 percent chance of producing less than.

The cumulative profile is given in Figure 34. After four years, actual production is 150 million Sm3, or 30 percent lower than estimated mean production. Average total estimated mean production for a field on the Norwegian shelf is approximately 20 million Sm3. In other words, the 58 fields underproduce with 7.5 average fields in the first four years.

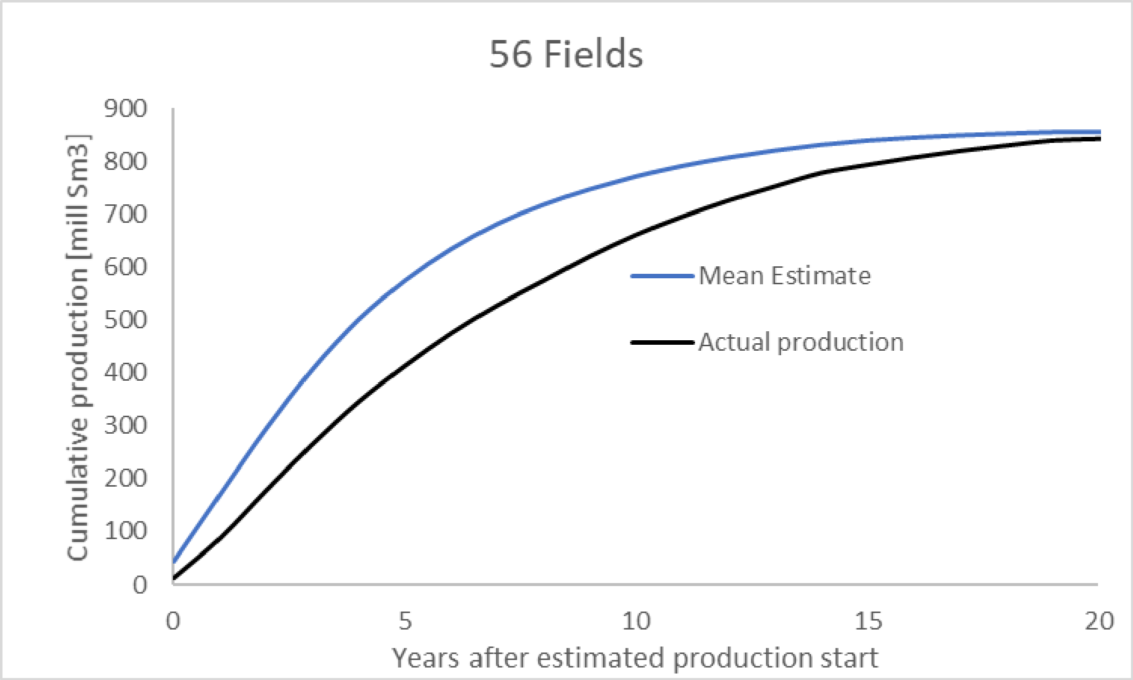

Figure 34: Yearly cumulative estimated- and actual production for all fields, normalized to estimated production start

Total production over the entire lifetime lies close to the mean estimate. This means that fields on the NCS have an increased tail production that in volumetric terms is equal to the decreased plateau production. As discussed, increased tail production can for example be due to further investments, technical developments or other factors that was unknown at the time of PDO approval. An increased tail production will also have less effect on the PV of the field, as expected revenues are discounted back to the point of time when the PDO was approved.

Figure 35 shows the share of yearly production relative to total production. Fields are forecasted to produce about 15 percent of the total volume in the first, second, and third year after estimated production start. About 50 percent of the total volume is estimated to be produced in the first four years of production. Actual data show that, on average, the fields need almost six years before producing half of their total reserves.

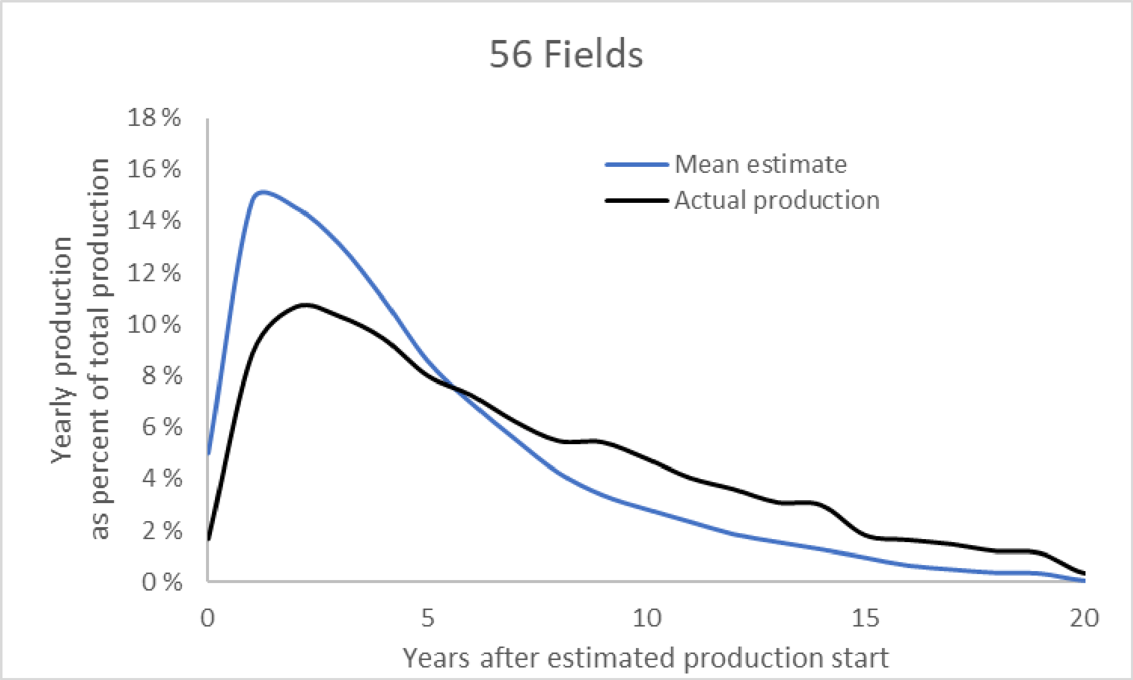

Figure 35: Yearly estimated- and actual production as percent of total production, normalized to estimated production start

5.2 Production profile – time shifted to actual production start

Time shifting data to actual production start reduces the effect of schedule overruns, as first actual oil is set as time zero. Despite this, overruns within a calendar year still have an effect. Results when using this method is illustrated in Figure 36.

The figure shows the same as Figure 33, now sorted as described in method two. Although the effect of time overruns is reduced, actual production the first years after production start is still significantly lower than estimated. Yearly actual production exceeds yearly estimated mean production in year 6 after actual production start and stays higher for the rest of the period. The spikes, although less prominent than in Figure 33, are due to the same reasons.

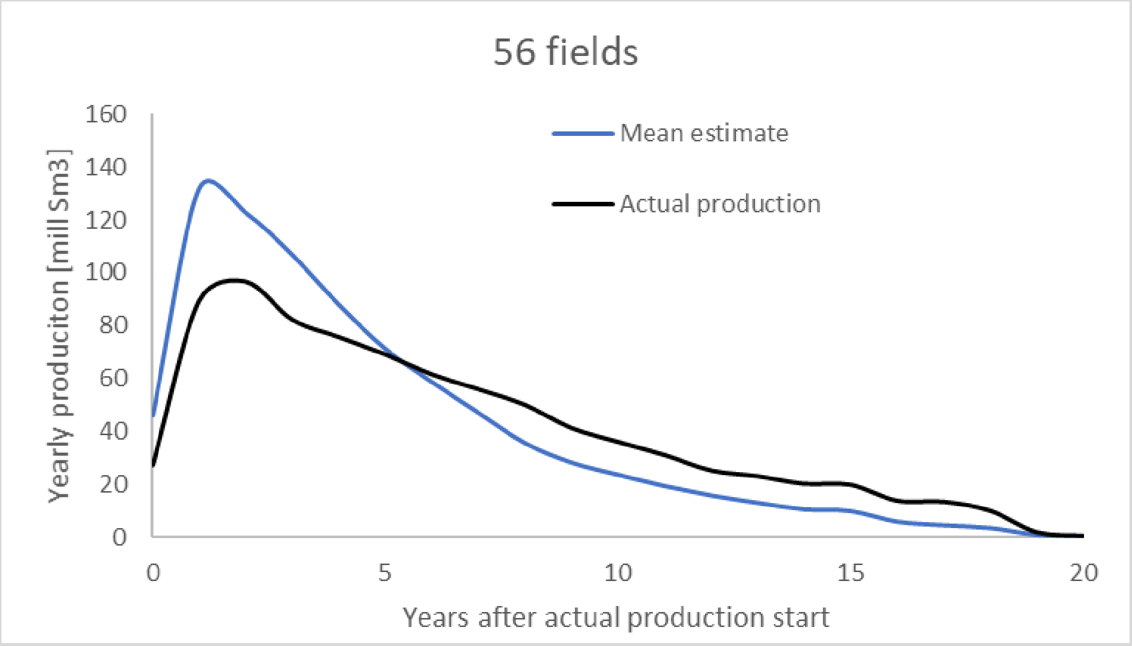

Figure 36: Yearly estimated- and actual production for all fields, time shifted to actual production start

This means that there is a "double dipping effect". First, developments tend to run late. On average, production start 202 days later than estimated. When production starts, yearly production rate is lower than estimated. The estimated mean production for the first year after first oil is twice as large as the actual production. In the second and third year, it is 30 percent larger. Figure 37 shows the relative cumulative profile of Figure 36. Fields were forecasted to produce half of their total volume in four years but spent six years doing so.

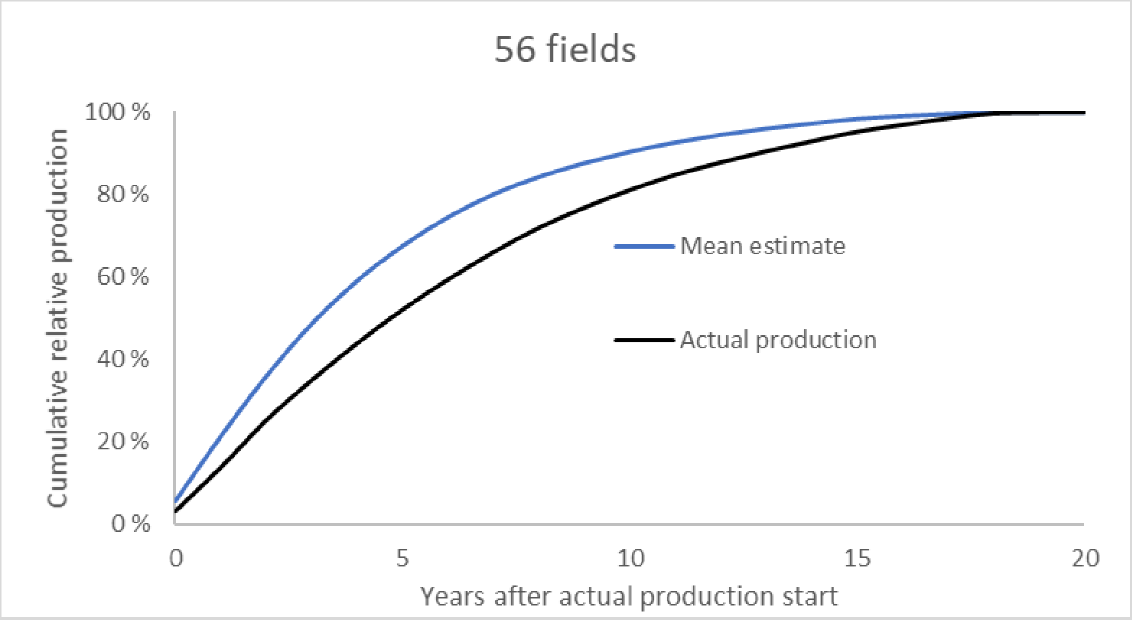

Figure 37: Yearly cumulative estimated- and actual production for all fields, time shifted to actual production start

When applying method two, total actual production is about 8 million Sm3 higher than the total mean estimate. Although total production outruns the mean estimate, one must keep in mind further investments, and the fact that tail production has a significant discounting effect which decreases its influence on the PV.

5.3 Present value of underproduction

From an ultimate recovery point of view, the mean estimate seems to be quite accurate. Total actual production lies close to the total mean estimate. However, from an economic viewpoint, underproduction in the early years lead to substantial value erosion.

This thesis addresses the approval of PDO’s and discuss whether the numbers presented in the plans are biased. To estimate the PV of underproduction, all actual- and expected revenues from production has been discounted back to the PV at the time of PDO approval, and then adjusted for inflation to reflect 2017-values.

Equation 2 is used to find the PV for a given production, *i*[12] years after startup, where *t* is years after PDO approval:

Equation 2: Present value of future revenues from oil production

$$PV_i\,[mill\,NOK] = \frac{Production_i\,[mill\,Sm^3]\cdot conversion\,rate\left[{}^{bbl}/_{Sm3}\right]\cdot exchange\,rate_i\,\left[{}^{NOK}/_{USD}\right]\cdot\,oil\,price_i\left[{}^{USD}/_{bbl}\right]}{(1+wacc_i)^t}$$

---

[12] Production can either be an estimate, or an actual production

5.3.1 Inputs

The conversion rate $[{}^{bbl}/_{Sm3}]$ is constant and equal to 6.29 (NPD, 2009). Exchange rates and oil price on the other hand, varies. Yearly exchange rate is downloaded from the Norwegian Bank (Norges Bank, 2018) and illustrated in Figure 38. Oil price, typically referred to as the brent spot price, is downloaded from the U.S. Energy Information Administration (2018). The price of oil quintupled from 1999 to 2011, which has a significant effect on revenues from oil production the respective years. Annual average Brent spot price is given in Figure 39.

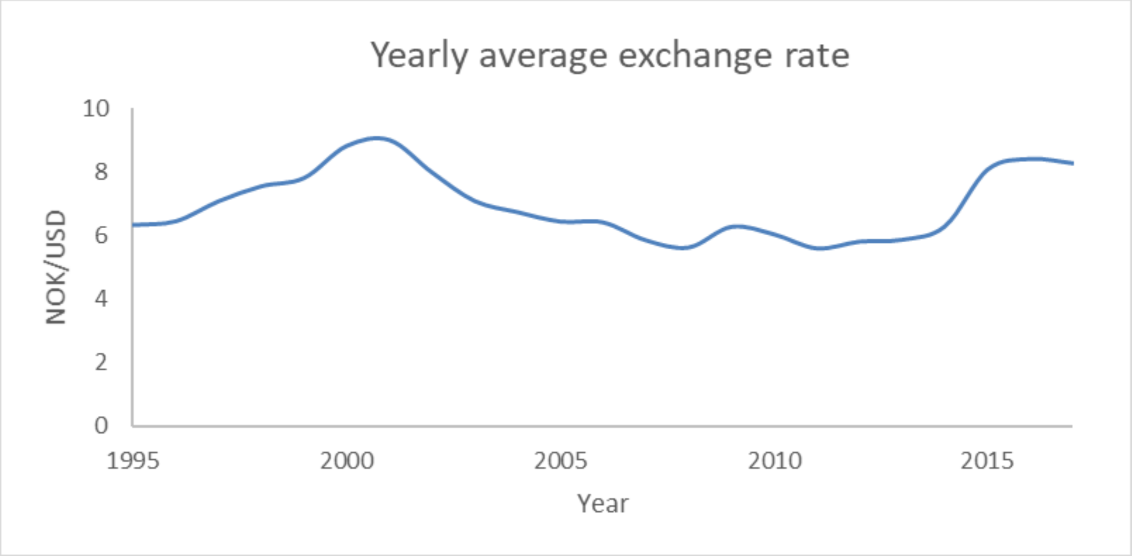

Figure 38: Annual average exchange rate between USD and NOK

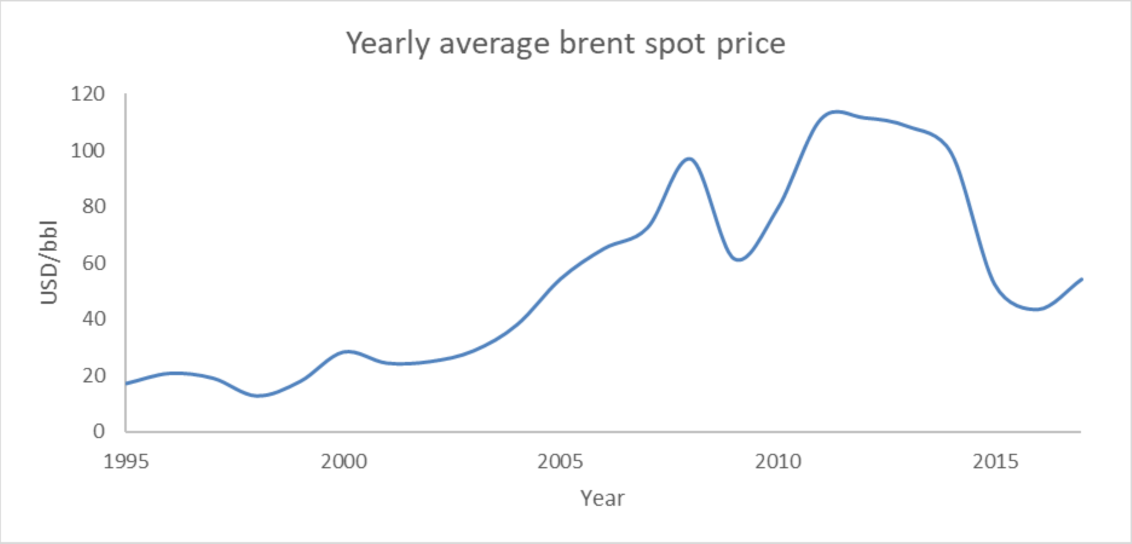

Figure 39: Annual average price of Brent spot crude oil (US EIA)

For all fields, economic value of both estimated and actual production each year is found from Equation 2. WACC is set to 10 percent, which is referred to as standard in the petroleum industry by Mercer Capital (2016). Equation 2 gives the forecasted and actual cash flow from the project, discounted to the year of PDO approval. Next, the numbers are adjusted with inflation factors from Statistics Norway (2018) to represent 2017-values

5.3.2 Example

The table below is an illustration of how PV loss is calculated for a random field on the NCS. The field had its PDO approved in 2007, and started producing two years later, without schedule overruns. In the year of startup, it produced the same volume as it was forecasted to but has since then produced at a higher rate than estimated. The total revenue lost is -1 781 million NOK in 2007-values, corresponding to an increased revenue of 2.2 billion 2017-NOK, indicating that the field has delivered more revenues than estimated.

Table 5: Example of revenue for a random oil field on the NCS.

Field	**XXX**										
PDO approved	**2007**										
Discounting factor	**10 %**										
Years after PDO	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Mean estimated production	0	0	0,26	0,21	0,14	0,09	0,07	0,05	0,04	0,03	0,03
Actual production	0	0	0,26	0,24	0,32	0,24	0,14	0,18	0,15	0,15	0,18
Oil price [USD/bbl]	73	97	62	79	111	112	109	99	52	44	54
Exhange rate [NOK/USD]	5,9	5,6	6,3	6,0	5,6	5,8	5,9	6,3	8,1	8,4	8,3
Conversion factor [bbl/Sm3]	6,3	6,3	6,3	6,3	6,3	6,3	6,3	6,3	6,3	6,3	6,3
Annual economic value of underproduction [mill NOK]			-4	-96	-714	-609	-271	-525	-300	-266	-425
Discounted value [mill 2007-NOK]	0	0	-3	-72	-488	-378	-153	-270	-140	-113	-164
Total revenue lost [mill 2007-NOK]	***-1 781***										
Inflation adjustment	1,24										
Total revenue lost [mill 2017-NOK]	***-2 215***										

The same calculation as illustrated in the table is done for all 56 fields, and then summed.

5.3.3 Results

Total accrued PV loss has been calculated using the two ways of normalizing data, as described in chapter 4.3.5.

Normalized to estimated production start

Total accrued lost value due to underproduction and delays is close to 65 billion 2017-NOK. This is the difference between the field developments estimated and actual revenues, when taking the time value of cash flow into account, expressed in 2017 values.

Time shifted to actual production start

Estimated total accrued lost value due to underproduction is almost 19 billion 2017-NOK. This is the lost value when reducing the effect of delays, expressed in PV.

5.3.4 Removing the effect of further investments

As this paper looks at the estimates in- and decision to approve PDO's, decisions regarding investments, improvements, and implementations that are taken later in a fields lifecycle are irrelevant. Figure 40 illustrates the investment profile for Balder, a field on the NCS. The field had its PDO approved in 1996 and started producing in 1999. In 2003, Ringhorne was opened close by, and implemented as a part of Balder. Further investments and PDO's affecting the production profile of Balder have been approved later (Norwegian Petroleum, 2018). As one can see from the investment profile, investments after production start in 1999 are higher than costs related to opening the field.

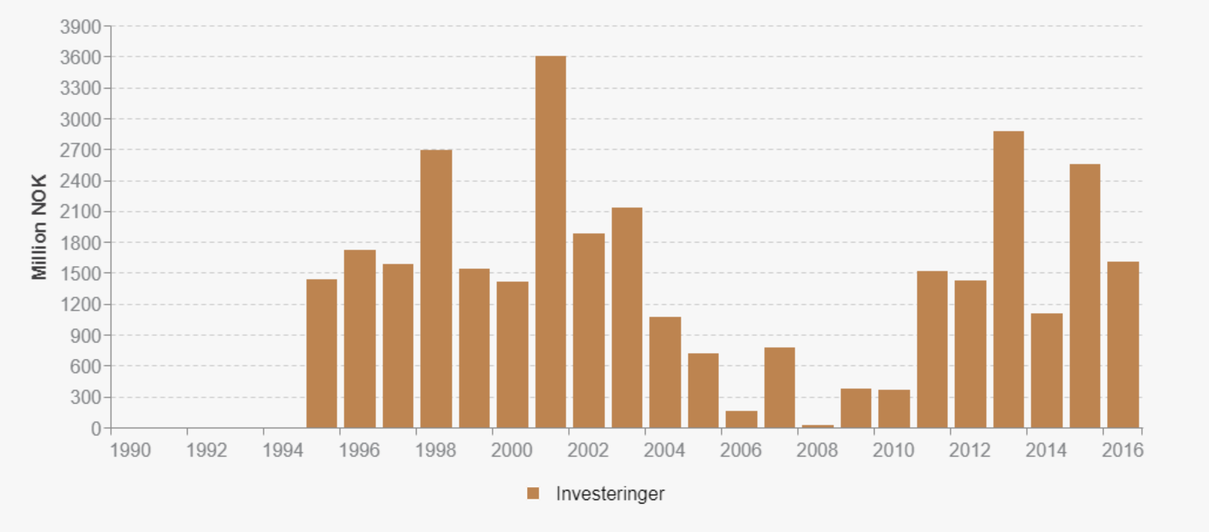

Figure 40: Investment profile for Balder (Norwegian Petroleum)

As a result, Balder increased its production drastically in 2003/2004. Production profile for Balder is given below. Oil production in 2005 was more than doubled from 2002. When further investments or new discoveries affect production in such a way, comparing numbers is irrelevant. Production from the point of the attachment of Ringhorne and on is not comparable with estimates given in the PDO.

Figure 41: Production profile for Balder (Norwegian Petroleum)

19 fields had investments that made the production profile incomparable with the PDO-estimate (Table 4). Removing estimated- and actual production from the point where investments affects production has immense influence on the economics. For some fields, almost all production years are removed, while for others, investments accrued after decades

of production. After adjusting for this effect, total loss is 261 billion 2017-NOK, when including the effect of schedule overruns. When data is normalized so that the effect of overruns is reduced the total PV loss accrues to almost 200 billion 2017-NOK. The results are summarized in Table 6.

5.4 Total loss due to budget overruns and underproduction

Delays and the effect of schedule overruns have been subject to earlier reports, among others by Rystad Energy and Haukaas & Mohus. A report published by Rystad Energy, sited in E24, says that 42 percent of the lost value is connected to delays and schedule overruns (Lorentzen, E24, 2017). Haukaas & Mohus estimated the total value lost due to cost overruns in 78 fields to be 231 billion 2015-NOK, while Taraldsen (2015) estimated it to be 200 billion 2015-NOK when using a smaller time-frame.

As opposed to development cost and schedule overruns, deviations from forecasted production on the NCS has yet to be the focus of a major study. This chapter has evaluated the economic impact of underproduction using two different normalization methods. None of them can fully isolate production shortfall due to delays or unexpected production stops after first oil, which is used as an explanation for underproduction in for example Goliat (Flekkøy, 2017). Despite this, the difference between them gives an estimated value of lost revenue due to delayed startup.

The results, using the two normalization methods, are as follows:

Table 6: PV lost because of schedule overruns and underproduction

Summary	Estimated PV [MNOK]		Actual PV [MNOK]		Difference [2017 MNOK]	
Method 1	kr	1 219 340	kr	958 246	kr	261 094
Method 2	kr	1 157 951	kr	958 246	kr	199 705
Lost PV due to schedule overrun/delayed production start					**kr**	**61 389**
Lost PV due to underproduction after production start					**kr**	**199 705**

5.5 Total accrued lost value

Not fulfilling budgetary goals leads a PV loss. When combining the economic impact of the three discussed measures, an estimated total lost value can be obtained. The results are summarized below.

Table 7: Total value lost due to cost- and schedule overruns, and production shortfalls

Reason	**Lost value [2017 MNOK]**	
Cost overrun	kr	213 219
Schedule overrun	kr	61 389
Underproduction	kr	199 705
Total PV loss	***kr***	***474 313***

Field developments on the Norwegian Shelf in the period 1995-2017 have a total PV loss of 474 billion 2017-NOK, equivalent to almost 90 000 NOK per Norwegian capita (Statistics Norway, 2018). They overrun their budgets with 213 billion. Despite this, schedule overruns lead to a loss in PV revenues of 61 billion 2017-NOK. When fields start to produce, they underproduce the first 5-6 years, resulting in a lost revenue of 200 billion. This only includes cost data for 68 fields, and production data for 56 fields. If data for all fields were available, it is reasonable to expect that the total value will be even higher.

Flyvbjerg proposed a rule of thumbs for megaprojects, saying that they went "over budget, over time, over and over again" (Flybjerg, Garbuio, & Lovallo, 2009, p. 171). For the Norwegian petroleum industry, the rule seems to be "over budget, over time, and reduced revenue, over and over again."

Table 8 below shows relative deviations from budgeted cost, time and production. Cost and production are given as economic PV, while the schedule overrun is given in days.

Table 8: Relative overrun on terms of cost (NOK), time (days) and underproduction (NOK)

Source	**Percent deviation**
Cost overrun [NOK]	26 %
Schedule overrun [days]	25 %
Underproduction [NOK]	17 %

On average, offshore development projects on the Norwegian Shelf overrun their budgets by 25 percent. Even though they overrun their budgets, projects are finished 25 percent later than estimated. When developed and installed, despite the cost- and time overrun, they lose 17 percent of their forecasted profits due to underproduction.

6 Discussion

Chapter four shows that cost- and time overruns are evident in development projects on the NCS. It also shows that the industry has a clear tendency to overestimate production the first years after startup. Chapter five shows that these factors combined result in a PV loss estimated to be approximately 474 billion 2017-NOK. This chapter look at research in other industries and discussed underlying psychological and corporate factors that affects estimators when they forecast the outcome of a project.

6.1 Overruns in other industries and countries

6.1.1 Megaprojects across sectors

Cost- and time overruns in large industrial projects have been thoroughly investigated by several researchers, professors, and companies specializing in analysis. In *Industrial Megaprojects* (2011a, p. vii) Edward Merrow stated that of more than 300 projects across several industries, 65 percent did not meet their financial goals. Merrow classified a successful petroleum project by the following criteria's (Merrow E. W., 2011b):

- Was the project developed without fatal injuries or deaths?
- Was the project completed with less than 25 percent cost overrun?
- Was the project completed with less than 25 percent time overrun?
- Did the field produce as much as expected the first years after production start?

6.1.2 Infrastructure projects

Bent Flyvbjerg is a Danish professor of Major Programme Management, and one of the worlds most cited scholar in papers regarding megaproject management (University of Oxford). He specializes in infrastructure, and concludes that “across the globe, large infrastructure projects almost invariably arrive late, over budget, and fail to perform up to expectations” (Flybjerg, Garbuio, & Lovallo, 2009, pp. 171-172). In a paper published in 2003 where 258 projects were analysed, he concludes that cost escalation is a global phenomenon, existing across 20 nations on five continents. He further states that “cost estimates have not improved, and cost escalation not decreased over the past 70 years” (Flyvbjerg, Skamris Holm, & Buhl, 2003).

6.1.3 Petroleum Development Projects

In an interview with Oil & Gas IQ (2013), Ed Merrow said that in the petroleum industry, 78 percent of development projects were not classified as successes. Of the projects that are not classified as a success, 66 percent has lower production than expected the two first years after production start. According to his research, projects across other industries have success rates of about 50 percent. The petroleum industry matched this rate in 2003, but when updating his research in 2011, petroleum projects had fallen short (Merrow E. W., 2011b)

In 2014, Ernst & Young (EY) investigated the oil and gas sector, analysing performance for LNG, pipeline, refining and upstream projects. Their research included cost data for 205 projects, and time data for 242 projects, from across the globe. Results show that completion costs, on average, are 59 percent higher than estimated. Of the projects, 64 percent had cost overruns, and 73 percent had time overruns (EY, 2014).

The British Oil and Gas Authority (OGA) published in 2017 out a report on time- and cost overruns for projects on the United Kingdom Continental Shelf (UKCS) in the period 2011-2016. The research shows that of 34 completed projects, fewer than 25 percent had been delivered on time, averaging an overrun of 10 months. The projects were also finished 35 percent above their cost estimates. For 20 projects that were still under execution, the average delay was 13 months and cost overrun 24 percent. Figure 42 gives an overview of the delays and cost overruns, sorted by the type of installation (OGA, 2017, p. 8).

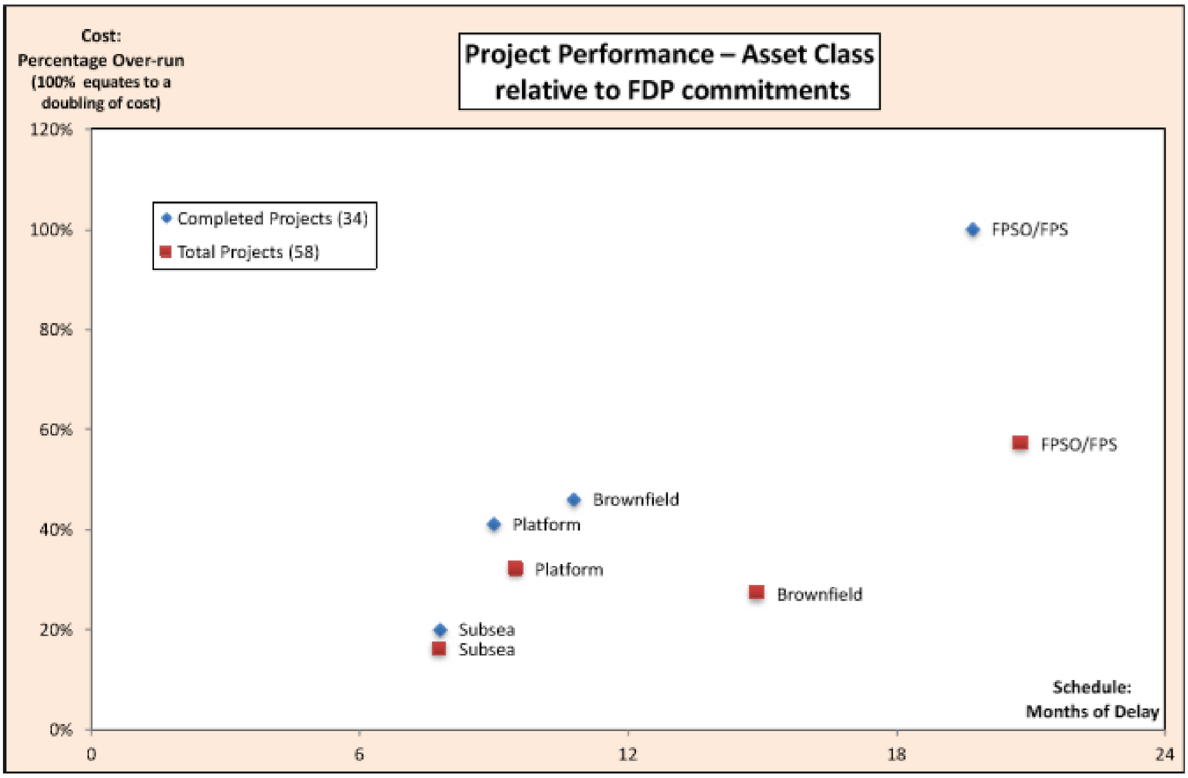

Figure 42: Schedule- and cost overrun for projects on the UKCS (OGA)

6.1.4 Production shortfall

According to Nandurdikar & Wallace (2011) petroleum projects on average deliver 81 for each 100 barrels of predicted production. In 1995, they delivered 94, while they in 2011 only delivered 75 percent of what they were forecasted to. Their research concluded that projects with an aggressive and schedule driven approach are far more likely to experience production shortfalls than projects with a conservative appraisal (2011, p. 4). It also showed that only 30 percent of projects conduct root-cause analysis to understand why they fail to deliver predicted production rates.

6.1.5 Summary

As the reports sited show, cost- and time overruns seem to be the norm in several industries, in all parts of the world. In the petroleum industry, we seem to produce 20 percent less than expected, and the results keep getting worse. The industry seems to overrun budgets more often than they meet them, and there is no research that indicate that they are improving. But why is it that they never seem to learn from their mistakes? Cost overruns have been a major focus in the Norwegian news media, and both public and private projects managers, in different industries, have been subjected to heavy criticism when overspending budgets (Ramsdal & Andersen, 2016; Riekeles, 2018; Oskarsen, 2018). In the next chapter we discuss factors that contribute to overconfident estimates. Psychological and hierarchal factors that affect us when forecasting future outcomes will be presented, and we explain why the industry's estimates tend to be optimistic.

6.2 Reasons for forecasting errors

The research summarized in chapter 6.1 show that overspending budgets and not meeting budgeted goals in large projects is a known phenomenon across the world. When explaining why the industry fail to meet their estimates, the papers seem to be unambiguous; it is the forecasts, and not the ability to manage projects that is to blame. As stated by the OGA "there has been no visible improvement in the ability to predict outcomes" (2017, p. 12). Flyvbjerg and his colleagues also concluded that cost estimates have not improved over the past 70 years (2003).

Human judgement was in 1979 documented by Kahneman & Tversky to genereally be optimistic due to overconfidence and insufficient regard to distributional information (1979a, b). They introduced the *planning fallacy* as the tendency to believe that your own project will proceed as planned, even when research show that earlier comparable projects have run late (ezeconomics, 2016). In *Delusions of Success* (Lovallo & Kahneman, 2003) the definition was expanded to also include the tendency to underestimate cost, time and risk of future events. A result of the planning fallacy is that planners and managers pursue projects that are unlikely to deliver on budgeted costs and schedule, and to deliver estimated returns (Flyvbjerg, 2005b).

Flybjerg, Garbuio & Lovallo (2009, p. 172) argues that forecasting errors can be grouped into three main categories:

- Bad luck
- Delusion
- Deception

Bad luck is a general and common term for explanations that managers and companies use when asked questions about why they underperform (Flybjerg, Garbuio, & Lovallo, 2009, p. 172). Respondents often use factors that are seemingly out of their control and indicate that the poor outcome could not have been avoided. They argue that the reasons were unknown when planning the project. Thus, they are not liable.

Delusion is a term which explains underlying psychological effects that lead to underestimation of tasks. Flyvbjerg, Garbuio & Lovallo explains it as when "managers make decisions based on delusional optimism rather than on a rational weighting of gains, losses, and probabilities" (2009, p. 172). In other words, it is an involuntary mistake that forecasters make when they predict the outcome of a project. It can be caused by several factors but is characterized by executives taking an inside view on the decision at hand.

Deception on the other hand, is a strategic misrepresentation of facts to present the project at hand as better than it is. It can be caused by what is generally known as the principal-agent (P-A) problem. A P-A problem occurs when an agent and a principal have conflicting self-interests.

6.3 Bad Luck

When confronted with poor outcomes, managers often use bad luck, or events that were out of their control, to explain the result. Haukaas & Mohus (2016) presented several excuses used by Norwegian leaders, expressed in both the media and to the government. Among the most prevalent were bad weather, lack of quality from suppliers and change of complexity in the reservoir. Recent projects such as Goliat, Martin Linge, Kristin and Yme have all used weather as an explanation for cost overruns of more than 20 percent (MPE, 2006; Stenberg & Skodje, 2011; Kongsnes, 2015; Stangeland, 2015). Bad weather on the Norwegian Shelf should not be surprising to anyone, especially not managers leading megaprojects that are dependent on a specific type of weather to complete offshore installations. Future weather is simply another uncertainty that need to be factored into forecasts for cost, time, and production.

This paper does not deny that some projects are subject to changes and conditions that lead to an unexpected risk. However, as seen from the results presented in chapter four and five, it is evident that the forecasts that are presented and accepted in the PDO are biased, and that there are underlying psychological and motivational factors that in the long run makes it impossible to reach budgeted goals. If there is a substantial risk of a project being delayed due to weather conditions, this risk should be addressed in the PDO. In addition, the consequences and probabilities of it occurring should be included in the stochastic analyses that cost-, time- and production estimates should be based on.

6.3.1 Do they really want to learn?

Site manager in Hydro, Karsten Knudsen, appraised in 2000 a Norwegian yard for punctuality and high quality in the development process. He said that this was one of the reasons why the project was completed “without cost overruns” (Mydland, 2000). The specific project was completed with a cost overrun of 20.6 percent. Haukaas & Mohus gives examples of similar statements from other Norwegian managers. When overrunning budgeted costs with 20 percent is presented as finishing “without cost overruns”, does this indicate that the industry really wants to learn from their mistakes?

In their analysis of production shortfall, Nandurdikar and Wallace revealed that only 30 percent of projects conducted a root-cause analysis to understand the reasons for their forecasting errors. They argue that these problems persist because companies lack a single point of accountability for delivering production. Improvement require first an admission of poor or faulty forecast and then the introduction of changes to improve over time

6.4 Delusion – the planning fallacy

According to Flyvbjerg, “overoptimism can be traced to cognitive biases, that is, the way the mind thinks” (2005b, p. 9). He argues that decision makers are usually faced with a specific project. The project has its characteristics and details, which often result in the decision maker adopting an inside view when evaluating it. When adopting an inside view, managers focus more towards the specifics of the projects, rather than looking at the project in a bigger picture (Flyvbjerg, 2006). Kahneman & Tversky (1979b) argue that underweighting distributional information of earlier completed projects is perhaps the major source of error when forecasting outcomes.

If budgets for a project is developed by a group that are subject to the planning fallacy, the result will be that initiatives that are unlikely to deliver expected returns, or to deliver on cost or time, are pursued (Flybjerg, Garbuio, & Lovallo, 2009). Delusion is a term for cognitive psychological factors that predictors unwillingly are facing when estimating the outcome of future events. In petroleum development projects, delusional bias affecting estimates can be grouped into four main categories.

6.4.1 Information availability

Availability of information is a factor that often leads to cognitive bias. There are numerous examples where humans are affected by the information that is made available through mass media, instead of making their decisions based on facts. The same mechanisms are valid when a leader makes decisions in a company. Bratvold & Begg (2010, p. 165) explains that humans perception of reality is distorted because of the most available, newest and most vivid information. If a decision maker recently has been involved in a project that was successful, he will bring a feeling of success into the next project and decision. As a result, he might feel overconfident, and forget that earlier similar projects historically have not delivered the same success. This could affect his decision into being biased. Similarly, if a recent project was finished with poor results, the manager might be underconfident.

6.4.2 Anchoring

When estimating time- and cost of development projects on the NCS, it is common to use earlier completed projects as a base (Bratvold, Begg, & Campbell, 2002). Despite similarities in reservoir, depth, weather conditions and other factors, installations on the NCS will always require specific technology and adjustments. The complexity and size of the required installations are massive, and you will never find two development projects that are identical.

If you use an earlier project as base, this project might work as the anchor. You will then adjust the away from the anchor based on analyses of differences between the projects. Bratvold & Begg (2010, p. 169) outlines that these adjustments rarely account for all deviations. If the deviations are not sufficiently accounted for, estimates for the new project will be biased, and likely to be overconfident rather than underconfident (Welsh & Begg, 2010). Anchoring is a well-known source of bias, and several experiments have been pursued, revealing its effect on human estimation (Kahneman & Tversky, 1974). Yet, estimators still fail to sufficiently address all differences between projects when applying the method.

Anchoring has been laid out as a reason for overruns on the NCS earlier. The Office of the Auditor General of Norway wrote in its report in 2001 that cost estimates for Åsgard and Visund were based on earlier completed projects. NORSOK was implemented in 1994 with the aim of reducing cost and time of development projects with 40 to 50 percent by 1998. As a result, numbers from the anchorage were cut by a given percentage, without any calculations to support the cost reduction (2001, p. 3). NOU 1999:11 (1999), which was meant to describe the status on the shelf after the implementation of NORSOK, describes that several forecasts were biased due to anchoring. The report says that estimates for production wells were reduced based on recent improvement in drilling velocity for exploration wells. Estimators assumed that this improvement would be valid also for production wells. It was not, and as a result, the cost estimates were too low. The report further says that there is a “close connection between overruns related to implementation of recent technology and a flimsy cost base” (1999, p. 97).

6.4.3 Overconfidence and the illusion of control

Welsh, Begg & Bratvold published in 2007 a paper on the consequences of anchoring, overconfidence, and biases in oil and gas development projects (Welsh, Begg, & Bratvold, 2007). They used reservoir models to create estimates for producible reserves, oil price and recovery factor. Development costs were estimated by using actual cost data from projects similar in shape and size. PV was then calculated with basis in different degrees of overconfidence, from zero to 30 percent. PV for projects with debiased estimates was 246 million USD. With 30 percent overconfidence, the PV was -10 million USD. The results are illustrated below and shows the consequences that overconfidence can have on the outcome of development projects.

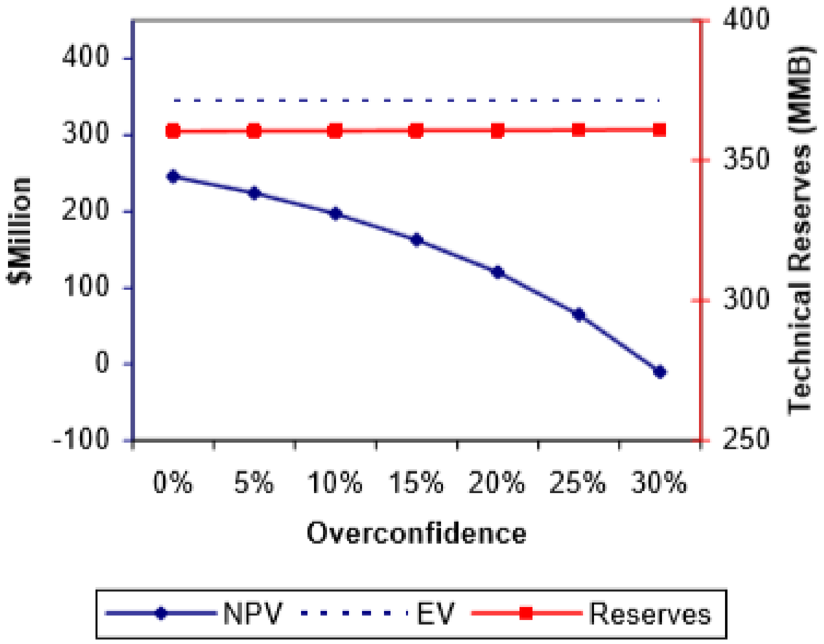

Figure 43: Consequence of overconfidence on NPV of a standard project (Welsh, Begg and Bratvold, 2007)

Overconfidence is one of the sources of bias that has been subject to most research, and there are proposed several models on how to avoid being over- or underconfident. Alarfaj & McVay (2016) measured the impact of bias in project evaluation. They concluded that moderate overconfidence and optimism can cause a portfolio disappointment of up to 35 percent. Further, their research showed that underconfidence is just as detrimental to portfolio performance as overconfidence. In other words, decreasing development costs with 20 percent is just as damaging for the company as overrunning costs with 20 percent, because it means that the company has set aside resources that could have been used in other projects.

6.4.4 Group thinking and trust heuristic

Most decisions in the petroleum industry are taken by groups. If several alternatives to solve a problem are relevant, a group of leaders and experts will gather to discuss strengths and weaknesses in each option. After discussing, the group will choose one of the alternatives.

Group thinking occurs when there are several persons involved in a decision-making process. Imagine that five managers are meeting to discuss which one of two solutions they should choose to solve a problem. If four managers agree that solution one is best, the last person might be intimidated to speak his mind. Science has shown that we seek consensus when we are making decisions in groups (Bratvold & Begg, 2010). Implicit we assume that agreement means that the decision is good, while disagreement could mean that the decision has a lower quality. The fear of disagreement could result in key facts and opportunities not being mentioned, as managers are afraid of expressing thoughts that diverge from the common consensus of the group.

The "trust heuristic" (Mackie, 2007) refers to an observation that managers tend to rely on judgments from persons that they have learned to trust, rather than expressing their own ideas and the opinion of others in the team. Welsh, Begg & Bratvold (2007) argues that using multiple sources of information acts to reduce overconfidence. Their research show that including a single additional expert opinion reduces overconfidence by about five percent when agreement is high, and ten percent when agreement is low. The results are illustrated below.

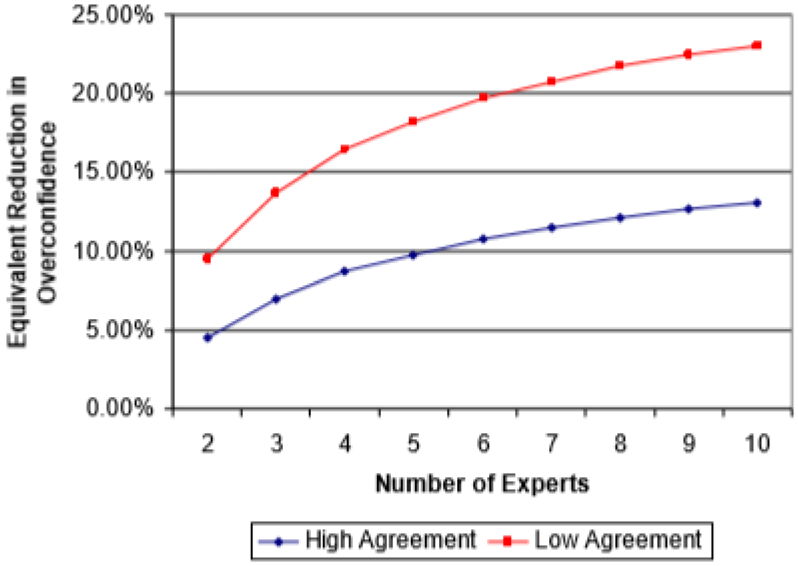

Figure 44: Effect of adding additional expert opinions (Welsh, Begg & Bratvold, 2007)

Nandurdikar & Wallace revealed that only 30 percent of projects tried to find out the reasons for their production shortfalls. In part two their study, they present results from a questionnaire by the IPA. It shows that 85 to 90 percent of teams reported that their procedure for producing forecasts were of high quality. They further asked the teams to rate the quality of their production forecasts. Comparing the teams own rating with their results show that production attainment for teams that rated the quality of their forecast as fair/poor or screening, is equal to those that gave themselves the score good/excellent. Clearly, the teams evaluating the quality of their own work as good and excellent could use an outside opinion. The results are illustrated in Figure 45 (Nandurdikar & Wallace, 2011).

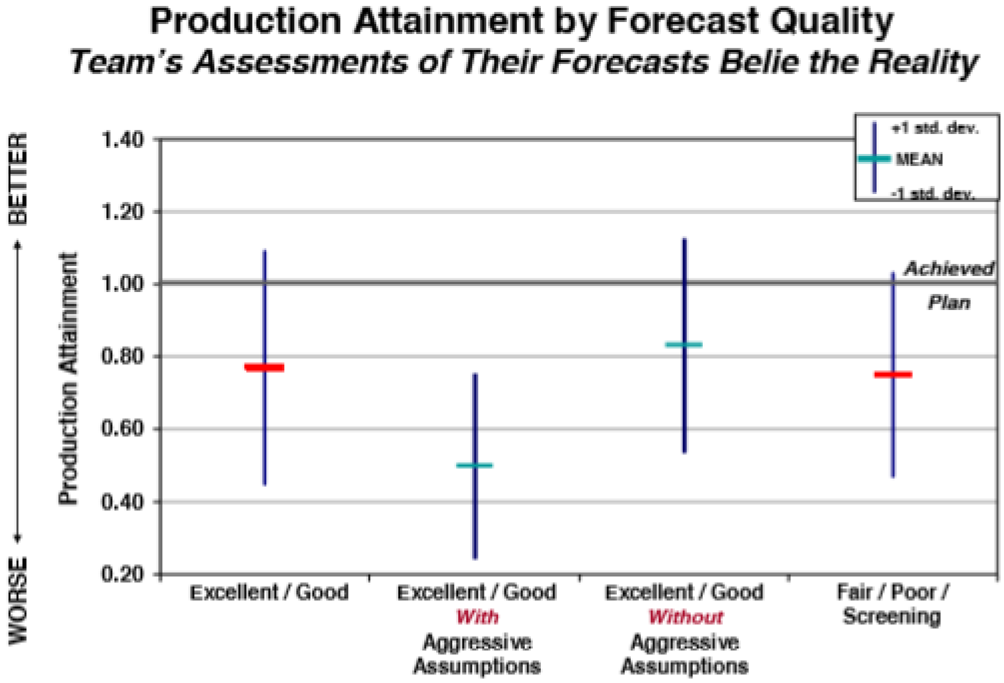

Figure 45: Production attainment by groups of forecast quality (Nandurdikar & Wallace, 2011, p. 8).

6.5 Deception

While delusion derives from psychological factors that influence our decisions and way of thinking, deception accounts for flawed planning in decision making in terms of politics and agency issues (Flybjerg, Garbuio, & Lovallo, 2009). As with delusion, deception is also common in major projects as discussed below.

6.5.1 Principal – Agent problem

The principal-agent (P-A) theory is a well-known phenomenon in economics. A P-A problem occurs when an agent acts on a principal's behalf, but their incentives are not aligned. A typical example could be a contractor (agent) working on the behalf of an operator (principal). If the contract and its incentives are constructed in a way in which the contractor benefits from working in the best interest of himself rather than the operator, he will do so. I.e. maximizing his own benefit rather than delivering a product that maximizes the operators benefit. There is a P-A relationship for every two levels of an organization, and every two levels of a supply chain (Flybjerg, Garbuio, & Lovallo, 2009).

In bigger projects, such as an offshore development project, a multi-tier P-A problem exist (Bolton & Scharstein, 1998). Figure 46 is an illustration of such a multi-tier P-A relationship (Flybjerg, Garbuio, & Lovallo, 2009, p. 177)

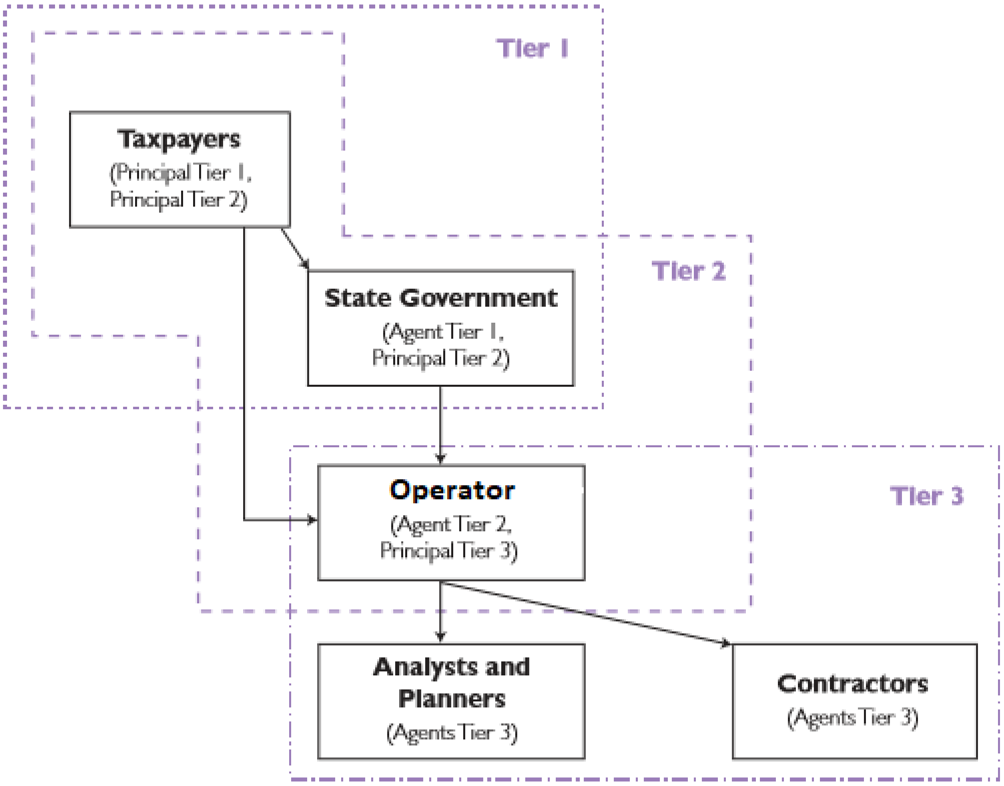

Figure 46: Illustration of P-A tiers for a megaproject (Flyvbjerg, Garbuio & Lovallo, 2009)

The first tier is the relationship between tax payers and the State Government. Tax payers are principals, while the State Government is the agent. When approving the PDO for a development project, the State Government must act in the interest of the tax payers and look at the benefits the project at hand gives back to them. Tax payers can expect the Government to accept projects that give the maximum benefit in terms of costs and risk, especially as the tax payers are liable for more than 89 percent of the costs related to development (Taraldsen, 2015). The state government is also acting as agents for other principals, and must approve projects that are within the limits of climate pollution, fishing conditions, environmental climate etc.

The Norwegian State Government is determined by election every fourth year. Knowing this, politicians have incentives to focus more on benefits than risks, as they are dependent on positive media coverage coming in to new elections. An example from the NCS could be Goliat. Goliat was approved in 2009 by Jens Stoltenberg's second government. The project was pointed out as an important milestone for future developments in the Barents Sea, and would work as the centre of oil production for the whole area. It would also lead to further investments in the area, which again would give more jobs and other repercussions. Although the project was approved by the sitting government in 2009, the current Minister of Petroleum and Energy has received heavy criticism in Norwegian news media regarding the profitability of the field (Suvatne, 2017). Politicians are likely to change position up- or downwards in the chain, depending on the outcome of an election. As a result, they have incentives to act in a way that benefits themselves coming into a new round of voting. This is outlined as a reason for overruns by the Office of the Auditor General of Norway. In a report from 2003, they mention that when approving PDO's, the Government have been focusing towards the socioeconomic results of the projects, which could result in neglecting the importance of cost control in the development phase (2004-2005).

A second tier involves the operator, which acts on behalf of the licensees, which again act on behalf of the Government. The operator is the one responsible for preparing the PDO, which the Government use as their source of information when approving a development. The operator is also the one with best insight to the project. If a project is marginal, one could imagine a situation where numbers are manipulated to appear in a way that outlines the potential benefits, rather than discussing risks involved with the investment.

In the PDO for Goliat production was estimated to start in the fourth quarter of 2013 (MEP, 2009). One year before estimated production start, MPE had a meeting with the licensees where they were assured by the operator that the field would start production according to plan (Lewis, 2012). In retrospect[13], it is evident that the information communicated in this meeting was biased; either the manager was overconfidence and felt that he had control of something he did not, or he deliberately gave false information.

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[13] Goliat started producing more than two years later than estimated

A P-A relationship also exist between the operator and suppliers that are given contracts related to developments. If contracts are designed in a way where the contractors do not have incentives to reduce costs for the operator, they will maximize their own benefit. From May 2003 to September 2008, rig rates on the NCS increased by 646 percent (Osmundsen, Dahl, & Tveterås, 2010b). A study about productivity in exploration drilling showed that in the period of rising rig rates from 2005 to 2008, average drilling velocity was 43 meters per day. In the earlier period, from 2001 to 2004, the velocity was 76 meters per day (Osmundsen, Roll, & Tveterås, 2010a). An explanation could be that contractors felt the price they agreed when signing the contracts did not reflect the cost level in the industry at the time the wells were drilled. They then took advantage of how the contracts were designed, and found a way to increase their profit, by working at a slower tempo.

6.5.2 Strategic deception

Flybjerg et al. (2009, p. 179) outlines strategic deception within each P-A relationship as a possible source of bias. Strategic deception can be caused by self-interest, difference in risk preferences and time horizons, or asymmetric information.

Self-interest is the basis of every P-A conflict. When deciding, the decision maker will always try to maximize his or her own benefits. The only way to reduce this form of bias is to create incentives that are designed so that the interests of each party involved is aligned. This is impossible, as the different stakeholders (e.g., government, contractors, engineers, bankers, suppliers, lawyers, bankers, banks, politicians etc.) have widely different goals and ways to measure their benefit. If these stakeholders are involved in, or can influence the forecasting of cost and benefit at the approval stage, this is liable to bias the entire subsequent process (Flybjerg, Garbuio, & Lovallo, 2009, p. 179)

Asymmetric information is a term for a situation where the agent has information about a project that the principal does not, or the other way around. As the principal is unaware of the information, he or she may be easily deceived. A study by Flyvbjerg & COWI (2004) revealed that there are strong interests and incentives to present projects costs and benefits as favourably as possible at the approval stage. If a project is presented without addressing possible threats and risks, it could be approved in favour of other projects where downsides are properly addressed. The result could suboptimal capital allocation, where less profitable projects are prioritized.

Another example of a P-A problem is differences in risk preferences and time horizons. While the Norwegian State’s tax payers typically have a long time horizon, companies and politicians might look at benefits in the shorter term. Companies are dependent on developing projects as fast as possible, so that production and cash flow can start. OGA concluded that schedule driven projects commenced in 2012/2013 tend to deliver late and over budget due to unclear objectives and priorities (OGA, 2017). Unsatisfactory pre-design is outline as one of the main reasons for overruns in several reports (The Steering Commitee, 1980; NOU1999:11, 1999; Office of the Audit General of Norway, 2001; NPD, 2013) The Office of the Auditor General of Norway says that it is not the MPE’s responsibility to secure the quality of the cost analyses or forecasts. Consequently, a lot of trust is put on the licensees and operator to produce reliable and well calibrated estimates, a situation where asymmetrical information could diverge unless there are incentives related to presenting unbiased estimates.

Differences in risk preferences might lead to asymmetrical flow of information between the agent and principal. For instance, if the principal is risk averse, the agent that submit a plan for approval has an incentive to downgrade risks related to development. This might occur inside an organization, when managers lower on the organizational chain misrepresent numbers to get funds or requests approved (Flybjerg, Garbuio, & Lovallo, 2009, p. 180). The taxation system for petroleum related industry on the NCS is constructed in a way where risk preferences for the companies and the Government can diverge.

6.5.3 Taxation system

The petroleum taxation system is set out in The Petroleum Taxation Act of 1975 (Ministry of Finance, 2016). Because of the returns on production of hydrocarbons on the shelf, companies operating on it are subject to an extraordinary tax rate (Ministry of Finance, 2016; Norwegian Petroleum, 2018). A special tax of 55 percent[14], makes the total marginal tax rate 78 percent for companies operating in the petroleum industry.

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[14] In 2018

To justify the extraordinary tax rate, the Norwegian Government covers 78 percent of costs related to exploration, development and production of petroleum. On top of that comes the uplift and a special system for depreciating installations and equipment. The uplift is a special deduction given on extraordinary taxable income. According to Taraldsen (2015), this means that the Norwegian Government covers 89.2 percent of costs related petroleum development projects on the NCS.

The Petroleum Taxation Act is created to secure that the industry is profitable for both companies and the Government. It has obviously been successful[15], but has also been subject to criticism. Frederic Hauge, leader of the independent non-profit organization Bellona, said in 2015 that "the state should only cover costs that the government has approved, neither more, nor less. If petroleum companies let costs run wild, they should be accountable for the overruns themselves" (Hauge, 2015).

As 89.2 percent of the costs related to developing a project are covered, companies might initiate projects where the risk of overruns and delays are high. As Frederic Hauge outlines, there are no incentives related to the quality of the forecasted budgets on cost and time. MPE have said that their influence is reduced when projects enter the development stage. Questioning and challenging the estimates given in the PDO is therefore most important instrument for ensuring governmental influence in the projects (Office of the Auditor General of Norway, 2004-2005).

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[15] The Government Pension Found Global is worth more than 8 322 billion NOK as of 04.05.2018

7 How can the industry improve?

There is no doubt that budgets are overrun, both in terms of time and cost. Furthermore, as shown by this work, production goals are rarely met, and that the result is a loss in PV. Table 9 summarizes the consequence of cost overrun and underproduction for a random field on the shelf. The field was approved in 1997 and started production 67 days before estimated. It overran its budget with 19 percent, and has underproduced in all years since start up, except the first and second year. Based on this easy calculation, there is no doubt that the field has been profitable. But the PV of the profit is 23 percent lower than if they had met budgeted goals. What would have happened if decision makers knew the outcome of this development when deciding what solution to go for? And what can we do to improve estimates, so that in the future, examples like this is the exception, rather than the norm?

Table 9: NPV loss in a standard field on the NCS

Field	**N/A**		
Year of PDO approval	**1997**		
	Mean estimate [mill NOK]	**Actual outcome [mill NOK]**	**Lost value**
Present value of revenues	kr 63 618	kr 52 645	17 %
Present value of development costs	kr 9 099	kr 10 797	19 %
Profit	**kr 54 519**	**kr 41 848**	**23 %**

7.1 What do they do wrong

To address how estimators can improve, we must first examine what they do wrong. Although there are several factors that affect both the estimates that projects are based on, and the development itself, they can all be sorted into two main categories; biased estimates and project management.

7.1.1 Project management and control

To explain overruns, managers often blame conditions that they claim are out of their control. Weather, unexpected events; such as work conducted by contractors and change of complexity in the reservoir, are used as explanations for overruns. These are factors that can affect the outcome of a development, but they have one thing in common; they should all be addressed in the PDO. The guideline says that “the licensees must present analysis for financial parameters which provide a good picture of the project’s range of uncertainty“ (MPE, 2017,

p. 42). If uncertainties are not sufficiently discussed and addressed, it can be argued that the PDO is approved on a lacking basis.

Another factor that must be considered is the project management, including the approval of contractors. Haukaas & Mohus (2016) and Rystad Energy (2013; 2015) showed that developments where EPC-contracts was given to Asian shipyards had a higher cost overrun and delay than those given to Norwegian yards. This could be due to unsatisfactory knowledge with Norwegian NORSOK standard and/or communicational/cultural issues. If an unknown contractor is chosen, the risks of communicational problems will be higher than in the case of a well known contractor. Risks and potential issues as these should be adressed in the PDO.

OGA outlines the use of probabilistic rather than deterministic estimates as one of the key lessons learned in their survey. Their report says that although project management and the value it brings is increasingly recognised, “there have been no visible improvement in the ability to predict outcomes” (2017, p. 17). They further conclude that finishing the FEED and detailed engineering before starting construction is one of the most important aspects if a project wants to finish on estimated time and cost. When discussing areas of improvement in project management, the report mentiones improved co-operation between companies and stakeholders as one of the main necessities. Nandurdikar & Wallace (2011) argues that when projects are driven by speed to first oil, they usually have to adopt an aggressive appraisal strategy. When doing so, project teams have to make assumptions about missing data and remaining risks in their forecasts. These assumptions almost always turn out to be optimistic (Nandurdikar & Wallace, 2011, p. 5).

7.1.2 Biased estimates

If estimates given in the PDO are biased, reaching the budgeted goals requires over- or under performance by the project management. Further, misrepresenting costs, benefits, and risks of a project can lead to a suboptimal capital allocation, as a project might be approved in favour of other projects where estimates are debiased.

According to the PDO guideline, “Development investments, operating costs, tariff costs and income [..] must be listed in debiased, fixed NOK values each year” (MPE, 2017, p. 42). Earlier research show that estimates related to development costs and time schedule are biased. This paper has presented results that indicate that production estimates, i.e. the income forecasts, are biased as well, and that the consequence is a significant loss in PV.

There are several factors that can explain why we fail to produce debiased budgets. One reason is psychological factors that affect us when estimating. Although the effects are well documented and have been subject of several reports across many industries, these are underlying factors. To reduce the influence of biases, training and implementation of debiasing procedures is essential.

Welsh, Begg, & Bratvold (2007) outline the economic impact of bias in oil and gas projects. Their study shows that overconfidence, on the level that people normally demonstrate, result in an NPV loss of $259 million USD. Availability bias makes a project that would likely result in a $55 million loss, to look like it will end up with an NPV of up to $329 million USD (2007, p. 1). The paper clearly demonstrates the need for debiasing estimates in the petroleum industry.

Deliberate misrepresentation is another reason. Managers depend on forecasts where costs are low and revenues high for their project or solution to be prioritized in favour of competing possibilities. P-A relationships on several levels and information asymmetry could also lead to biased estimates, for example when contracts are created in a way that does not align the interests of the involved parties.

7.2 Solutions for improvement

As discussed, budget overruns happen for two main reasons; either the estimates were biased, or the management failed to develop the project according to the quality and standards that was expected. After fifty years of large offshore developments, one could expect the management and companies operating on the shelf to have sufficient insight and experience on how to manage these projects. OGA’s research resulted in a similar conclusion: project management at the value it brings is increasingly recognised, but there is no improvement in our ability to predict outcomes (OGA, 2017). If estimates are biased, it will over time be impossible to reach budgeted goals. The main challenge for the industry is therefore: what can be done to debias their estimates?

According to Welsh, Begg and Bratvold (2006) awareness-style training, where debiasing techniques are explained to participants by consultants, is the most common way to train and educate the industry. They further argue that these debiasing methods are old, and that their effect is hard to measure. To reduce bias, estimators must know which biases they are affected by, and which measures to implement. As debiasing services are usually given by consultants, who aim to keep their methods and knowledge confidential, results are rarely published (Welsh, Begg, & Bratvold, 2006, p. 1648). Welsh and his colleagues research is based on experiments conducted, trying to debias the effect of anchoring and overconfidence, by giving final year petroleum students awareness-style training. The results show that there is no support in saying that awareness of anchoring will reduce susceptibility to the bias. On the other hand, awareness of overconfidence and its effect did improve their estimates.

In *Superforecasting: The Art And Science of Prediction* (Tetlock & Gardner, 2015), characteristics of extraordinary well calibrated forecasters, so-called superforecasters, are outlined. The book is the result of decades of research and a massive government-funded forecasting tournament. The authors show that superforecasters are familiarized by the ability to gather evidence from a variety of sources, working in teams, keeping score, thinking probabilistically, being willing to admit error and to change course. The book also offers a demonstrably effective way to improve our ability to predict future outcomes (Goodreads). American statistician Nate Silver observed in his research that the most accurate forecasters tend to have superior understanding of probability, and that they can distinguish the predictable from the unpredictable (Silver, 2012).

Rather than hiring superforecasters or educate employees to develop superior probability understanding, Flyvbjerg recommends debiasing estimates by taking an outside view of the project. When adapting an outside view, the estimator looks at projects from a historical point of view and uses the outcome of similar projects to get a better understanding of the risks related to the development at hand. He argues that using distributional information from other projects is “the cure to the planning fallacy” (2006, p. 6). One way to do so is by implementing RCF.

7.3 Reference Class Forecasting

RCF is based on the Nobel Prize winning work of Kahnemann & Tversky (1979a, b) and later by Lovallo & Kahnemann (2003). The idea is to use historical results and known outcomes of similar projects as a base and derive uplifts and adjustments that can be applied to modify forecasts for the project at hand (Leleur, Salling, & Nicolaisen, 2015). The reference class must consist of projects that are comparable, preferably in term of both size and complexity.

7.3.1 Background

When applying RCF to adjust forecasts, the estimator adapts an "outside-view" on the project. The technique places the project in a statistical distribution of outcomes in similar projects, rather than trying to forecast the specific outcome of uncertain events for the project at hand. Applying RCF requires the following three steps (Flyvbjerg, 2005b, p. 17):

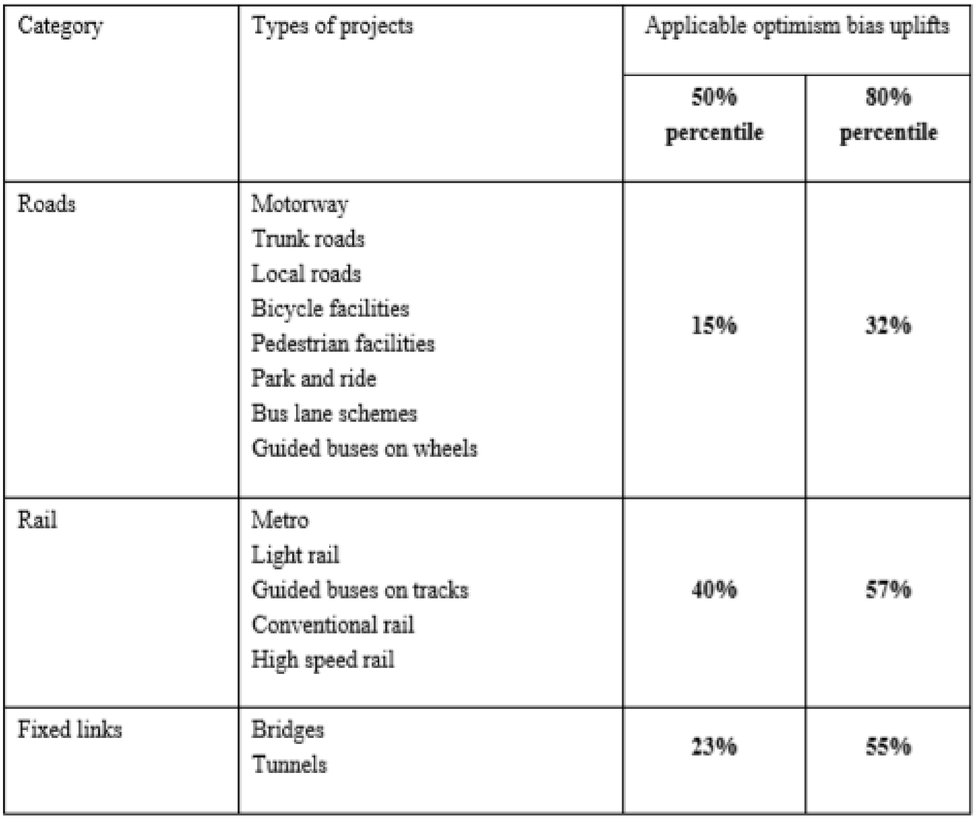
1) Identify a class of relevant, comparable projects. The class must be broad enough to be statistically meaningful but narrow enough to be truly comparable to the specific project.
2) Use the reference class to establish a statistical distribution of outcomes for the measure that you would like to research. The measure could for example be development cost, scheduled time, or production/benefit.
3) Compare the project at hand with the statistical distribution. Use uplifts and results from the reference class to adapt and debias your own forecasts.

7.3.2 RCF in other industries

The main challenge when applying RCF, is to create the reference class. Projects must be comparable, and the data must be complete, reliable and available. Companies are often reluctant when it comes to sharing data regarding their projects. As a result, RCF have mostly been applied to public megaprojects.

Bent Flyvbjerg, in association with COWI, created a guidance document called "*Procedures for Dealing with Optimism Bias in Transport Planning*" on behalf of the British Department of Transport in 2004. As the research was supported by the government, the authors were given a large amount of data from public infrastructure projects in Britain. Based on statistical tests, Flyvbjerg divided projects into three main categories: roads, rail and fixed links. Flyvbjerg chose to focus on development costs. Using his reference class, the following uplifts were established (Flyvbjerg & COWI, 2004, p. 20).

Table 10: Uplifts in UK infrastructure projects (Flyvbjerg & COWI, 2004)



Category	Types of projects	Applicable optimism bias uplifts	
		50% percentile	**80% percentile**
Roads	Motorway Trunk roads Local roads Bicycle facilities Pedestrian facilities Park and ride Bus lane schemes Guided buses on wheels	**15%**	**32%**
Rail	Metro Light rail Guided buses on tracks Conventional rail High speed rail	**40%**	**57%**
Fixed links	Bridges Tunnels	**23%**	**55%**

8 RCF for the Norwegian Petroleum Industry

Although development projects on the NCS and elsewhere in the words have experienced overruns like those of British infrastructure projects (EY, 2014), RCF for petroleum projects have yet to be presented. To do so, there is a need to develop a database of earlier projects. Collection of data itself may be hard, as numbers are often hidden in various parliamentary propositions, and in PDO's that are considered as company secrets.

The database that this paper is based on, is considered large enough to be statistically meaningful as a reference class for future developments. Flyvbjerg & COWI had a reference class of 34 international bridge and tunnel projects, while our dataset counts 68 for costs, 42 for scheduling, and 56 for production.

To see whether the uplifts that our reference class give are reasonable, the class includes projects with PDO approved from 1995-2010 and is applied to projects approved after 2010. The three measures will, as earlier, be treated separately. For each of them, the established multiplicators will be presented, and then applied to the test group. Further, results and observations will be discussed.

8.1 Methodology

To establish the statistical distribution for each reference class, a set methodology is used that includes different statistical theories and approaches. This sub-chapter is dedicated to describing this methodology.

8.1.1 Reference class

The reference class is built with projects that had their PDO approved from 1995-2010. Data is the same as used in earlier analyses. In some cases, projects are taken out of the reference class because they are considered as extreme outliers and not comparable to new projects. These projects will be mentioned when relevant.

8.1.2 Bootstrapping

As the reference class consist of a limited number of projects, bootstrapping has been used to create statistically valid distributions of outcomes. Bootstrapping is a metric that rely on random sampling with replacement. The technique allows estimation of the sampling distribution for almost any statistic using random sampling methods (Efron & Tibshirani, 1993).

To perform the bootstrap, an Excel add-in from XLSTAT has been used (XLSTAT.com). The add-in picks 500 series of random samples from the reference class. Each of these 500 data series illustrates a random picked reference class and has the same size as the original reference group. The add-in then uses the mean and percentiles from these 500 newly created datasets of samples to give the P5, P50, and P95 for the entire bootstrapped distribution.

8.1.3 Metalog distribution

These three values are used to fit a Metalog distribution (Keelin, 2016). The metalog distribution is chosen because of its flexibility, and ability to handle percentiles as input. Based on the input, the add-in creates a metalog distribution, where P10, P50, and P90 values can be found. These values are the multiplicator uplifts that will be used to adjust the forecasts for the project at hand.

Figure 47 illustrates the results Flyvbjerg obtained when studying cost overruns in infrastructure projects. It shows that 40 percent of projects had a maximum cost overrun of 10 percent. To find a P50-value, the project at hand must be adjusted with an uplift of about 15 percent (arrow).

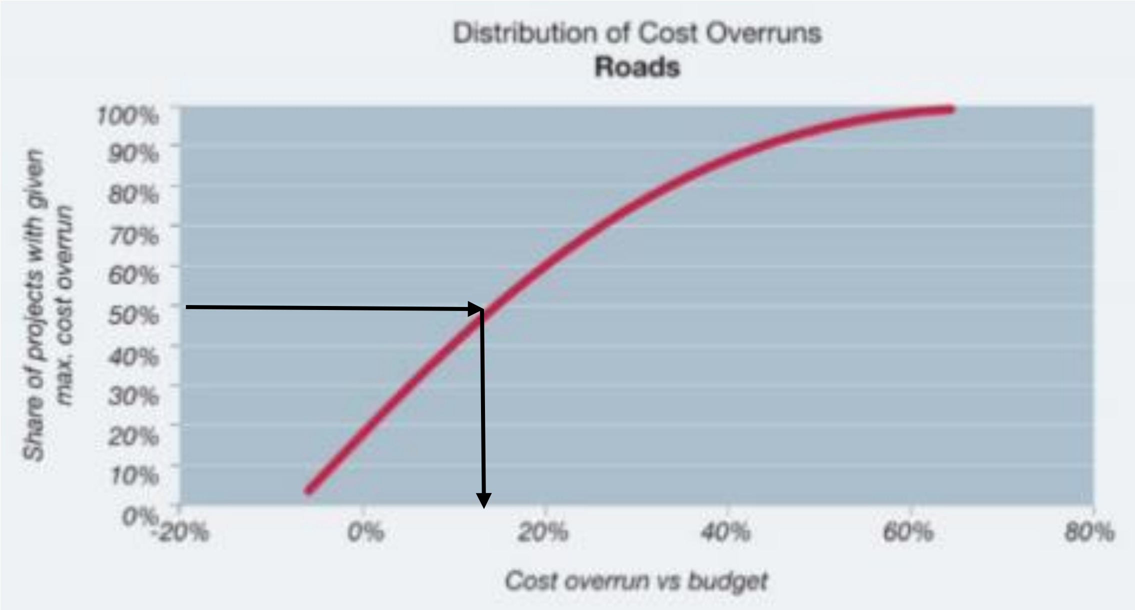


Figure 47: Distribution of cost overruns (Flyvbjerg & COWI, 2004)

8.1.4 Testing distribution on later projects

The multiplicators for P10, P50, and P90 are taken out from the distribution and used as multiplicators to adjust the new forecast. To test whether applying the multiplicators will reduce the bias and increase the understanding of the related risk. Estimates for projects approved after 2010 are adjusted and tested against their actual outcome.

8.2 Development costs

For development costs, the reference class consist of 44 fields, approved from 1995-2010. Fields with cost overrun higher than 60 percent are removed, as they are usually affected by extraordinary circumstances. For example, Gugne had an overrun of almost 250 percent, but the development had costs less than 1/10th of what is considered a megaproject[16]. It is therefore considered as not comparable to the projects in the test group. Seven of the 68 fields where cost data is found were removed when setting this limit.

8.2.1 Probability distribution and multiplicators

The reference class gives the cumulative distribution function of cost overruns illustrated in Figure 48. The figure is built the same way as Figure 47 (Flyvbjerg & COWI, 2004), but the axes

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[16] Merrow (source)

are flipped, and the uplifts shown as multiplicators rather than percentage values. The figure shows that if you want to be 10 percent sure that your estimate is lower than the actual outcome, you must adjust the original forecast with a factor of 0.94. To get a P50-value, you must multiplicate with 1.12.

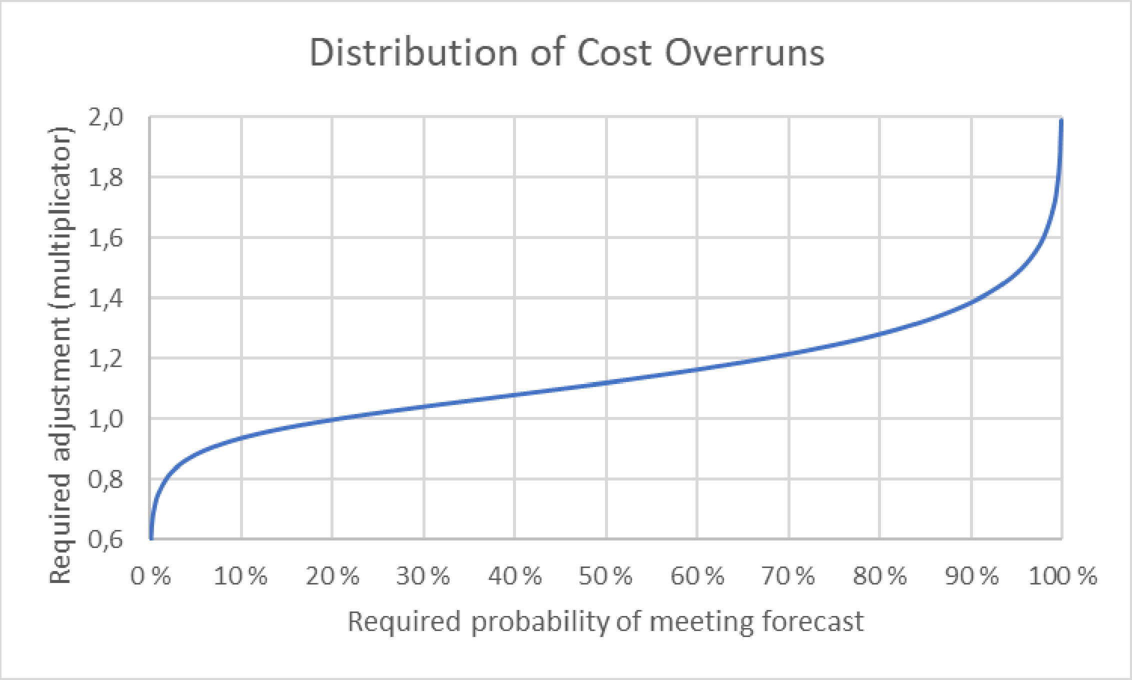

Figure 48: Distribution of cost overruns for reference class

The following multiplicators were established from the distribution.

Table 11: Multiplicators for cost estimates

Percentile	Multiplicator
P90	0,94
P50	1,12
P10	1,39

8.2.2 Test - example

To illustrate how the obtained multiplicators are tested, an example is given in Table 12. The PDO estimate is adjusted with the three multiplicators to get P10/P50/P90 values. Then actual outcome is given to see how well calibrated the adjustments are. The field, Edvard Grieg, overran its PDO budget with approximately 10 percent. When applying the adjustments, the project finished slightly below the P50-estimate.

Table 12: Example on the use of multiplicators for development cost

Field	*Edvard Grieg*			
PDO estimate	**Percentile**	**Multiplicator**	**Adjusted estimate**	**Actual cost**
	P90	0,94	22 322	
kr 23 855	P50	1,12	26 713	**kr 26 334**
	P10	1,39	33 068	

8.2.3 Test

Rather than testing the multiplicators on specific projects, they should be applied on a test group. When doing so, you can find the rate of projects that finish above/below the three estimates, which says how well calibrated they are. If well calibrated, 50 percent of the test group should have final costs lower than the P50-value, and 80 percent have costs inside the P10/P90 interval. For costs, the test group consist of 17 fields. Applying multiplicators on the group gave the following results.

Table 13: Results from testing cost multiplicators on projects approved after 2010

Applying multiplicators to test group				
	Percentile	Multiplicator		
	P90	0,94		
	P50	1,12		
	P10	1,39		
Results	P90	P50	P10	Original estimate
Over budget	80 %	25 %	10 %	65 %
Under budget	20 %	75 %	90 %	35 %

A multiplicator of 0.94 was applied to get the P10 value. 82 percent had final costs higher than this value. 24 percent of the projects had costs above the P50 estimate, and 6 percent finished with costs higher than the P90 value.

At first sight one could argue that the adjustments do not give a better understanding of the risks of overrunning budgets, as the original estimate is closer to a P50-value than the adjusted one. But the class of projects where the multiplicators are tested is limited, and small variations in the multiplicators would give ideal results. In addition, projects the test group have been developed in a period where oil price dropped by more than 50 percent, resulting in cost reduction and cut-offs. Similar periods of cost reductions have historically proved to give a short-time effect on costs reduction, rather than a permanent change.

Further, there are small margins in some fields that makes the multiplicators, especially the P50- multiplicator, slightly high. The ideal multiplicator would be 1.09 while the obtained one is 1.12. Still, 76 percent of the projects finished inside the 80 percent confidence interval, indicating that the high- and low estimates are well calibrated. It can therefore be argued that applying the multiplicators do give a better understanding of the risk of overrunning budgeted costs.

8.3 Development scheduling

For development schedule, the reference class consist of 30 fields, approved from 1998-2010. No fields are removed, as all fields are considered comparable to future developments. The fields vary a lot in terms of size, the longest development was expected to take more than four and a half year, and the shortest just above four months.

8.3.1 Probability distribution and multiplicators

From the reference class, the following cumulative distribution function is obtained. It shows that to be 90 percent sure that your estimated startup is later than the actual startup, you must multiply the time of development with 1.45.

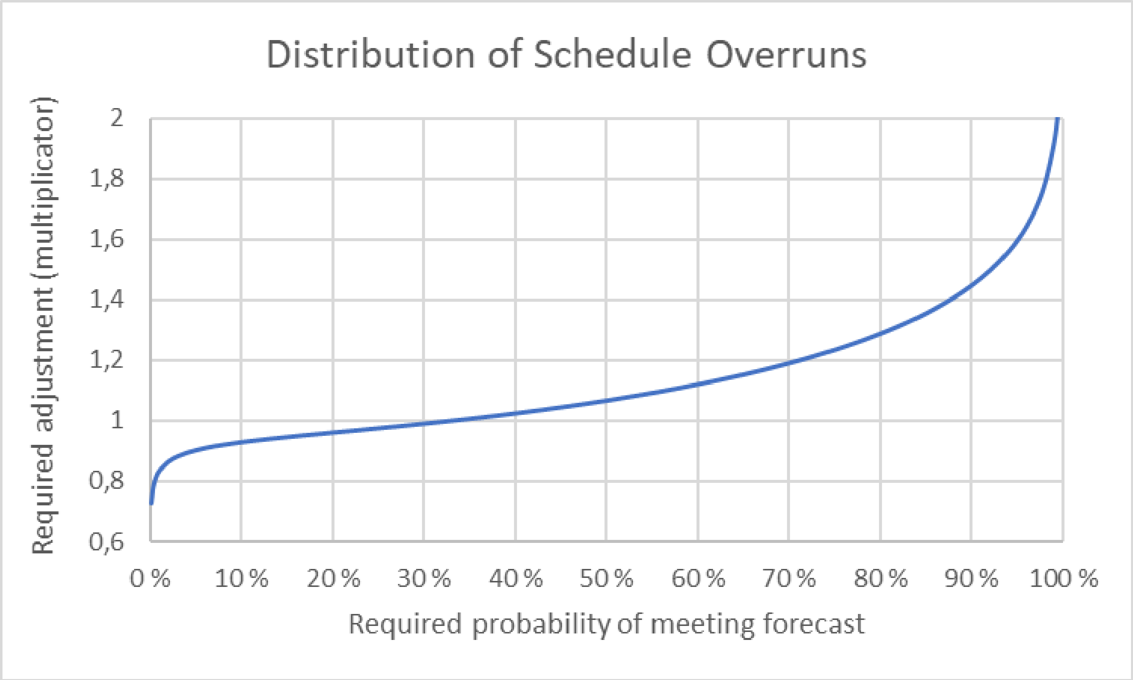

Figure 49: Distribution of schedule overruns for petroleum projects

The following multiplicators were established form the distribution.

Table 14: Multiplicators for schedule forecasts.

Percentile	Multiplicator
P10	0,93
P50	1,07
P90	1,45

8.3.2 Test

The test group comprises 12 fields that have all started production. Applying multiplicators to the test group gave the results illustrated in Table 15.

Table 15: Results from testing schedule multiplicators on projects approved after 2010

Applying multiplicators to test group				
	Percentile	Multiplicator		
	P10	0,93		
	P50	1,07		
	P90	1,45		
Results	P10	P50	P90	Original estimate
After Scheduled	100 %	56 %	22 %	67 %
Before Scheduled	0 %	44 %	78 %	33 %

A multiplicator of 1.07 was applied to create the P50-estimate. After applying the multiplicator, 56 percent of the group used more than their median time frame. 22 percent overran the P90-value. The results must be viewed with the size of the test group in mind. In addition, schedule forecasts are harder to handle than other estimates, because startup often is given as a time interval, for example: first quarter of 20XX. It is also very uncommon for projects to finish before estimated schedule, and small outliers in the reference class can cause the P10-value to be too low, as the reference class is smaller than for costs. To increase the reference class, more data must be found, or made available by the authorities/companies. Results indicate that applying multiplicators does give a better understanding of the risk of overrunning scheduled development time. The probability of overrunning scheduled median time is more than 10 percent lower than that of the mean given in PDO's, and there is a 78 percent chance of finishing inside the P10/P90 interval.

8.4 Production forecasts (normalized to estimated production start)

For production, the reference class consist of 39 fields. Production for the first four years (0-3) have been used and high- and low estimates are neglected. Chapter 4 showed that the estimates that the companies give are biased. Therefore, the mean estimate is used as basis for creating new, debiased estimates. No projects were taken out of the class.

8.4.1 Probability distribution and multiplicators

When normalizing data to estimated startup, the following cumulative distribution function for production overrun was obtained (Figure 50). The figure shows that if you want it to be a 10 percent chance that your forecast is lower than the actual production, you must adjust the estimate with a multiplicator of 0.22. To be 50 percent sure, you must multiplicate with 0.73.

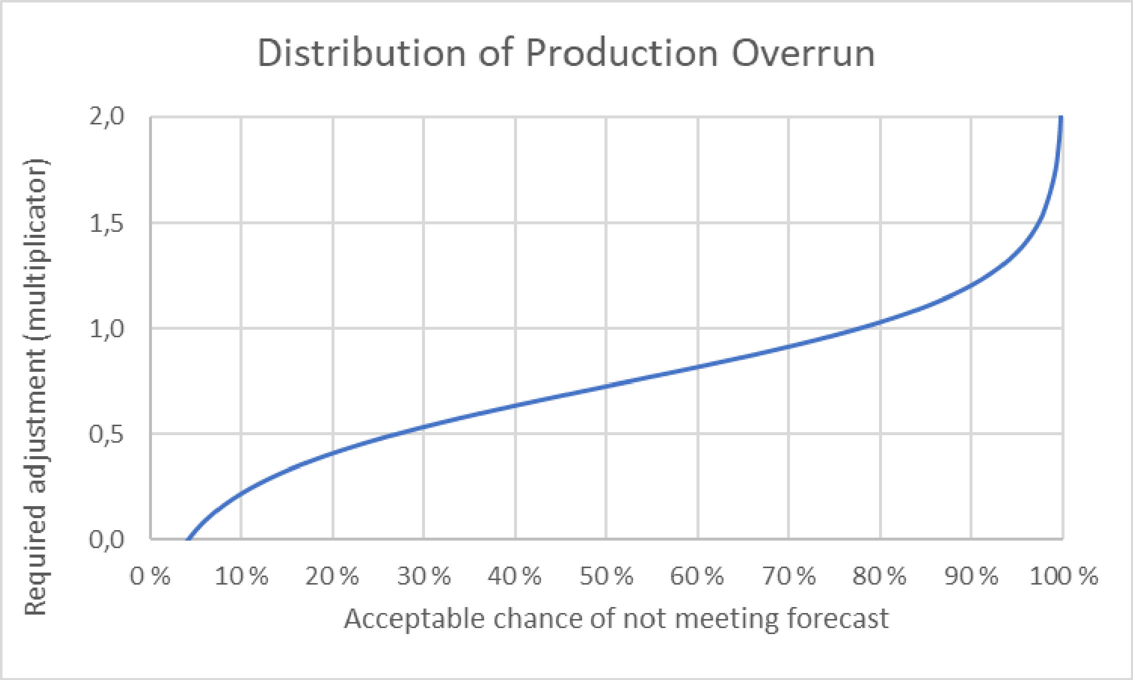

Figure 50: Distribution of production overruns, when normalizing to estimated production start

The following multiplicators was established from the distribution.

Table 16: Multiplicators for production, when including the effect of schedule overrun

Percentile	Multiplicator
P10	0,22
P50	0,73
P90	1,21

8.4.2 Test

The test group consist of 17 fields, all approved after 2010. Applying multiplicators to the mean estimate, the following results were obtained (Table 17).

Table 17: Results from testing production- and schedule multiplicators on projects approved after 2010

Applying multiplicators to test group				
	Percentile	Multiplicator		
	P10	0,22		
	P50	0,73		
	P90	1,21		
Results	P10	P50	P90	Actual
Over estimate	88 %	47 %	12 %	24 %
Under estimate	12 %	53 %	88 %	76 %

The mean estimate that is given, is historically a P76 estimate. After adjustment, 53 percent of the projects produced less than the P50 estimate. The P10- and P90 estimates obtained after using outside view multiplicators are also very close to reflecting what they should; that there is an 80 percent probability of producing between the two. Applying multiplicators to the mean estimate gives a good understanding of the risks of underproducing. All adjusted forecasts are well calibrated, and considerably better than the ones that the companies give (ref. Table 3).

8.5 Production forecasts (when time shifted to start of actual production)

When time shifting data to actual startup, the reference class still comprise the same 39 fields. But, the shift changes the probability distribution (Figure 52).

8.5.1 Probability distribution and multiplicators

From the reference class, the following cumulative distribution function for production overrun is obtained. It shows that to be 50 percent sure that production will exceed your estimate, you must adjust your forecast with a multiplicator of 0.82.

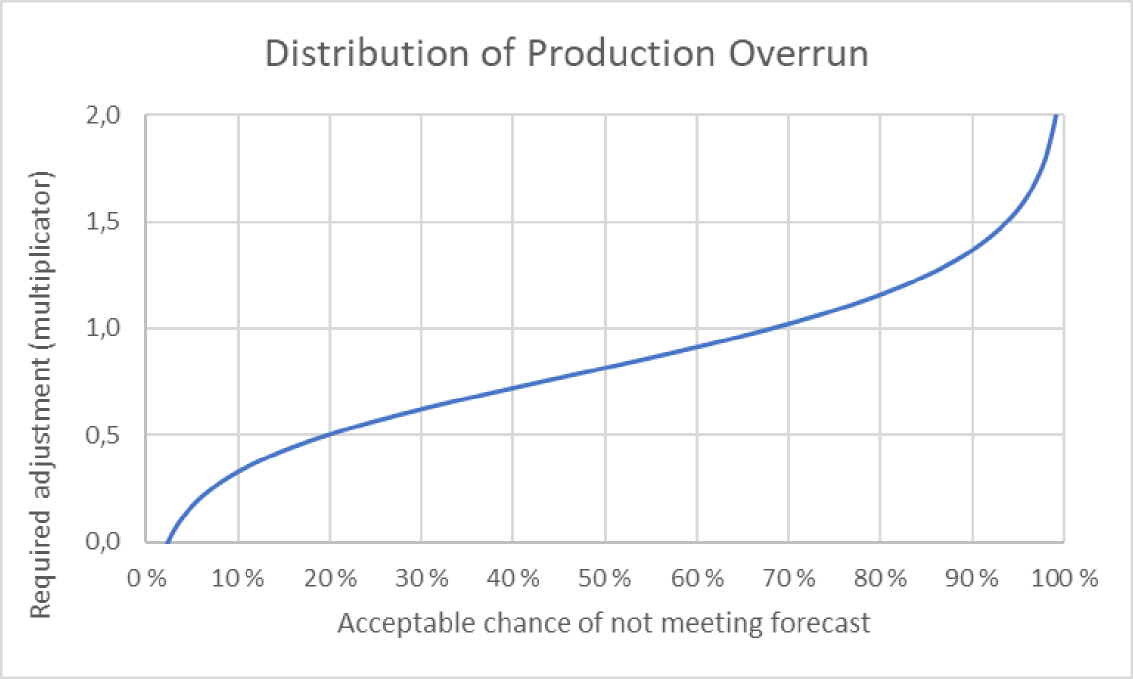

Figure 51: Distribution of production overruns, when normalizing to actual production start

Multiplicators from the distribution are given in Table 18 below.

Table 18: multiplicators for production, when reducing the effect of time overruns

Percentile	Multiplicator
P90	0,33
P50	0,82
P10	1,37

8.5.2 Test

Applying the multiplicators to the test group gives the following results

Table 19: Results from applying production multiplicators on projects approved after 2010

Applying multiplicators to test group				
	Percentile	Multiplicator		
	P90	0,33		
	P50	0,82		
	P10	1,37		
Results	P10	P50	P90	Actual
Over estimate	88 %	44 %	13 %	25 %
Under estimate	13 %	56 %	88 %	75 %

After adjusting the mean estimate, there is a 44 percent chance of producing more than forecasted median for the first four years. 74 percent of the fields produce inside the estimated 80 percent confidence interval. The results indicate that applying the multiplicators would improve the industry's understanding of the probability of underproducing in the first four years.

8.6 RCF summary

Table 20: Summary of multiplicators.

	Multiplicator		
Measure	**P10**	**P50**	**P90**
Development cost	0,94	1,12	1,39
Time schedule	0,93	1,07	1,45
Production (method 1)	0,22	0,73	1,21
Production (method 2)	0,33	0,82	1,37

The obtained multiplicators are illustrated in Table 20 above. For each measure, three multiplicators are presented, using a reference class of earlier completed projects on the NCS. Production estimates given in PDO's are often denoted as most likely, or mean estimates. For cost estimates, some projects give estimates as P50, and others as mean value (Office of the Auditor General of Norway, 2004-2005). The PDO guideline say that cost estimates must be stated as an anticipated value (MPE, 2017), but has been subject for changes over time. As PDO's are secret, it is therefore subject for discussion what cost estimates are describing; a P50-value or the mean estimate. To get a better understanding of the probability of not delivering as forecasted, it is recommended that future estimates are presented in relation with uncertainty measures and probability distributions, for example by using the probability distributions an multiplicators presented in this paper.

In the cumulative probability distributions introduced, all development projects on the NCS with available data is included. A further development of the database and number of fields in the reference class would increase the statistical quality of the distribution. To do so, the Norwegian Government must use its power to collect data from companies, or publicly available data from developments in other countries must be included. If the database is further developed, the classes could be divided into specific sub-categories based on for example type of development[17]. Haukaas & Mohus (2016) showed that projects with estimated costs higher than 10 billion NOK had a higher relative cost overrun than less costly projects. This could be an interesting way to group projects. But, more data must be collected to introduce these or other sub-classes.

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[17] NPD often divide projects by development solution: topside/subsea/FPSO

8.7 Adjusting uplifts for project stage and phase

RCF can also be applied to projects in earlier- or later stages of their lifecycle. If a project is still in its FEED-stage, or has moved past the approval stage, uplifts should be adjusted to reflect this (Flyvbjerg & COWI, 2004, p. 33). Uncertainty is typically reduced throughout the feasibility study, and as the development moves closer to the start of production (Figure 52). Therefore, uplifts for projects that have not reached DG3 should be adjusted up, while uplifts for projects that are approved should be adjusted down. Flybjerg (2004) suggest the following adjustment for projects that are past their approval stage (Table 21).

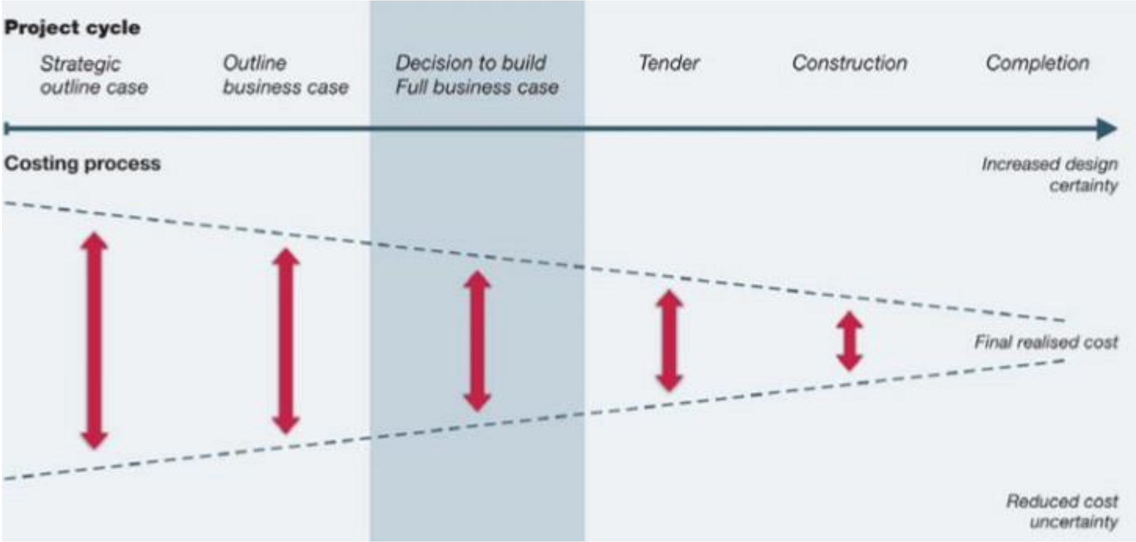

Figure 52: Illustration of uncertainty reduction for a development after project approval

Table 21: Overview of relation between uplift and project maturity

Percentage of total budget spent	Uplift as percentage of initial uplift
0 %	100 %
10 %	90 %
20 %	80 %
30 %	70 %
40 %	60 %
50 %	50 %
60 %	40 %
70 %	30 %
80 %	20 %
90 %	10 %
100 %	0 %

8.8 Pitfalls

Flyvbjerg and his colleagues outlines some possible pitfalls related to introducing RCF. One of them is that budgets that are approved tend to be used. Incentives related to project management and control must therefore be structured so that managers are always looking to maximize benefit, even though this means that budgets must be cut, or increased (2004).

Another issue is related to asymmetrical information. Flyvbjerg argues that the use of uplifts may introduce an additional moral hazard between the principal and agent. Another, and perhaps the most critical issue, is that forecasters over time will gradually return to focusing towards the specifics of projects. He argues that this pitfall may be avoided by sticking to the method of RCF (Flyvbjerg & COWI, 2004, p. 35).

To use RCF, it is important to understand what it adjusts for. If managers start to ease the work they already do when coming up with the first estimate, using RCF will no longer be meaningful. RCF creates multiplicators based on the historical tendency to overrun predictions that forecasters have put maximum effort and knowledge into. If forecasters start to skimp on the work they do to come up with the estimate, the reference class is no longer applicable.

Over the past decades, the use of uncertainty quantification and advanced simulations have increased in the oil and gas industry. For example, in Statoil, there is a requirement to undertake uncertainty analysis before making an investment decision (Neumann et al., 2012). Despite this, forecasts are just as biased as they were 20 years ago. It is therefore the data that is put into simulations, and not the simulations themselves, that are biased. In an ideal world, RCF would adjust inputs, so that the output from simulations were debiased. Unfortunately, that would require elaborated research, and RCF as presented in this paper is therefore the best available method for taking an outside view, as it covers all bias that affect the forecast.

8.9 Further Research

This paper has proved what Flybjerg showed for infrastructure projects: taking on an outside view, and apply RCF, can help increase the industry's understanding of risks and probabilities related to estimates in a specific project. Fields are underproducing the first years, and then producing more than expected as they mature. A yearly RCF, which can be applied to estimated production x years after startup will therefore be more relevant than applying uplifts for several production years at once, as done is this paper.

To fully remove and analyse the effect of schedule overrun, monthly production data must be used. If such data was made available, complete analyses and reference classes for costs, development time and production would be possible to develop. Increasing the reference classes will also improve the quality of the method and uplifts.

9 Conclusion

The analyses presented in this paper shows that in development projects on the NCS, there is a clear tendency to underestimate time and cost of development, and overestimate benefits from production.

Production data for 56 fields approved from 1995-2017 has been analysed. When focusing on total production the first four years, only 25 percent of them delivered inside their estimated 80-percent confidence interval. As many as 56 percent delivered production less than the P10-estimate.

Not delivering on forecasts causes value erosion. Total value lost from not reaching budgets sums up to 474 billion 2017-NOK. Companies underestimate cost and time by about 25 percent, whilst 17 percent of expected revenues are lost due to underproduction. A field on the NCS lost 23 percent of its expected profit when overspending budgeted costs with 19 percent, starting production two months before scheduled, and earning 17 percent less revenue than expected due to underproduction. The results also show that although simulations and probability measures are used more now than in the mid 90's, the industry have failed to improve their forecasts the last two decades. As OGA (2017) outlines: although project management has received increased attention over the last decades, the industry's ability to predict outcomes in petroleum development projects has not improved.

Forecasts are affected by two types of bias: delusion and deception. There are four relevant sources of delusional bias in development projects: anchoring, overconfidence, system availability, and group thinking. Methods and training can be applied to reduce their effect, but research and historical data show that we fail to remove their impact, even when measures are taken, and training applied. Deception bias will mainly occur when one or more of these situations are present: a principal-agent problem, self-interest, difference in risk preferences, or asymmetric information. It can be reduced by creating contracts and incentives that align the interests of all involved parties, but is in practice impossible to fully remove, as stakeholders always will benefit from different outcomes.

One way to debias estimates is to adapt an outside view. Based on the Nobel Prize winning research of Kahneman & Tversky (1979a, b), RCF is endorsed by APA (Flyvbjerg & COWI, 2004), and the use of uplifts recommended by Her Majesty's Treasury. Applying multiplicators from relevant reference classes will reduce both deceptional and delusional biases, as historic performance is used to establish adjustment multiplicators from the probability distribution of outcomes. This paper shows that using these multiplicators will increase the quality of forecasts, as well as the understanding of risks and probabilities related to them. Despite this, it also indicates that a larger reference class and test group is preferable.

As this is the first known major study on companies' ability to deliver forecasted production on the NCS, further research is recommended. Interesting topics involves including gas estimates, as well as using monthly data to fully isolate the effect of time overruns. Furthermore, a different system for reporting estimated- and actual production in fields would facilitated the process of removing effects of further developments, additional wells and extra PDO's that is implemented in already opened fields. To continue this research, NPD must continue to provide researchers with necessary data and supervision.

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