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Abstract

This thesis focuses on the causes leading to cost overruns in energy projects. The motivation to write about this subject arose from discovering the fact that most companies avoid releasing accurate information surrounding costs of their projects, and for this reason, few studies have been done on the subject matter. While researching this subject, the author came to the conclusion that the explanation behind the occurrence of cost overruns would be complex, and that a single method of study would not be sufficient to comprehensively answer the research question. Therefore, a mixed-method study was chosen.

The result of using a mixed-method study has led to the analysis of quantitative data from 424 projects, which was then mixed with a set of quantitative and qualitative data from a variety of sources, making this a comprehensive study on this topic. The focus of this thesis has been on the accuracy of information available at the time of decision to approve the initiation of a project, i.e. project sanctioning, and should only be interpreted as such.

The author has found that bias, deception and lack of understanding of risk and complexity are widespread in the energy industry. The results indicate that projects in the nuclear sector experience cost overruns regardless of their size (indicated by budget and capacity), proposed project time or completion date within its sector. These projects had the highest average and frequency of cost overruns of any sector. Meanwhile, hydro projects represented the highest average cost overruns in total dollars of any sector. Oil and gas projects showed better forecasting performance, but still had arguably high average and frequency of cost overruns. On the other hand, wind and solar projects had high degrees of standardizations with shorter project lead times and were the least risky options of all the sectors.

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Table 1: List of abbreviations

Abbreviations	Explanation
MW	Megawatts
CO	Cost Overrun
PDO	Plans for Development and Operations
NCS	Norwegian Continental Shelf
R.H.S.	Right Hand Side
NPP	Nuclear Power Plant
Sm^3	Standard Cubic Meter
NGL	Natural Gas Liquids
MOPU	Mobile Production Unit
i.e.	Id Est (In other words)
MPE	Ministry of Petroleum and Energy
EY	Ernst & Young
IEA	International Energy Agency
Q-Q plot	Quantile-Quantile plot
SD	Standard Deviation
SW	Shapiro-Wilkins
JB	Jarque-Bera
NPD	Norwegian Petroleum Directorate
SBM	Single Buoy Moorings
e.g.	Exempli Gratia (For example)
LNG	Liquefied Natural Gas
FEED	Front-End Engineering Design

1 Introduction

1.1 Scope and Purpose of the Thesis

Cost overrun is a significant and persistent challenge in energy projects. A study from 2002 by Flyvbjerg et al found cost overrun to be a global phenomenon, and that the projects showed no improvement in the last 70 years by the time the study published its findings [1].

This thesis uses the definition of cost overrun given by Lorentzen et al [2], which is "*the relative inflation-adjusted difference between the final and the initial estimate of the cost of a project.*" This is a large-scale study over a longer period of time, including a sample size of 424 projects for testing. It focuses on the determinants of cost overrun; how and why it happens.

Cost overruns are problematic for projects in several ways. A cost overrun means that the initial estimates that created the baseline for the decision of a project sanctioning either are irrelevant or inaccurate. The initial estimates can contain analyses like net present value (NPV), which can be used to rank and select between different projects. If the NPV for a project was inaccurate, that would mean that the decision for sanctioning that specific project was based on inaccurate information. Or, as Bacon et al puts it; "*cost overrun represents a possible loss of economic justification that was used for sanctioning a project* [3]". This is troublesome, both because it can mean that another project with a higher actual NPV was ignored, and because it negatively effects the bottom line of the company, since the actual NPV was lower than first anticipated.

Studies on the topic of cost overrun are few and far between. This is because companies would rather not share detailed information on project costs that can either put the company in a negative light or reveal company secrets to their competitors. Cost overruns in the public sector can, in the public eye, be seen as tax money being wasted. These create incentives for governing bodies, both public and private, to either hide or misreport the results of their projects to protect their reputations. As a report by Ernst & Young in 2014 on the topic of megaprojects in the oil and gas sector puts it:

"*Where organizations develop a reputation for successful delivery and environmentally conscious development of megaprojects, they will often develop a competitive advantage* *over their less successful rivals, becoming a preferred partner, gaining preferential access rights and cheaper finance, and (most tangibly) seeing an increase in share price* [4].”

This is a mixed-method study, meaning that both qualitative and quantitative methods of research have been used to study projects within the oil and gas, nuclear, hydro, wind and solar sectors. The motivation behind choosing a mixed-method study was to do a deep dive into the nature of how cost overruns occur and discuss the complex nature of behavioural economics behind cost overruns. Therefore, the author of this thesis concluded that quantitative methods alone were too surface level. Rather, the author uses the dataset for the 424 projects to perform a series of statistical tests that supplement the analysis and discussion of various journal articles, reports, interviews, books and theories to more fully explore the determinants of cost overrun [5].

The over-arching goal is informing decision-makers about the misconceptions and avoiding the pitfalls of cost overruns.

1.2 Structure

This thesis is divided into eight chapters. Chapter 2 focuses on the definitions of terms and theories relevant for answering the research question. Chapter 3 details the four most central papers for the creation of this thesis. It describes their motivations and methods for conducting the studies, and their findings and importance in shaping this thesis. Chapter 4 details the methodology behind the making of this thesis, i.e. the methods in which author has employed to analyse the data. Chapter 5 specifies how the data was collected, which variables have been used to test the different hypotheses and why. Chapter 6 is split into four subchapters. It opens with a brief overview of all five sectors, then continues with descriptive statistics and normality tests for a deeper look. The last subchapter is dedicated to testing four hypotheses about cost overruns in this industry. Chapter 7 is a discussion of all the collected data. It is split into five subchapters, one for each sector. And lastly, chapter 8 concludes about the findings.

1.3 Limitations

The dataset used in this thesis comprises of data from two different sources; the yearly reports from Ministry of Petroleum and Energy (MPE) for oil and gas projects [6], and Sovacool et al's dataset for the projects in the other sectors [7]. Since the availability of information was scarce at the time of writing, the dataset includes different variables between oil and gas and the other four sectors. The numbers from MPE have a limited number of variables compared to Sovacool et al's dataset. In other words, comparability between these sectors will be somewhat limited. This is the most apparent in chapter 6.

It is important to note that the data collected for this thesis and the numbers in the various papers will not always match exactly. The biggest reason is due to data being inflation-adjusted at different times. This thesis uses the consumer price index by the Statistics Norway [8] to inflation-adjust the data collected.

Furthermore, cost overruns in this thesis are painted in a negative light, i.e. as something that should be avoided. But this may not always be the case. A cost overrun does not always equate to poor cost estimation. For example, some project managers may intentionally overspend slightly, for the purpose of managing expectations for future projects in hopes of getting adequate funding for them.

This thesis assumes that the values from the government reports and the dataset from Sovacool et al's study, which itself stems from a variety of sources, are correct. Their definitions of cost overrun, project start and end, initial estimate, etc., may differ from the ones used in this thesis.

Only completed projects have been included in the dataset. For oil and gas projects, this means that there were 19 projects still under construction at the time of writing. And for the numbers from the four other sectors, Sovacool et al also only included completed projects in their dataset. This means that any project that was still under construction or cancelled, was excluded. In theory, this could hide some projects that were truly disastrous in terms of cost performance. But this thesis has not attempted at validating this theory. Sovacool et al ended their data collection in 2014 of January [9].

Lastly, the period of time analysed for the different sectors have different lengths for each. This again relates back to the availability of data. This means that the results of the analyses can have varying levels of strength and be interpreted differently depending on the sector, something the author has taken into account.

2 Theory

This chapter provides relevant definitions and theories for this thesis.

Subchapter 2.1 provides a definition of the concept of cost overruns. Subchapter 2.2 gives an overview of contract management. Contract management can play a central role for projects, as is demonstrated in chapter 7. This subchapter clarifies what it means to plan and execute an effective contract management strategy with the aim of avoiding cost overruns. Subchapter 2.3 explains how the need for project management arises, why it plays an important role in implementing a cost-effective project, and a relevant theory of how it can be improved, which will be explored in the later chapters. Furthermore, this subchapter states how this thesis defines complexity, an important factor for cost overruns in some projects. And lastly, subsection 2.4 and 2.5 explain several aspects of optimism bias and strategic misreporting; how this thesis defines them, in what ways they differ from each other and how they lead to cost overruns.

2.1 How Do We Define Cost Overruns?

Academics have an ongoing disagreement on the definition of a cost overrun. A project can have several cost estimates throughout its lifetime; from the concept phase to as late as the project closing phase. Therefore, it can be difficult to pinpoint which estimate to compare the actual costs to when calculating cost overruns.

Flyvbjerg defines an initial estimate as "*the latest available budget at the time of decision-making*", and chooses this number as the basis for his calculations of cost overruns [1]. Love and Ahiaga-Dagbui strongly disagree with Flyvbjerg's methodology, and state that only the latest budget created after a scope change is relevant. To them, the estimate at the time of project sanctioning then becomes irrelevant [10].

The problem with Flyvbjerg's methodology is perhaps that it does not account for scope changes. But, his paper from 2002 focuses on the accuracy of the information available at the time of decision-making. His methodology evaluates whether a decision is informed or not, which makes estimates made after project sanctioning irrelevant [1]. One can even argue that the existence of scope changes points to an uninformed decision-making. That is why the cost estimate at the time of decision-making is the most interesting and is called the "initial" estimate.

2.2 Contract Strategy

Table 2: Often used abbreviations in contract management.

Abbreviation	*Explanation*
E	Engineering
P	Procurement
C	Construction
I	Installation
C	Commissioning
H	Hook up
F	Fabrication

A well-planned and -executed contract strategy is often an essential part of the implementation of a cost-effective project. The importance of contract strategy will vary depending on the individual projects, but early and accurate procurement planning can sometimes be the difference between a successful project, and a project with severe cost and time overruns [11]. A well-defined change management strategy, a potentially key part of an effective contract strategy, see Figure 1, can also help in avoiding further cost and time overruns when met with unexpected challenges mid-project.

Consequently, this makes the design of contracts an essential part of an effective procurement. Each party agrees upon the terms of the contract, so that, ideally, everyone's roles are well defined, and everyone is protected against the risk of unexpected changes in their partner's future behaviour. This is important in order to build trust and allow safe and efficient planning, investing, and production for companies to engage in. Fixed obligations in contracts ensure that a buyer receives the agreed upon item, like a service or a good, on the agreed upon time, cost and terms of the contract [12].

Examples of the processes involved in procurements can be seen in Figure 1 and Figure 2.

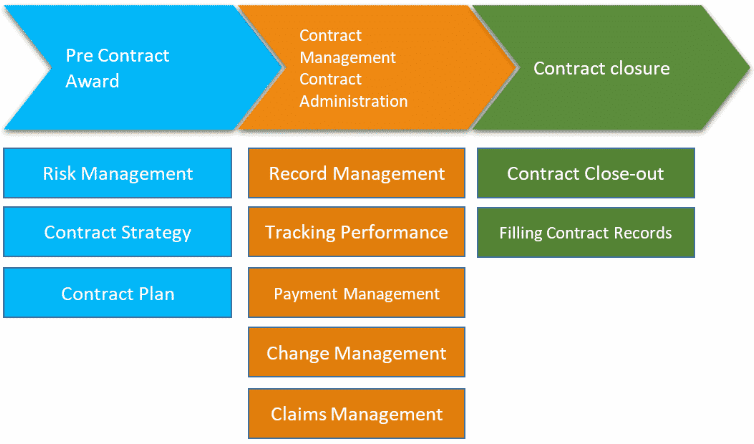


Figure 1: An example of a flowchart for each of the stages in a procurement process [13].

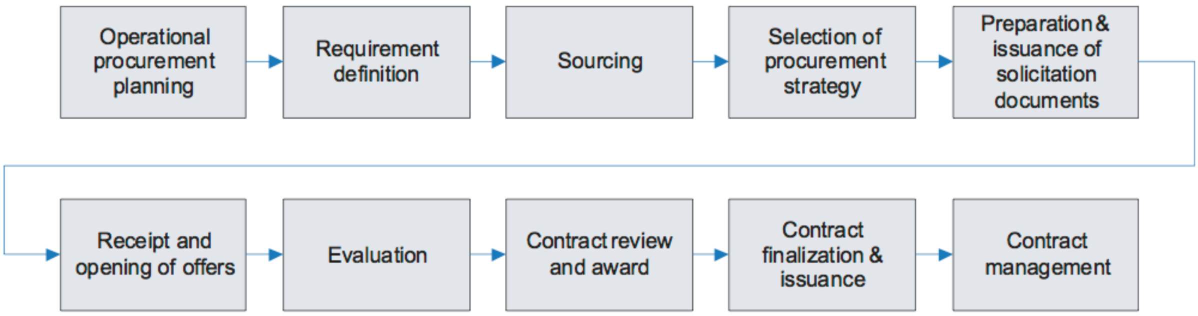


Figure 2: Another example of a flowchart for each of the stages in a procurement process [11].

2.3 Project Management and Complexity

Organizations are using projects more and more to stay competitive in a rapidly evolving business environment. Projects arise to fulfil an organization's needs, either to solve a critical problem or to take advantage of an untapped business opportunity. In either case, estimations of the scope of work that needs to be done, and estimations of the cost of the project are presented as part of a business case to advocate for the approval to pursue the appropriate project [14].

Similar to contract management, project management often plays a key role in an effective project implementation effort. It can be the difference between a project that delivers the promised product or service with little to no cost and time overruns, and a project that fails to be on time and budget. The latter can also arise from overpromising or creating overly optimistic estimates. Some projects can even fail to deliver the product or service entirely, which means that the project has spent company time and resources with no end result.

Moreover, projects are complex by nature. Complexity in projects often negatively impacts the forecaster's ability to make accurate estimations. This thesis differentiates between technical and organizational complexity. Technical complexity is characterized as the engineering challenges and the involvement of a diversity of disciplines [15]. Organizational complexity comes from rules and regulations, politics, stakeholder management, etc., that an organization has to adapt to.

And lastly, as a response to complexity, projects can be significantly improved by learning. Learning causes increased productivity, effectiveness of teams and efficiency when performing future activities [16]. Sarin et al claims that learning has a much stronger impact on performance than team size or diversity [17].

2.4 Optimism Bias

Optimism bias is one of the most prevalent biases in behavioural economics. In economics, we can categorize an estimation as optimistic if it overestimates the likelihood of success of a financial investment, and/or underestimates the probability of experiencing negative events [18]. In other words, it often leads to creating unrealistic expectations by overpromising the benefits, and/or downplaying the risks, of a project and underdelivering on its promises. A project's promises can be in relation to cost, time, quality of the service or product to be delivered, or some other metric used to measure the success of a project.

Optimism bias in this thesis is related to decision-making in the early phases of the project. Although it is easy to identify the characteristics of a project estimate that exhibits this behaviour after the fact, it can be difficult to state with certainty which estimates do or do not suffer from optimistic biases at the time of decision-making. Optimism bias can also be mistaken for strategic misreporting, and vice versa, which is explained in the next subchapter.

2.5 Strategic Misreporting

The results of optimism bias and strategic misreporting in estimations are often the same when looking at the individual results. However, there are two key differences. Firstly, strategic misreporting is intentionally deceiving, i.e. intentionally overpromising the benefits and/or downplaying the risks inherent in a project in order to get project approval, while optimism bias is self-deceiving and non-intentional. Secondly, the distribution of cost overruns, in the case of optimism bias, converges to a zero average and skewness in the long run. This means that when looking at the project results collectively and over a longer period of time, the bias will have corrected itself as people have more experience and access to more information. On the other hand, strategic misreporting retains the positive average and positive skewness for the distribution of cost overruns [19].

There can be a number of reasons for intentionally putting a project in a better light than what is warranted by actual experience, i.e. deceiving. There can be competition for limited resources within a company, a promotion to be gained from the approval of a project, the approval of a project can be of political importance to someone, among many other reasons.

3 Literature Review

For this thesis, a number of papers have been analysed in order to compare and contrast with the results from the dataset in chapter 6. Each paper plays a central role in answering the research question. *Assessment of completed projects on the Norwegian Continental Shelf* [20] by the Norwegian Petroleum Directorate (NPD) gives an in-depth look at determinants of cost overrun in five projects on the NCS. Lorentzen et al's *Pro-Cyclical Petroleum Investments and Cost Overruns in Norway* [21] explores the effects of economic activity, which is an important topic for this thesis, in rigorous detail. *Risk, innovation, electricity infrastructure and construction cost overruns: Testing six hypotheses* from Sovacool et al [9], focuses on macro-level trends of cost overruns in the industry. And lastly, *Spotlight on oil and gas megaprojects* by Ernst & Young [4], focuses on cost and time overruns in megaprojects in the oil and gas sector.

3.1 Assessment of Completed Projects on the Norwegian Continental Shelf

As a request by the Ministry of Petroleum and Energy, the Norwegian Petroleum Directorate reviewed projects that, at the time, had recently started production with an investment scope of over NOK 10 billion. NPD is a governmental specialist directorate and administrative body whose main purpose is to maximize value for the Norwegian society from the Norwegian oil and gas sector.

The report is about oil and gas projects on the NCS with a plan for development and operation (PDO) approved between 2005 and 2008. The purpose was to understand the factors that lead to success or failure on the counts of time, quality and cost [20].

Oil and gas companies must deliver a PDO for each project, which creates the basis for the comparison between estimated plans and actual outcomes. The report has sections detailing what went right and wrong, and what can be done better next time. The specific reason for its inclusion is the unique perspective it provides to the topic. It goes into great detail about the projects, including interviews with the operators on what they learned from their experiences.

In short, much of the same findings of a report from 1999 by The Investment Committee, *Analysis of investment trends on the continental shelf* [22], were relevant once again. The most important factor for a project's success was perhaps the need for a thorough early-phase work. A persistent issue in projects with noticeable cost overruns was having too ambitious plans with too little time put into the planning of their executions. The technical and organizational challenges and the quality needed for certain components to implement the projects were severely underestimated.

Having a proper contract strategy have, in some cases, assured quality and progress of a project, and in others, avoided the further escalation of cost and time overruns. The report recommends the operators to have a clear strategy for pre-qualification and follow-up of suppliers for a successful project.

Moreover, high economic activity has been the culprit for low supply of resources and high prices. For projects that, for various reasons, started badly, high economic activity has had an amplifying effect on further cost and time overruns.

3.2 Pro-Cyclical Petroleum Investments and Cost Overruns in Norway

This paper by Lorentzen et al investigates the effects of business cycle developments on cost overruns. It analyses how price developments, with shocks or surprises to oil price, employment, etc., can cause cost overruns in projects [21].

The first hypothesis that they tested for is whether or not business cycle of the oil industry has a positive impact on cost overruns. They make a distinction between global and local indicators of business cycle. The global indicator that they use to test for this hypothesis is oil price and oil price surprise, in which the oil price surprise is defined as "*the relative difference between the current oil price and the oil price at the time of the project sanctioning*" [21]. The idea is that an increase in a variable used to measure economic activity, e.g. oil price, can lead to higher economic activity, i.e. more companies competing in the same sector. Consequently, this will lead to more companies competing for the same resources, meaning fiercer competition for rigs and qualified personnel. This in turn leads to higher rig rates and lower availability in qualified personnel, meaning relatively higher costs and time delays. Their second hypothesis is to test whether cost overruns are more responsive to global or local indicators. Their local indicators are employment surprise, investment surprise, wage surprise and surprise in rig rates in new contracts on the NCS.

In short, Lorentzen et al show that cost overruns on the NCS have a cyclical nature. They show that cost overruns are relatively higher during times of high economic activity. The best indicator to support the claim of the business cycle effect proved to be the labour market. A low supply of qualified personnel leads to higher wages and reduced productivity. They also find that project size, in terms of investment size, positively affects cost overruns. Lastly, they find that cost overruns are more likely to appear in the later stages of a project and that longer lasting projects are more prone to experiencing cost overruns [21].

3.3 Risk, Innovation, Electricity Infrastructure and Construction Cost Overruns: Testing Six Hypotheses

Sovacool et al have gathered a dataset comprising of 401 electricity projects built between 1936 and 2014 in 57 countries. This paper is unique in the sense that it is one of the few that has been able to gather and analyse such a large dataset of projects over a longer period of time. It uses regression analysis with the goal of capturing macro-level trends in the industry [9].

The six sectors of focus for this paper are hydroelectric dams, nuclear reactors, thermal plants, wind farms, solar facilities and transmission lines. The database is used to test how size (in terms of production capacity), project delays, project completion date and geographical location impact cost overruns in projects.

The authors developed six hypotheses relating to location, reference class of technology and external comparison between each of the reference classes. The dataset consists of any power plant with over 1 MW installed capacity, or greater than 10 km of transmission lines for transmission projects.

Some of the same limitations for this thesis applies for this paper as well. Sovacool et al mention the deliberate overspending by project managers, in order to manage expectations for future project funding. There is also the problem of inconsistent use of the term “project start”, making it difficult to agree on which estimate is the “initial” one.

The paper uses linear regression analysis to represent the robustness of their trendlines. They employed a "slope intercept" form of $y = mx + b$. Given a dataset (x_i, y_i) with n data points, the slope, y-intercept and correlation coefficient, they determined the r in each graph by using the formulas in Figure 3.

$$m = \frac{n\sum(xy) - \sum x \sum y}{n\sum(x^2) - (\sum x)^2}$$

$$b = \frac{\sum y - m\sum x}{n}$$

$$r = \frac{n\sum(xy) - \sum x \sum y}{\sqrt{\left[n\sum(x^2) - (\sum x)^2\right]\left[n\sum y^2 - (\sum y)^2\right]}}$$

Figure 3: Formulas used in "Risk, innovation, electricity infrastructure and construction cost overruns: Testing six hypotheses" for regression analysis [9].

Each hypothesis was rarely, if at all, validated across all six sectors. For example, most sectors showed a statistically significant relationship between project delays and cost overruns. This supports their hypothesis that the longer a project goes on after its planned completion date, the costlier it gets. On the other hand, other hypotheses, like the ones relating to size and completion date, were only validated for a few sectors each. They define their results as significant if the R^2 value exceeds 0.2, i.e. 20%, for their polynomial and logarithmic trend lines. They also acknowledge that there is no universally accepted number for what passes as a significant R^2 value, as some will argue that an R^2 value as low as 1% is statistically significant.

In terms of experiencing cost overruns, the paper found nuclear reactors to be the riskiest projects, hydroelectric dams to have the largest cost overruns in terms of total dollars, and smaller projects to perform the best. In general, the paper found that "*many hypotheses grounded in literature appear to be wrong; and that financing, partnerships, modularity, and accountability may have more to do with overruns than technology* [9]".

Some of the same calculations and figures in this paper can be found in this thesis too. This has been done for the sake of overview for the reader, and to compare some of the sectors in Sovacool et al's dataset with the oil and gas sector.

3.4 Spotlight on Oil and Gas Megaprojects

A report from 2014 by Ernst & Young (EY), is the result of reviewing 365 projects with an estimated investment of above US$1b in the upstream, LNG, pipeline and refining segments of the oil and gas sector. They used a 2-step process for gathering their data. The first step was researching several research articles, company websites and reports. Their criteria were based on the projects being proposed for, but had not yet reached, the final investment decision, and the projects that passed this decision and were in the construction phase but had not yet begun operations. In the second step, they collected data from, in addition to the already-mentioned sources, analyst reports via Thomson One, company websites and annual reports, and press announcements via Factiva and company websites [4].

They found that megaprojects are fast becoming the new norm, spurred on by the growing demands from emerging markets and the need to replace depleting supply sources. This has caused an increase in capital spending on oil and gas projects, consequently leading to higher oil and gas prices. This trend is expected to continue according to the International Energy Agency (IEA). Global spending is forecasted to be dominated mostly by North America, Europe and Asia-Pacific.

Since finding oil is getting harder and harder, companies are now more actively looking to diversify their portfolios. This leads to looking for other options of income in emerging opportunities in shale gas, coal seam gas, light tight oil, etc. To fund these new ventures, companies are engaging in multibillion-dollar technically and operationally complex projects, called megaprojects. Megaprojects represent high risks and high rewards. For oil and gas companies, this is represented by huge investment sums needed over a long payback period. To limit their exposure to risk, companies often engage in joint venture agreements.

Governments and local communities are also stakeholders in these ventures. These projects can drive economic development, but the positives must be balanced against long term interests and environmental drawbacks.

The results of their findings from analysing 365 megaprojects are that most of them fail to deliver within estimated time and budget. Long term industry outlook suggests that project delivery success is decreasing, especially in areas where complexity is relatively higher [4].

4 Methodology

How do cost overruns occur in energy projects? This chapter details the methods in which the author employs to answer these questions. As mentioned before, this thesis uses the consumer price index by the Statistics Norway [6] to inflation-adjust the data collected.

4.1 Descriptive Statistics

Histograms have been used to display the frequency and average cost overruns for each sector. These numbers have been combined into a single figure with two histograms for the sake of comparison, see Figure 4. The former tells us something about how likely it is, or at least was for the tested time period, for a project to experience cost overruns. The latter tells us something about the severity of cost overruns.

Furthermore, a combination of correlation tables and summary statistics have been used for a deeper look. The correlation tables measure the correlation between two variables. The variables used in these tables are capacity, initial budget, actual cost, cost overrun, proposed time, actual time and time overrun. The correlation between these variables vary from -1, 0 and 1. A correlation of -1 means that the variables show a perfectly negative linear relationship between them, while a correlation of 1 demonstrates a perfectly positive linear relationship. A correlation of 0 means no relationship between the two variables [23]. Other than perfect and no correlation, there are low, moderate and high degrees of correlations. A strong degree of correlation are coefficient values between ± 0.50 and ± 1, medium between ± 0.30 and ± 0.49 and low between 0 and ± 0.29 [24].

The discussion of the correlation tables is supplemented by summary statistics, including calculations of the average, standard deviation (SD), skewness, kurtosis and maximum and minimum values of the variables mentioned above. The average gives an overview of the central location of the distribution of these variables. The standard deviation detects the degree to which the distribution deviates from the average. Skewness measures the symmetry of the distribution, or lack thereof, while kurtosis measures whether the data is heavy or light tailed relative to a normal distribution. Lastly, maximum and minimum values are also included to check for high deviances from the average. If so, it could indicate the existence of outliers in the data, a heavy-tailed distribution, etc. [25] [26]

4.2 Normality Tests

Although the above-mentioned methods do a good job of informing the reader of how each sector performs in terms of cost overrun, another set of tests have been done to more fully map out the state of forecasting performance in these sectors. The distributions of cost overruns for each sector are shown in histogram plots and supplemented with Q-Q (quantile-quantile) plots and normality tests. Both of these latter methods test whether or not the data is normally distributed. These tests are important in order to check for biases and deceptions in the sectors, as mentioned in chapter 2.4 and 2.5. The Q-Q plots display the values of an expected normal distribution and compares them to the actual values in order to check for deviations [27]. These plots can be visually analysed. The two normality tests are comprised of the Shapiro-Wilks (SW) and the Jarque-Bera (JB) tests. Normal distributions are expected to have (near) 0 skewness. If the p-value produced by these tests are less than the chosen alpha level (usually 5%), then it is evidence that the data is not normally distributed. The SW test is the most suited for smaller sample sizes ($n < 50$). Since some sectors have rather large sample values, it has therefore been supplemented with the JB tests and the Q-Q plots [27] [28] [29].

4.3 Regression Analysis

Much like Sovacool et al's method of research, which was detailed in chapter 3.3, this thesis also uses linear regression analysis to determine the strength of the findings based on the dataset. The analysis indicates the percentage of the variance in the dependent variable, y, can be explained by the independent variable(s), x. An R^2 value is used to measure the strength of the relationship between the variables. An R^2 value of 0.15 means that the independent variable can explain 15% of the variation in the dependent variable. R^2 is joined by a *p-value*, which indicates if these relationships are statistically significant, a $\beta 0$, which is the intercept parameter, and a $\beta 1$, which is the slope parameter. There are n number of observations, with each observation signified by i. Ordinary least squares method is used for estimating the unknown parameters, $\beta 1$ and $\beta 0$. A low *p-value* (< 0.05) indicates a statistically significant relationship between the variables [30]. The right-hand side parameters are often displayed with an error term, ε, which captures factors influencing the dependent variable excluding the independent variable. The error term is not focused on in this thesis [31]. See Equation 1.

$$y_i = \beta 1 * x_i + \beta 0 + \varepsilon_i$$

Equation 1: Formula used for linear regression analysis.

The least squares estimates are given by the formulas in Equation 2. $\bar{x}$ and $\bar{y}$ are the averages of *x* and *y*, while $\widehat{\beta 0}$ and $\widehat{\beta 1}$ are the estimators of $\beta 1$ and $\beta 0$, respectively.

$$\widehat{\beta 0} = \bar{y} - \widehat{\beta 1}\bar{x}$$

$$\widehat{\beta 1} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

Equation 2: The ordinary least squares estimators.

The motives behind the choice of variables, and thereby the hypotheses, are explained in chapter 5.

4.4 Putting It All Together

The results from the above-mentioned analyses are mixed with the data collected from a wide variety of sources, including reports, studies, interviews, etc. In other words, chapter 7 is not simply a discussion of the results from chapter 6. Rather, the author uses multiple sources of data to discuss and draw conclusions about the research question, also known as the triangulation method [32]. See chapter 5.1 for more details on the data collection methods used.

The discussion of the development of the newest Indian nuclear power plant (NPP) in the dataset, Tarapur phase II, is a great example of the use of this method. The author considers the statement made by the Nuclear Power Corporation of India Limited (NPCIL), which operates this plant, about the project [33], and finds that it conflicts with the numbers from the collected database. This conflict of information sparks a more interesting topic of discussion, which includes data from other cost performance sources of the same project [34] [35], an interview in a journal article about megaprojects [36], the results from chapter 6, books about the state of the nuclear technology/industry in India [34] [37], a news article about Tarapur phase II [38], and a report about the financing of NPPs [39]. As is stated by the book about research methods in education, the more contrasting the research methods that the data has been collected from, the greater the researcher's confidence is about the findings [5].

As mentioned earlier, the discussion in chapter 7 has been split into five subchapters, one for each sector. Each subchapter has been dedicated to discussing several factors which can potentially explain the forecasting performance of these sectors. Note that for oil and gas, the report *Assessment of completed projects on the Norwegian Continental Shelf* [20], has taken a central focus. As previously mentioned, this report focuses on specific projects and not the general state of the sector. However, the findings of the report have been linked to the results in chapter 6, the findings from various other papers and relevant theories. In addition, it has been compared to the findings from two additional reports [4] [22], in order to create a bigger picture of the general state of the oil and gas sector.

5 Data

This chapter explains how the data has been collected and from which sources. Furthermore, it explains which variables have been used for analyses. Finally, it details the ex-ante expectations regarding the relationship between the dependent and the list of independent variables used in regression analysis.

5.1 Data Collection Methods and Their Sources

MPE publishes yearly reports with investment estimates from the oil and gas projects on the NCS. From these reports, the author has collected initial and final estimates for projects dating as far back as the year 2000. A total of 109 projects have been considered for this sector. These numbers have been supplemented by Sovacool et al's dataset used in the study, *Risk, innovation, electricity infrastructure and construction cost overruns: Testing six hypotheses* [9], with nuclear reactors, hydroelectric dams, wind farms and solar facilities. Sovacool et al built their database from searching energy studies and electricity, transport and infrastructure literature, all of which have been peer-reviewed. They further built upon those numbers by creating their own database through contacting energy experts and searching project documents, press releases and reports. They collected data about projects' date of completion, capacity, budget, cost and time.

Another great source of data has been the report, *Assessment of completed projects on the Norwegian Continental Shelf* [20], published by NPD. As previously mentioned, this is a unique source of data, as it goes into great detail about each of the five projects of focus. Furthermore, Lorentzen et al's paper on *Pro-Cyclical Petroleum Investments and Cost Overruns in Norway* [21] has been a great source of information on economic activity. Meanwhile EY's report on megaprojects in the oil and gas sector [4] and the Investment Committee's report on earlier projects on the NCS [22] have been used to more fully map out this sector.

Other data collection methods include the use of search engines, like google.com and duckduckgo.com, and various databases for scientific research, like sciencedirect.com. Phrases like "cost performance", "cost overrun", "financial risk", etc., were combined with the names of specific energy sources to find material to answer the research question. In chapter 7, conflicting information about the cost performance of Tarapur phase II nuclear project was discovered. A combination of search phrases like "Tarapur Atomic Power Station", "cost" and "performance" were used to include more sources on this issue.

For theoretical insight on project management and contract strategy, various books have been studied. The list of books include "UN Procurement Practitioner's Handbook" [11] and "Effective Project Management: Traditional, Agile, Extreme" [14], among others.

5.2 Choice of Variables

For the regression analysis, the choice of variables has been chosen with the aim of explaining the macro-level trends within each sector. The choice of variables includes the initial budget, capacity, completion date and proposed time for projects. These variables often create the basis for the decision of project sanctioning.

The size of the estimated initial budget can be an indication of project size. Relatively speaking, within each sector, increase in project size can be positively associated with increase in complexity in projects and uncertainty in estimations. In short, the hypothesis to test for using this variable is checking if projects with bigger estimated sizes, indicated by their initial budgets, are more prone to cost overruns.

Another variable that can be used to indicate size, and consequently, complexity of a project, is capacity. The hypothesis then, is that projects which aim for higher capacity are also more prone to cost overruns.

Completion date is used to see if forecasting abilities have improved with time. The hypothesis behind the use of this variable is that with more information and experience, in addition to having better forecasting methods and tools, should make forecasting more accurate as time goes on.

Projects with longer estimated time are more prone cost overruns, according to the final hypothesis. Projects with longer time estimations are often linked with higher uncertainty, since the longer a project takes, the more prone it is to be affected by outside factors.

6 Results

This chapter is split into four subchapters, opening with an overview of the forecasting performance of the sectors. The next three subchapters are dedicated to descriptive statistics, normality tests and regression analyses.

Chapter 6.2 is dedicated to summary statistics and correlation tables. It is mainly a discussion of the correlation tables, with the results of summary statistics acting as a reference point for the entire chapter. Chapter 6.3 checks if the distributions of cost overruns in each sector are normally distributed. Furthermore, this subchapter can also be used to visually detect the levels of skewness, kurtosis and standard deviation. Chapter 6.4 is dedicated to testing four hypotheses mentioned in chapter 4 with the help of regression analysis.

6.1 A Brief Overview of Cost Overruns in the Five Sectors

Figure 4 paints an interesting picture regarding cost overrun in these five sectors. In the dataset for the nuclear sector, 97% of all projects experienced cost overruns. That means 175 of the 180 projects experiencing cost overruns. And with an average cost overrun of 117%, nuclear projects reveal to have the worst cost estimation performance in the dataset. Second worst out is the hydro sector, with 75% of projects experiencing cost overruns and an average cost overrun of 71%. Hydro projects consist of the biggest projects compared to the other sectors, both in terms of estimated average capacity and average initial budget, see Table 3.

Performance numbers from oil and gas might look good compared to the previous two sectors, but this sector still needs some improvements, since 66% of all projects experienced cost overruns and an average cost overrun of 12%. Wind demonstrates a somewhat better cost estimation performance; 57% of the wind projects experienced cost overrun and an 8% average cost overrun. Meanwhile, solar is the only sector with less than half of the projects experiencing cost overruns and an average cost overrun of only approximately 1%.

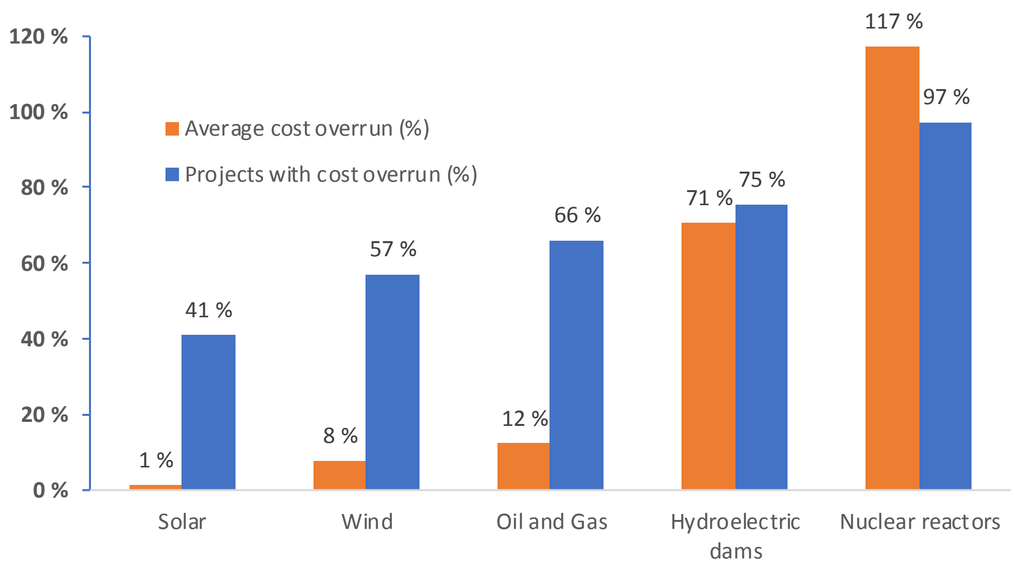


Figure 4: Comparison between average and frequency of cost overrun, by source.

Furthermore, from Table 3, one can see that nuclear projects have an average of 987 MW installed capacity. Hydro projects have an average of 1865 MW, almost double that of nuclear. In contrast, wind and solar projects have a much more modest, 177 MW and 61 MW respectively, installed average capacity. Note that this comparison was not available for oil and gas projects, as this sector uses other metrics to measure capacity.

Hydro projects have the highest average proposed and actual time results. The average actual time for these hydro projects lasted for almost a decade. Long project lead times could be positively correlated with cost overruns, as long lead times can indicate high levels of uncertainty in projects. This is further explored in the following subchapters. Nuclear projects have the second highest average estimated and actual time, while having roughly the same average time overrun as hydro (64%). Wind and solar on the other hand exhibit the best time estimation performances. Wind, with an average project lead time of just roughly one year, has only an average 0.2 months absolute and a 9.5% relative time overrun. Solar projects have an average project lead time of a little over two years and a -0.2 months absolute and a -0.2% relative average time overrun, see Table 3.

These results might suggest that bigger projects are more prone to cost overruns. On the other hand, size may not play a role, as the projects have wildly different scopes and challenges depending on the sector/technology. This is further investigated in the following subchapters.

Interestingly enough, the results from Table 3 also suggest that nuclear projects are the most efficient in terms the cost/kW numbers, which are based on the actual costs per kW installed capacity. Solar projects, which show the best estimation performance in terms of both time and cost, had the highest cost/kW. However, it is difficult to derive any conclusive arguments on the profitability of these projects based on these numbers alone. There are other factors, like the NPV of a project, payback period, operation and maintenance costs, among many others, that determine the profitability of projects. The initial budget is often a major factor for the approval of a project, and as mentioned before, exceeding these estimates have negative consequences for the estimated NPV. There are also consequences for experiencing delays. Project delays often mean that production, and therefore cashflow, is also delayed. This has a negative effect on NPV and payback periods.

Table 3: Summary of averages for each sector.

	Nuclear	Oil and gas	Hydro	Wind	Solar
# of projects	180	109	61	35	39
Capacity (MW)	986,6		1865,1	177,2	60,9
Initial budget (millions of $2012)	1267,5	900,0	2014,1	542,1	428,5
Actual cost (millions of $2012)	2549,0	1083,6	4450,8	574,9	424,3
Cost overrun (m$)	1281,5	183,5	2436,8	32,8	-4,2
Cost overrun (%)	117,3	12,2	70,6	7,7	1,3
Proposed time (months)	55,4		75,3	12,2	27,1
Actual time (months)	90,9		118,4	12,4	26,9
Time overrun (months)	35,7		43,2	0,2	-0,2
Time overrun (%)	64,0		63,7	9,5	-0,2
Cost/kW	2427,0		3093,2	2808,0	8311,6

6.2 Descriptive Statistics

This subchapter compares the correlation tables, tables 5 to 8, with the results from the summary statistics, tables 9 to 13. Note that even though there is a summary statistics table available for oil and gas, no correlation table is available for this sector due to insufficient data.

For hydro projects, capacity relates to cost overruns with 82.8% correlation. The size of hydro projects, in terms of MWs installed, have the highest SD of any sector, even relative to their own sizes (SD ≈ 2 × average), see Table 10. This result is likely highly influenced by the Three Gorges Dam in China. In absolute terms, this project represents the highest capacity and cost overrun of all projects in any sector by a wide margin, see Table 4. This table also reveals that 4 out of 5 projects with the highest absolute cost overruns are hydro projects. Looking at the dataset, one can see that 36% of the total capacity is made up of only five projects, which largely explains the high SD results. This is reflected in the results of the skewness, kurtosis and standard deviation for absolute cost overruns in hydro projects, which are also the highest in any sector. Nuclear shows strong levels of correlation with 50.1% between capacity and cost overrun. This sector has low SD relative to its average capacity (SD = 0.345 × average), suggesting that nuclear power plants are for the most part built with large capacity in mind. Meanwhile, wind and solar show almost no correlation between capacity and cost overrun. In fact, solar shows inverse correlation (-11.8%), suggesting that solar projects run into less cost overruns with growing sizes, but the correlation is too weak to make that statement with a strong degree of certainty.

Table 4: Table of projects ranked by the largest absolute cost overruns.

Source	**Name**	**Location**	**Capacity (MW)**	**Initial budget (millions of $2012)**	**Actual cost (millions of $2012)**	**Cost overrun (m$)**	**Cost overrun (%)**
Hydro	Three Gorges Dam	China	22500	11850	59480	47630	401,9
Hydro	La Grande 2	Canada	5328	7100	24560	17460	245,9
Hydro	Sayano–Shushenskaya	Russia	6400	4900	22199	17299	353,0
Nuclear	Darlington	Canada	3512	6103	22692	16589	271,8
Hydro	Nurek	Tajikistan	2700	7960	23870	15910	199,9

Correlation between actual cost and initial budget show roughly the same correlation for both wind and solar, which are 98.8% and 98.6% respectively. Hydro shows a 79.5% correlation. Meanwhile, a somewhat weaker, but still strong 65.0% correlation is shown for nuclear. Nuclear also has the highest SD (152.1) for relative cost overruns, see Table 9. As mentioned above, nuclear projects proved to have both the highest average and frequency of cost overruns.

Nuclear also has the highest kurtosis and skewness results in relative cost overruns of any sector. Followed by nuclear, the oil and gas sector also shows high kurtosis and skewness values, suggesting a skewed, heavy tailed distribution of cost overruns for both sectors. The only sector to have a 0 skewness in relative cost overruns is solar, suggesting a normal distribution of relative cost overruns.

Proposed and actual time variables strongly correlate with each other for wind and solar projects, 94.1% and 98.4% respectively, suggesting high accuracy of time estimates. In contrast, nuclear and hydro projects have a weaker correlation between these two variables, 41.1% and 49.6% respectively, suggesting weaker accuracy in this area. This notion is further supported by the tables for summary statistics, showing near 64% average time overrun for both nuclear and hydro projects, and 9,5% and -0,2% for wind and solar projects, respectively.

Table 5: Correlation between key variables - Nuclear.

	Cost overrun	*Capacity*	*Initial budget*	*Actual cost*	*Proposed time*	*Actual time*	*Time overrun*
Cost overrun	1						
Capacity	0,501	1					
Initial budget	0,324	0,598	1				
Actual cost	0,930	0,635	0,650	1			
Proposed time	0,199	-0,288	-0,053	0,140	1		
Actual time	0,639	0,243	0,115	0,557	0,411	1	
Time overrun	0,638	0,316	0,137	0,565	0,235	0,983	1

Table 6: Correlation between key variables - Hydro.

	Cost overrun	*Capacity*	*Initial budget*	*Actual cost*	*Proposed time*	*Actual time*	*Time overrun*
Cost overrun	1						
Capacity	0,828	1					
Initial budget	0,552	0,772	1				
Actual cost	0,944	0,906	0,795	1			
Proposed time	0,290	0,271	0,380	0,366	1		
Actual time	0,422	0,405	0,416	0,479	0,496	1	
Time overrun	0,337	0,327	0,284	0,364	0,059	0,896	1

Table 7: Correlation between key variables - Wind.

	Cost overrun	*Capacity*	*Initial budget*	*Actual cost*	*Proposed time*	*Actual time*	*Time overrun*
Cost overrun	1						
Capacity	0,049	1					
Initial budget	0,110	0,907	1				
Actual cost	0,264	0,888	0,988	1			
Proposed time	0,071	0,652	0,608	0,601	1		
Actual time	0,178	0,581	0,531	0,531	0,941	1	
Time overrun	0,228	-0,452	-0,450	-0,431	-0,574	-0,264	1

Table 8: Correlation between key variables - Solar.

	Cost overrun	*Capacity*	*Initial budget*	*Actual cost*	*Proposed time*	*Actual time*	*Time overrun*
Cost overrun	1						
Capacity	-0,118	1					
Initial budget	-0,163	0,889	1				
Actual cost	0,004	0,881	0,986	1			
Proposed time	0,026	-0,272	0,115	0,135	1		
Actual time	0,067	-0,257	0,150	0,186	0,984	1	
Time overrun	0,208	0,160	0,149	0,228	-0,383	-0,215	1

Table 9: Summary statistics - Nuclear.

	Date	Capacity (MW)	Initial budget (millions of $2012)	Actual cost (millions of $2012)	Cost overrun (m$)	Cost overrun (%)	Proposed time (months)	Actual time (months)	Time overrun (months)	Time overrun (%)	Cost/kW
Average	1982,0	986,6	1267,5	2549,0	1281,5	117,3	55,4	90,9	35,7	64,0	2427,0
Median	1982,0	955,5	943,4	1878,5	503,1	64,8	60,0	80,0	24,0	40,0	1776,0
Mode	1984,0	951,0	1698,1	964,4	440,3	22,2	60,0	65,0	17,0	35,4	1344,7
Standard Deviation	6,3	340,0	951,2	2445,9	1965,8	152,1	6,2	32,7	30,6	53,1	1885,5
Kurtosis	0,8	16,3	6,0	25,0	20,7	19,7	-1,2	0,5	0,7	1,1	6,4
Skewness	0,6	1,9	2,1	3,7	3,6	3,4	-0,7	1,0	1,0	1,1	2,1
Minimum	1969,0	100,0	21,9	41,5	-298,8	-7,9	40,0	40,0	-9,0	-15,0	190,7
Maximum	2005,0	3512,0	6103,0	22692,0	16589,0	1279,7	62,0	209,0	149,0	261,9	13260,1
Sum	356765,0	177591,0	228151,7	458820,3	230669,4	21110,8	9964,0	15912,0	6248,0	11193,0	436854,8

Table 10: Summary statistics - Hydro.

	Date	Capacity (MW)	Initial budget (millions of $2012)	Actual cost (millions of $2012)	Cost overrun (m$)	Cost overrun (%)	Proposed time (months)	Actual time (months)	Time overrun (months)	Time overrun (%)	Cost/kW
Average	1980,6	1865,1	2014,1	4450,8	2436,8	70,6	75,3	118,4	43,2	63,7	3093,2
Median	1981,0	300,0	659,0	655,7	99,5	30,1	70,0	91,0	19,0	32,1	2278,4
Mode	1984,0	80,0	-	-	-	6,5	60,0	72,0	12,0	30,9	-
Standard Deviation	16,2	3679,1	3823,2	9703,2	7054,7	111,7	29,8	67,1	58,4	89,9	2516,1
Kurtosis	0,8	17,1	21,1	17,7	28,9	5,5	1,0	0,8	4,6	7,1	0,8
Skewness	-0,3	3,7	4,1	3,8	5,0	2,3	1,0	1,2	2,1	2,5	1,2
Minimum	1936,0	4,0	2,8	7,3	-671,4	-50,6	18,0	36,0	-24,0	-28,6	146,8
Maximum	2013,0	22500,0	24738,4	59480,0	47630,0	512,7	150,0	301,0	241,0	401,7	10359,5
Sum	120819,0	113773,6	122859,6	271501,7	148642,2	4308,8	2483,3	3908,3	1425,0	2102,0	188686,5

Table 11: Summary statistics - Oil and gas.

	Date	Initial budget (millions of $2012)	Actual cost (millions of $2012)	Cost overrun (m$)	Cost overrun (%)
Mean	2010,1	907,8	1092,9	185,1	12,3
Median	2009,5	425,9	425,4	17,6	8,0
Mode	2017,0	-	-	-	-
Standard Deviation	5,3	1222,4	1661,0	571,5	36,9
Kurtosis	-1,3	8,9	13,2	18,4	13,3
Skewness	0,0	2,7	3,2	4,1	2,8
Minimum	2001,0	33,4	26,7	-236,4	-69,1
Maximum	2019,0	7546,9	11007,6	3460,7	218,8
Sum	217086,0	98042,4	118038,4	19996,0	1324,6

Table 12: Summary statistics - Wind.

	Date	Capacity (MW)	Initial budget (millions of $2012)	Actual cost (millions of $2012)	Cost overrun (m$)	Cost overrun (%)	Proposed time (months)	Actual time (months)	Time overrun (months)	Time overrun (%)	Cost/kW
Average	2009,5	177,2	542,1	574,9	32,8	7,7	12,2	12,4	0,2	9,5	2808,0
Median	2011,0	160,0	226,0	266,0	1,0	1,7	10,0	11,0	0,0	0,0	2459,0
Mode	2013,0	6,0	-	207,1	0,0	0,0	20,0	11,0	0,0	0,0	2465,5
Standard Deviation	3,7	187,8	695,6	716,8	112,9	13,1	6,9	5,9	2,4	22,6	1147,4
Kurtosis	0,5	4,0	3,1	2,5	12,2	1,3	-1,5	-1,3	0,7	0,0	0,8
Skewness	-1,2	1,8	1,8	1,7	3,1	1,5	0,4	0,3	0,4	0,9	0,8
Minimum	2000,0	2,0	4,6	5,0	-158,5	-9,1	4,0	5,0	-4,0	-19,0	405,6
Maximum	2014,0	845,0	2921,6	2972,2	526,4	44,4	24,0	23,0	6,0	60,0	5793,7
Sum	70331,0	6201,0	18973,6	20122,3	1148,9	270,3	219,0	223,0	4,0	171,8	98281,3

Table 13: Summary statistics - Solar.

	Date	*Capacity (MW)*	*Initial budget (millions of $2012)*	*Actual cost (millions of $2012)*	*Cost overrun (m$)*	*Cost overrun (%)*	*Proposed time (months)*	*Actual time (months)*	*Time overrun (months)*	*Time overrun (%)*	*Cost/kW*
Average	2010,5	60,9	428,5	424,3	-4,2	1,3	27,1	26,9	-0,2	-0,2	8311,6
Median	2011,0	50,0	357,2	364,8	0,0	0,0	26,0	26,0	0,0	0,0	7199,4
Mode	2010,0	50,0	357,2	-	0,0	0,0	30,0	32,5	0,0	0,0	-
Standard Deviation	1,8	55,0	371,0	366,0	62,2	17,8	11,5	10,9	2,1	8,0	5099,7
Kurtosis	1,3	9,2	10,0	10,9	7,7	1,4	1,9	1,1	1,9	4,0	5,1
Skewness	-0,8	2,8	2,9	3,0	-2,1	0,0	0,8	0,5	0,4	1,7	2,1
Minimum	2005,0	1,0	6,2	5,1	-266,6	-40,8	8,0	8,0	-5,0	-11,2	1773,5
Maximum	2013,0	280,0	2000,0	2000,0	102,3	50,0	60,0	55,0	5,0	25,0	27180,0
Sum	78409,0	2373,8	16710,0	16546,1	-163,9	50,5	623,0	618,3	-4,7	-4,6	324153,1

6.3 Normality Tests

The following is a series of tables and figures demonstrating the distribution of cost overruns for each of the sectors. The tables display the Shapiro-Wilk and the Jarque-Bera tests, which test for normality of these distributions. As evidenced by the previous tables of summary statistics, distributions of cost overruns in nuclear projects show high kurtosis, skewness and standard deviation, suggesting a distribution with a lack of symmetry, deviating highly from the average and possibly being heavy tailed. This can be observed in the following histogram and Q-Q plot, see Figure 5 and Figure 6. Similar to nuclear, Figure 9 and Figure 10 demonstrate a heavy tailed distribution for oil and gas.

Hydro on the other hand has the second highest standard deviation of relative cost overruns of all the sectors, which is reflected in Figure 7. Figure 8 shows the hydro sector to include some outliers, supporting the notion that a relatively small number of projects being responsible for the majority of cost overruns.

Wind shows light to moderate levels of skewness and kurtosis in its distribution of cost overruns, see Figure 11 and Figure 12. These distributions somewhat mirror the distributions in the hydro sector, but with much less extremes, especially in terms of outliers. This is likely due to wind projects having much smaller scopes and complexity. See chapter 7.3 on the discussion of these factors.

Furthermore, according to the normality tests, none of these distributions are normal, except, arguably, solar projects. As previously mentioned, cost overruns in solar projects have a 0 skewness, and the distribution of cost overruns passes the Jarque-Bera test, but not the Shapiro-Wilk test in Table 18. The number of observation for the solar sector was 39, and as previously mentioned, Shapiro-Wilk tests are more appropriate for smaller sample sizes ($n<50$) [29]. In either case, the solar projects are the closest to displaying a normal distribution of cost overruns.

Positive skewness and positive average in these figures suggest high levels of optimism bias. This is true for sectors of nuclear, hydro, oil and gas, and to a lesser degree, wind. However, tested over a longer period of time, the high levels of positive skewness and high positive average of nuclear and hydro sectors suggest strategic misreporting taking part in their cost estimations as well. This is further supported by the fact that estimations have gotten worse with time for both sectors, as demonstrated in the next subchapter.

It is difficult to say whether or not deception is widespread for the other sectors just by looking at these results alone. The longest tested time period for these sectors is 20 years, which is for the oil and gas sector. As mentioned before, the oil and gas numbers in the dataset reaches as far back as the year 2000. But one could still argue for a level of strategic misreporting existing in this sector. This notion is supported by the report from 1999, *Analysis of investment trends on the continental shelf* [22], that echoes the same shortcomings within projects as the more recent report from 2013, *Assessment of completed projects on the Norwegian Continental Shelf* [20]. In other words, the same problems leading to cost overruns have been prevalent in this sector before the year 2000 as well, suggesting deception playing a role in these estimates.

Table 14: Normality tests featuring Jarque-Bera and Shapiro-Wilk tests - Nuclear.

Normality Test	Score	P-Value	Pass?	5.0%
Jarque-Bera	3096.91	0.0%	FALSE	
Shapiro-Wilk	0.68	0.0%	FALSE	

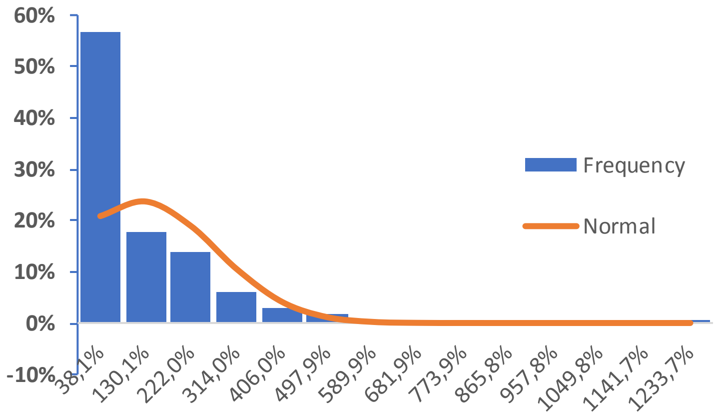


Figure 5: Histogram plot showing the distribution of cost overruns - Nuclear.

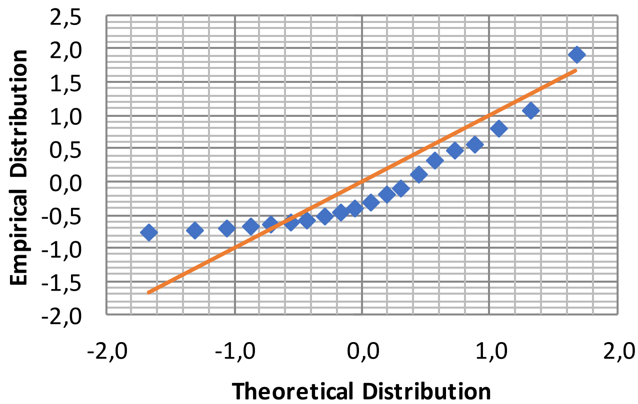


Figure 6: Q-Q plot comparing the expected (theoretical) and the observed (empirical) distributions - Nuclear.

Table 15: Normality tests featuring Jarque-Bera and Shapiro-Wilk tests - Hydro.

Normality Test	Score	P-Value	Pass?	5.0%
Jarque-Bera	114.68	0.0%	FALSE	
Shapiro-Wilk	0.72	0.0%	FALSE	

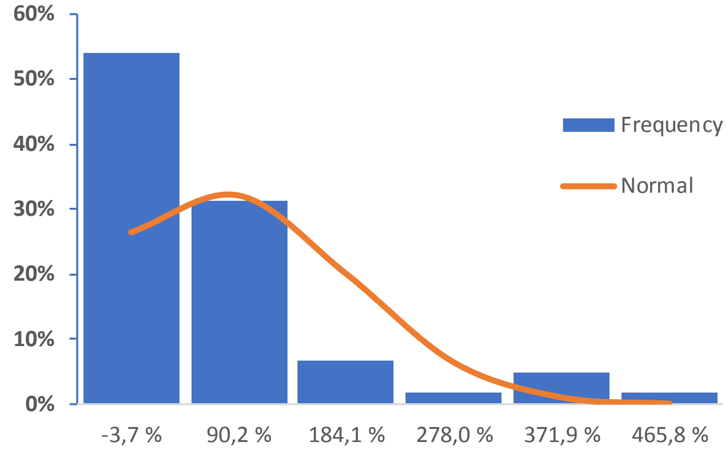


Figure 7: Histogram plot showing the distribution of cost overruns - Hydro.

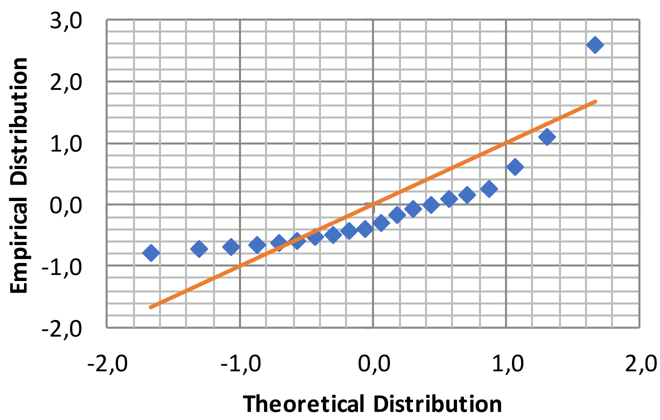


Figure 8: Q-Q plot comparing the expected (theoretical) and the observed (empirical) distributions - Hydro.

Table 16: Normality tests featuring Jarque-Bera and Shapiro-Wilk tests - Oil and Gas.

Normality Test	Score	P-Value	Pass?	5.0%
Jarque-Bera	768.24	0.0%	FALSE	
Shapiro-Wilk	0.74	0.0%	FALSE	

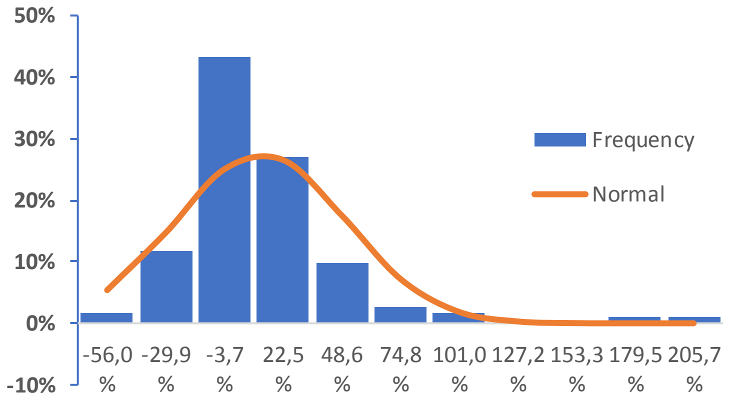


Figure 9: Histogram plot showing the distribution of cost overruns - Oil and Gas.

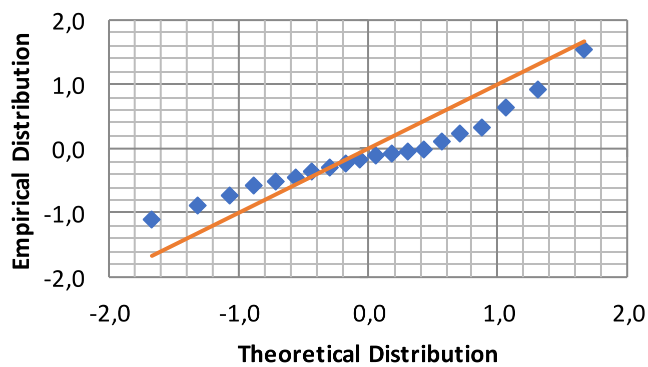


Figure 10: Q-Q plot comparing the expected (theoretical) and the observed (empirical) distributions - Oil and Gas.

Table 17: Normality tests featuring Jarque-Bera and Shapiro-Wilk tests - Wind.

Normality Test	Score	P-Value	Pass?	5.0%
Jarque-Bera	12.77	0.2%	FALSE	
Shapiro-Wilk	0.80	0.0%	FALSE	

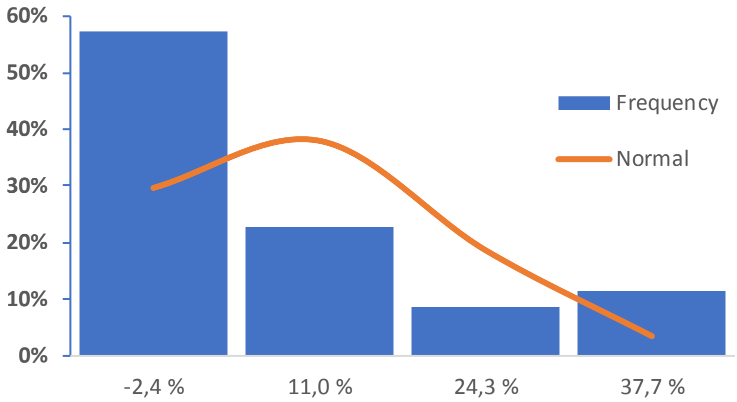


Figure 11: Histogram plot showing the distribution of cost overruns - Wind.

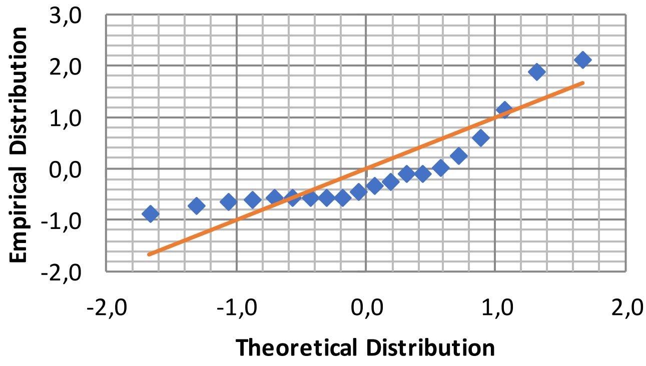


Figure 12: Q-Q plot comparing the expected (theoretical) and the observed (empirical) distributions - Wind.

Table 18: Normality tests featuring Jarque-Bera and Shapiro-Wilk tests - Solar.

Normality Test	Score	P-Value	Pass?	5.0%
Jarque-Bera	1.99	37.0%	TRUE	
Shapiro-Wilk	0.91	0.3%	FALSE	

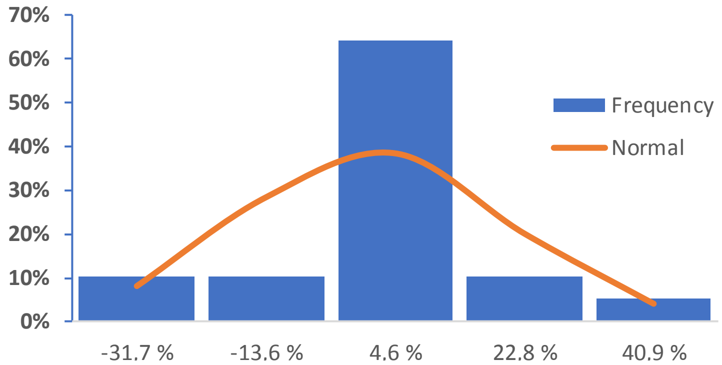


Figure 13: Histogram plot showing the distribution of cost overruns - Solar.

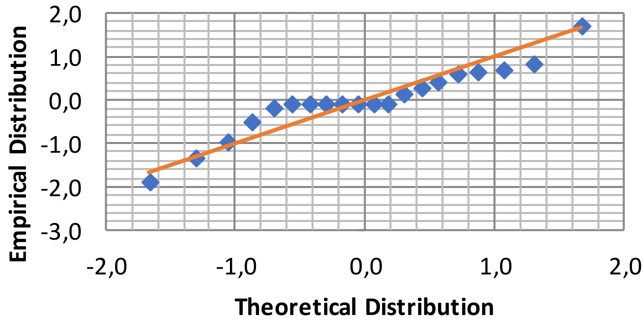


Figure 14: Q-Q plot comparing the expected (theoretical) and the observed (empirical) distributions - Solar.

6.4 Regression Analysis

This subchapter contains the results of linear regression analysis, presented with scatter plots for each sector. The values from the results are also summarized in tables. For the sake of readability, a short summary of chapter 4 regarding regression analysis is presented.

The main focus of this analysis is on the R^2 value, which demonstrates the proportion of variation in the dependent variable that can be explained by the independent variable. This value is accompanied by a p-value. The cut-off point for p-values are 5%, meaning that this value should be below 0.05 in order for the impact between the variables to be considered as significant.

6.4.1 Initial budget

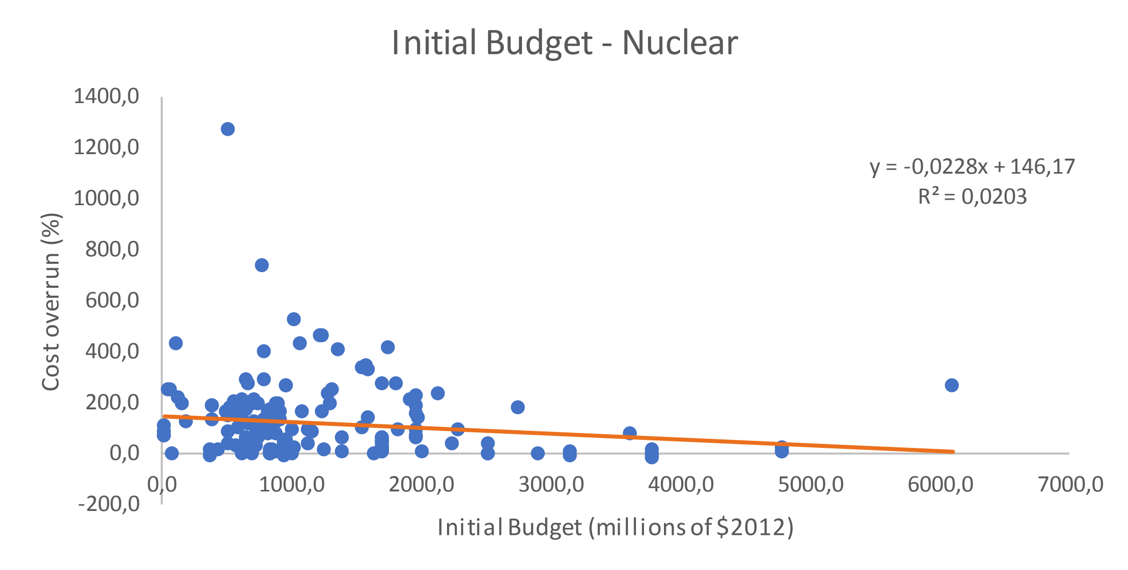
As mentioned earlier, the size of the estimated initial budget can be an indication of project complexity, and the hypothesis states that projects with higher initial budgets are more prone to making inaccurate cost estimations.

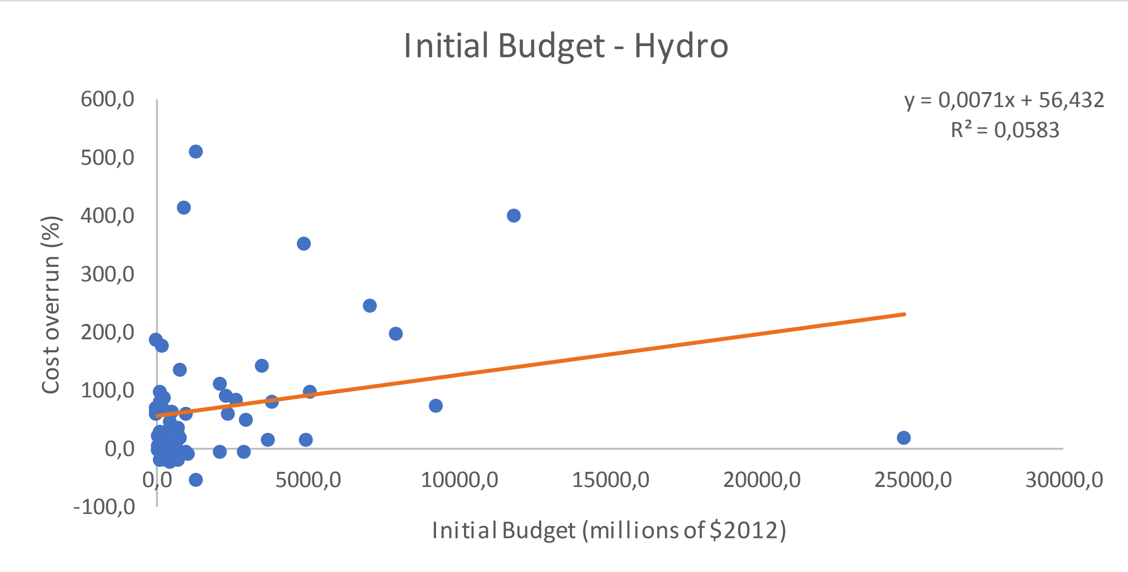
Looking at the results in Table 19 and Figure 15, only hydro projects show a statistically significant R^2 value. The p-value for this sector however is slightly larger than 5%, which could suggest otherwise. An outlier like the 1991 Itaipu Dam, which has a high initial budget and a relatively low cost overrun, is likely negatively influencing the strength of these results.

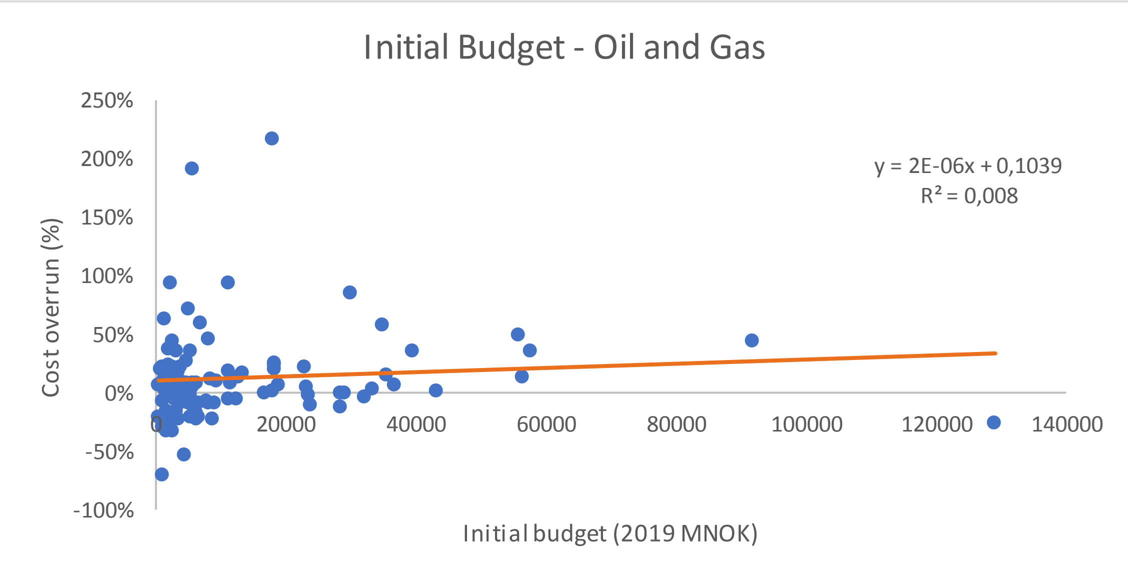
In short, the results display insufficient evidence for the size of the initial budgets having any effect on cost overruns in, arguably, all but one sector.

Table 19: The impact of initial budget on cost overrun for each sector.

	R^2	P-value	Beta1	Beta0
Nuclear	0,020	0,056	-0,023	146,170
Hydro	0,058	0,061	0,007	56,432
Oil and Gas	0,008	0,087	0,000	0,104
Wind	0,011	0,557	-0,002	8,769
Solar	0,023	0,357	-0,007	4,417


Initial Budget - Nuclear
y = -0,0228x + 146,17
R² = 0,0203
1400,0
1200,0
1000,0
800,0
600,0
400,0
200,0
0,0
-200,0
Cost overrun (%)
0,0
1000,0
2000,0
3000,0
4000,0
5000,0
6000,0
7000,0
Initial Budget (millions of $2012)


Initial Budget - Hydro
y = 0,0071x + 56,432
R² = 0,0583
600,0
500,0
400,0
300,0
200,0
100,0
0,0
-100,0
Cost overrun (%)
0,0
5000,0
10000,0
15000,0
20000,0
25000,0
30000,0
Initial Budget (millions of $2012)


Initial Budget - Oil and Gas
y = 2E-06x + 0,1039
R² = 0,008
250%
200%
150%
100%
50%
0%
-50%
-100%
Cost overrun (%)
0
20000
40000
60000
80000
100000
120000
140000
Initial budget (2019 MNOK)

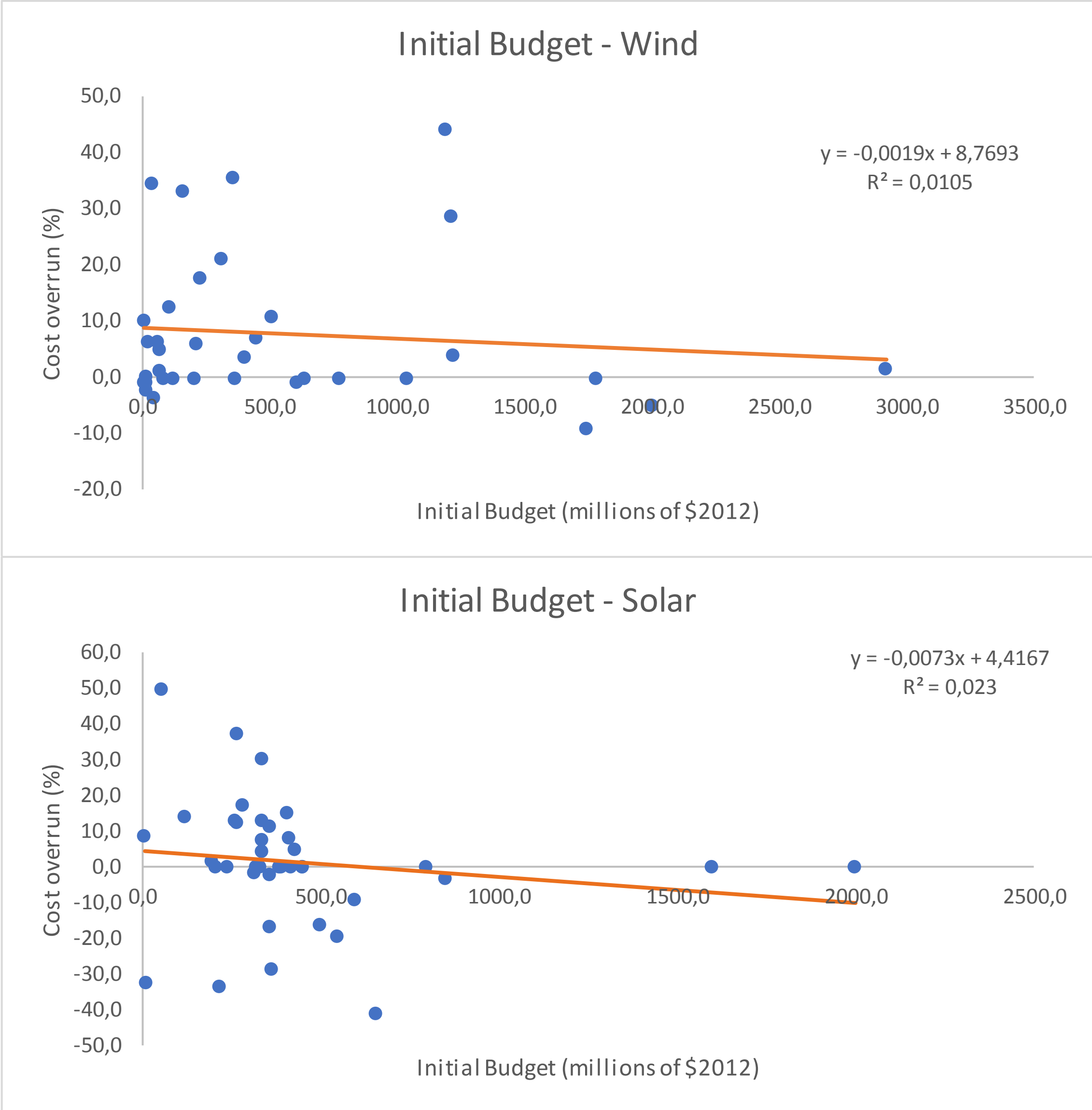


Figure 15: Linear trendlines showing the impact of initial budget on cost overrun for each sector.

6.4.2 Capacity

Recapping the hypothesis for this section: projects which aim for higher capacity are also more prone to cost overruns.

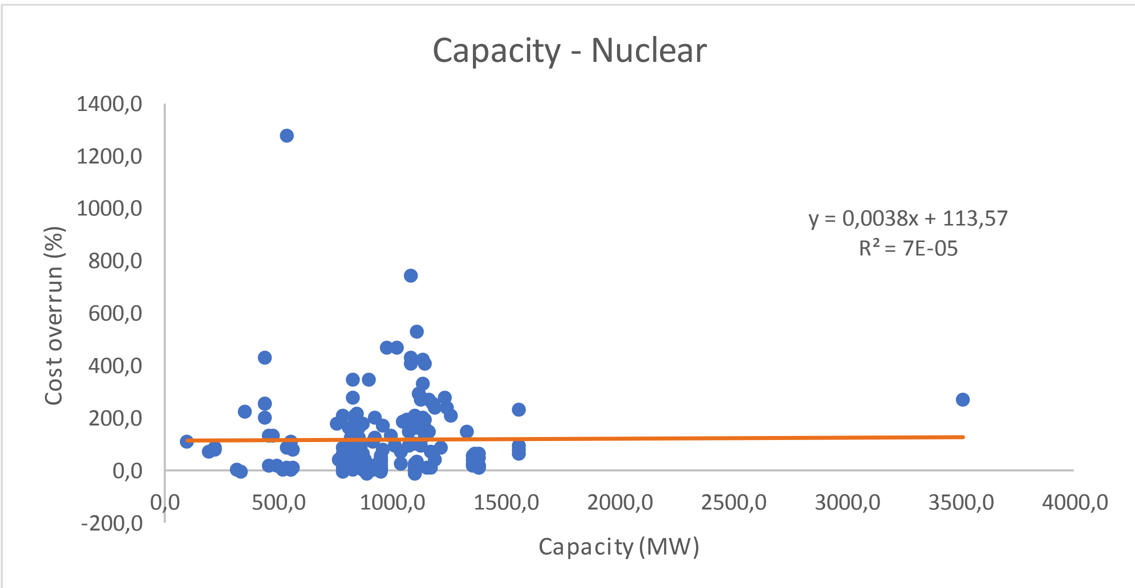
Nuclear projects show no strength between these variables. As mentioned before, 97% of all nuclear projects experience cost overruns. This suggests that nuclear projects experience cost overruns regardless of size. Wind and solar both have a very slight downward facing trendline. This could indicate economies of scale having an effect, but the results are too weak to make that conclusion.

On the other hand, hydro projects display a strong relationship between capacity and cost overrun (R^2 = 22%), see Table 20. The World Commission on Dams suggests that hydro projects are uniquely complex in their construction [40]. They are also difficult to make estimations for, as a significant portion of the information are discovered well into some of the projects' lifetime, resulting in inaccurate estimations [41]. The results can also be influenced by outliers, like the Three Gorges Dam, with its 22500 MW capacity and 401.9% cost overrun.

No other sector shows any significant results. In other words, the hypothesis is only validated for the hydro sector.

Table 20: The impact of capacity on cost overrun for each sector.

	R2	P-value	Beta1	Beta0
Nuclear	0,000	0,911	0,004	113,570
Hydro	0,220	0,000	0,014	44,069
Oil and Gas	-	-	-	-
Wind	0,010	0,568	-0,007	8,956
Solar	0,029	0,301	-0,055	4,642



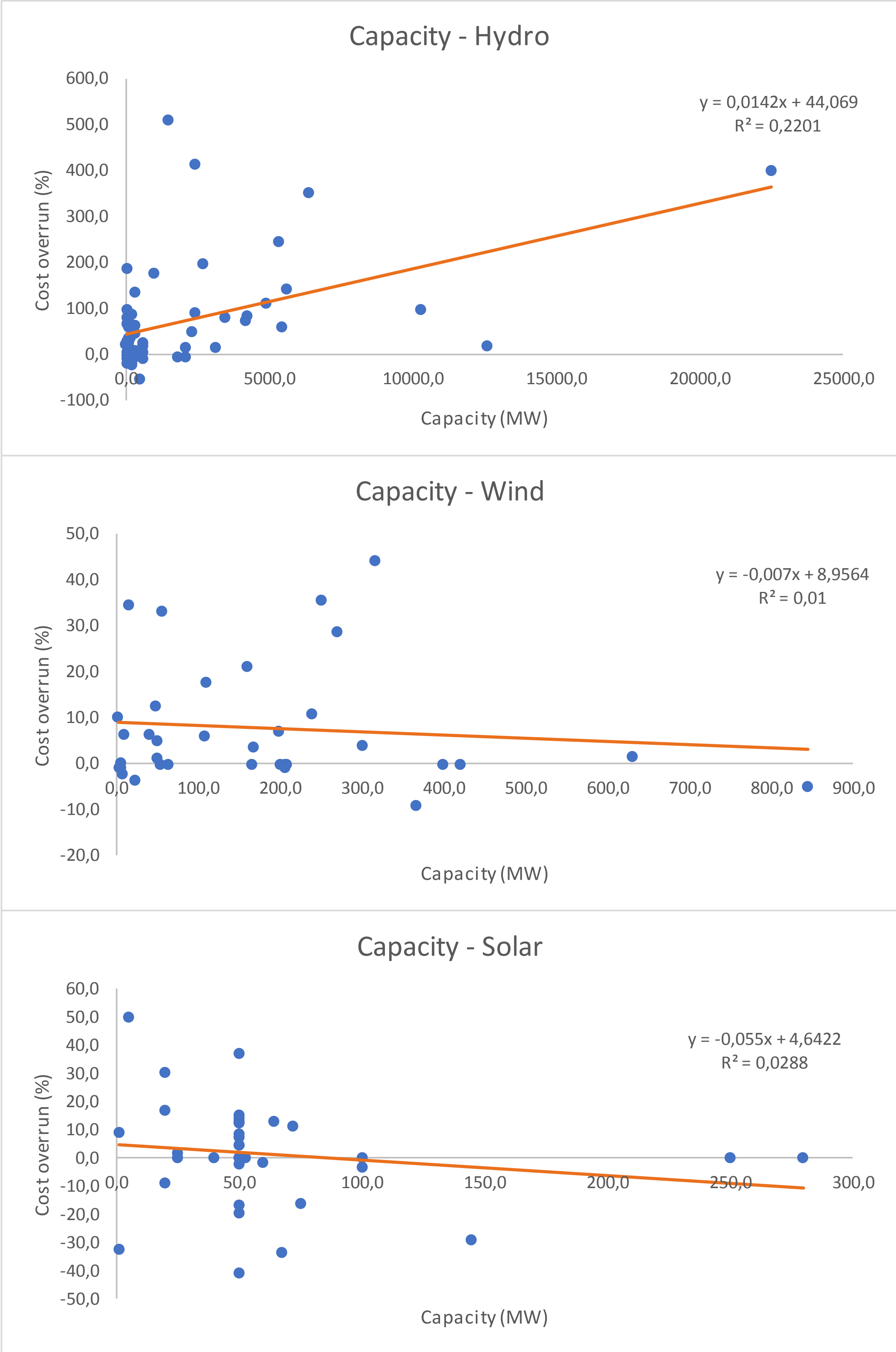


Figure 16: Linear trendlines showing the impact of capacity on cost overrun for each sector.

6.4.3 Completion Date

As mentioned in chapter 2, project management efforts can be significantly improved by learning as time goes on. Forecasters should also have access to more information and better forecasting methods and tools, all of which should make forecasting more accurate. Therefore, the hypothesis for this section states that projects should have more accurate estimations with time.

From the results, see Table 21, one can see that the oil and gas sector shows no improvement over the two decades. The same is true for the wind sector, which is measured over a time period of 14 years. These results could have a number of implications. It could mean that the time periods, which these sectors were tested for, are not sufficiently long enough to improve their forecasting and project management abilities in any meaningful way. It could also mean that these sectors did not see it as necessary to make any effort at improving their abilities in this aspect of the projects. In other words, the stakeholders for these sectors may be content with the results. For wind, this can stem from having a relatively low average and frequency of cost overruns. Oil and gas sector on the other hand, has a somewhat higher average and frequency, but these could be largely masked by increasing oil prices between the year 2000 and 2011, see Figure 17. There is a single price fall in this time period, most likely caused by the financial crisis of 2008. The prices start increasing sharply again the following year, and only start falling again in 2014 from the oil crisis. This period makes up 14 of the 20 years tested for in the dataset for this sector. The assumption is that increases in costs are paralleled with simultaneous increases in revenues, masking the shortcomings of these projects. Another explanation could be given by the low-hanging fruit theory, which states that businesses prioritize the most easily attainable goals [42]. In other words, the easiest projects take priority, leaving the more complex projects for later. This means that the more recent projects could suffer from higher degrees of complexity and uniqueness, counteracting any potential improvements that were made in the later projects. Lastly, strategic misreporting and optimism bias can also be a factor, as discussed earlier.

Table 21: The impact of completion date on cost overrun for each sector.

	R2	P-value	Beta1	Beta0
Nuclear	0,040	0,007	4,790	-9375,600
Hydro	0,069	0,041	1,814	-3523,000
Oil and Gas	0,000	0,936	0,001	-0,966
Wind	0,000	0,974	-0,021	49,556
Solar	0,041	0,214	-2,058	4138,600

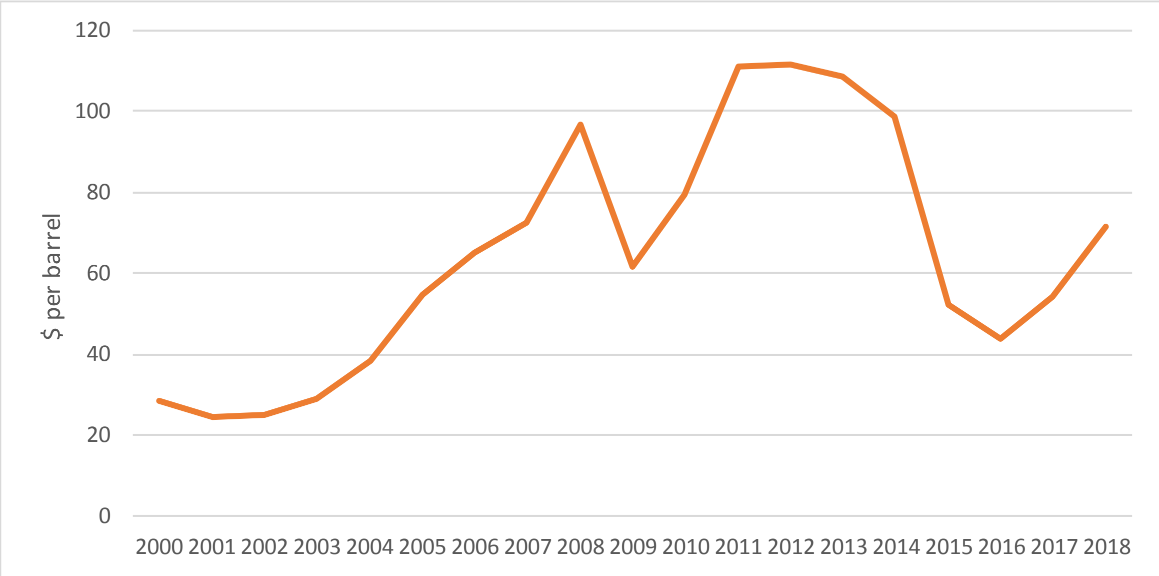


Figure 17: Europe Brent Spot Price FOB Dollars per Barrel [43].

Nuclear shows negative forecasting ability with time, although slightly ($R^2 = 0.04$). At best, no improvement has taken place. There are a number of possible explanations for this outcome. One could be stricter rules and regulations due their riskier nature. No doubt that the Three Mile Island and Chernobyl accidents, in 1979 and 1986 respectively, had a significant impact on the regulations imposed on ongoing and subsequent nuclear projects. This could help explain the visible spike of cost overruns that occurred in nuclear projects completed in the 1980s, see Figure 20. Another explanation could be uniqueness and technical complexity. With respect to learning, uniqueness and complexity stemming from the high replacement frequency of the technology makes it difficult to gain any useful knowledge and experience for future projects [15]. A third explanation could be strategic misreporting, as mentioned earlier.

Hydro also shows negative performance. Measured over a time period of 77 years, it shows slightly worse performance than nuclear. Some of it may be explained by the growing size, in terms of capacity, of some the more recent projects, see Figure 18, although the results show a p-value that is slightly too high to be considered significant. The low-hanging fruit theory could be a factor here, as hydro-electric dams are, relative to the other sectors, limited in terms of the construction location. Perhaps this theory is also linked with the growing sizes. Strategic misreporting could also play a part in this sector.

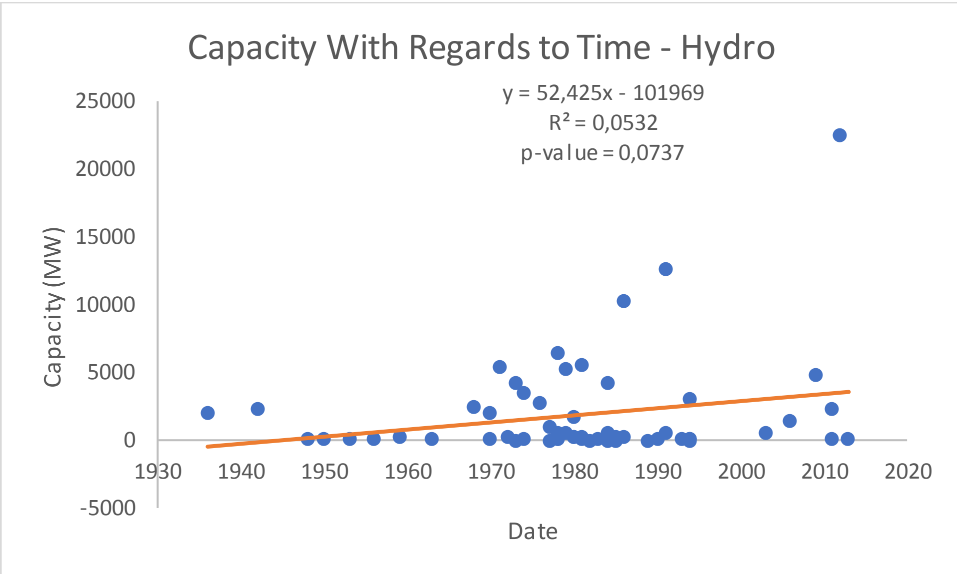


Figure 18: The change of size of capacity in hydroelectric dams with time.

The only sector to show any sign of improvement is solar. Although it is important to notice that it was tested for just 8 years, which might explain the high p-value, see Table 21. Furthermore, the negative relationship may be partially explained by learning, as most of the solar projects were undertaken by a few companies in only a couple of countries. These companies then did duplicate projects, experiencing less cost overrun with the subsequent projects compared to the originals, see Table 22. Solar projects were also subject to falling material prices, somewhat due to overproduction [44] [45], see Figure 19. And lastly, solar projects saw an increase in manufacturing plant sizes with time, which lead to lower costs [46].

Table 22: Duplicate projects of CSP plants.

YEAR	NAME	LOCATION	CAPACITY (MW)	COST OVERRUN (%)
2008	Andasol-1 (AS-1)	Spain	50,0	15,4
2009	Andasol-2 (AS-2)	Spain	50,0	0,0
2011	Andasol-3 (AS-3)	Spain	50,0	5,0
2011	Palma del Rio I	Spain	50,0	13,3
2010	Palma del Rio II	Spain	50,0	4,6
2010	Solnova 1	Spain	50,0	37,5
2010	Solnova 3	Spain	50,0	12,5

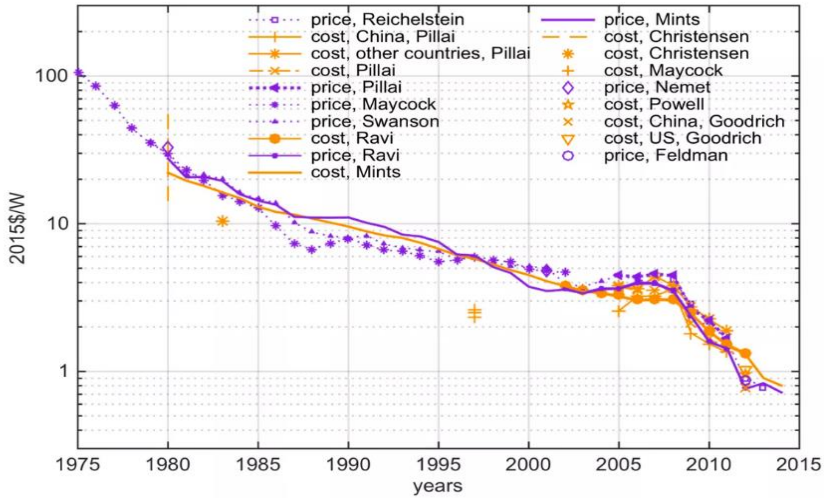
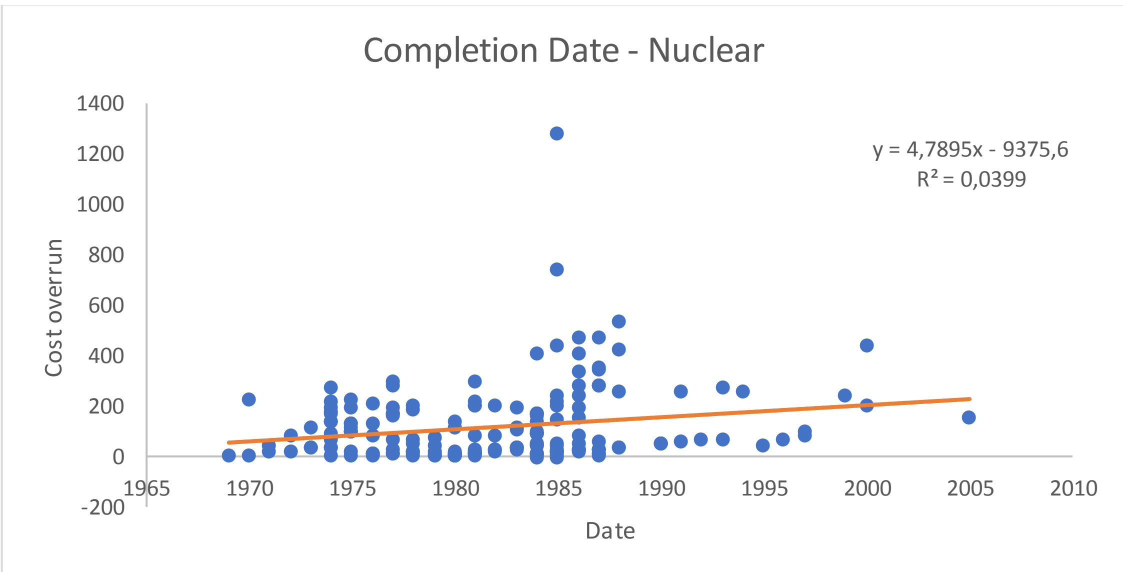
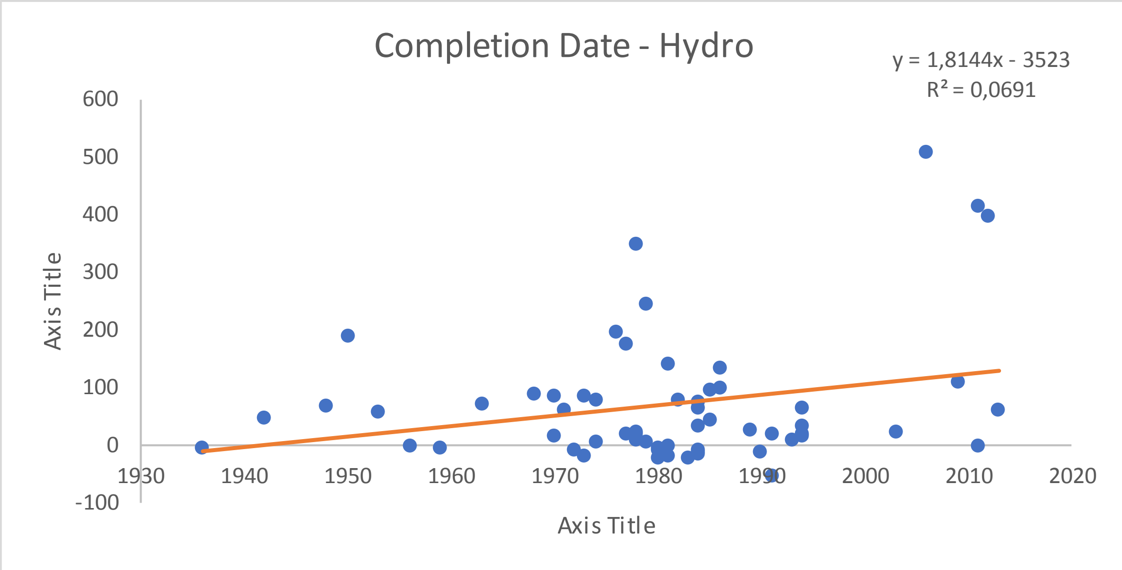
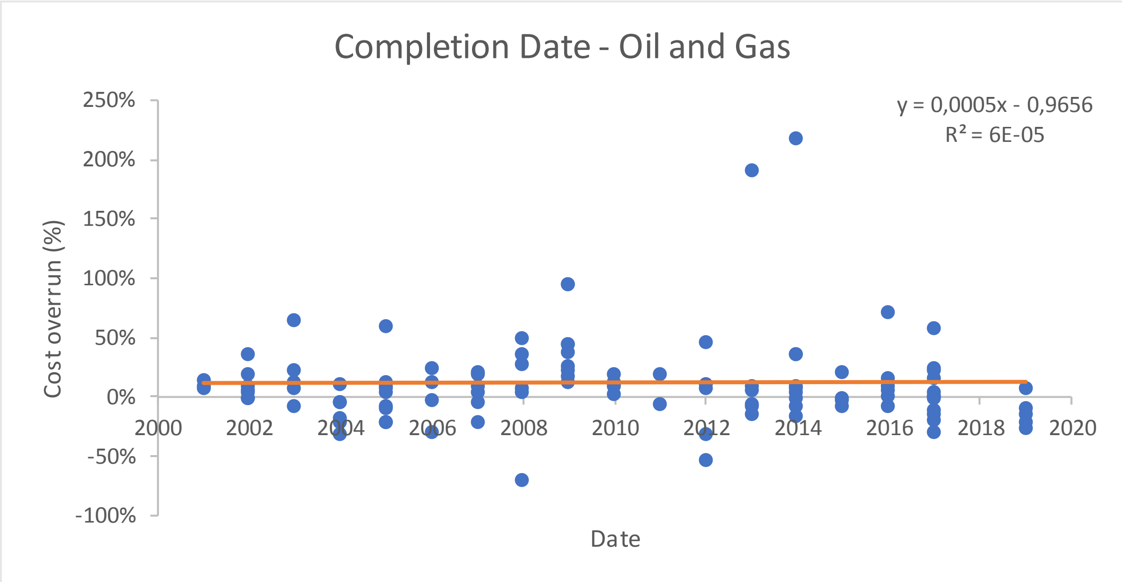
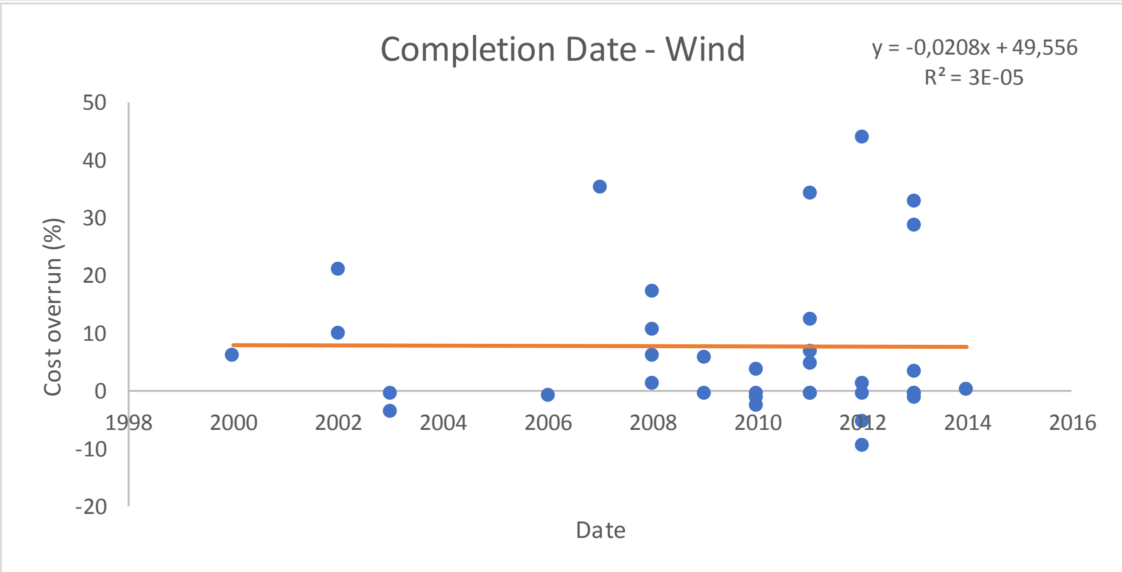


Figure 19: Module costs and prices since 1975.




Completion Date - Hydro
y = 1,8144x - 3523
R² = 0,0691
600
500
400
300
200
100
0
-100
Axis Title
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Axis Title


Completion Date - Oil and Gas
y = 0,0005x - 0,9656
R² = 6E-05
250%
200%
150%
100%
50%
0%
-50%
-100%
Cost overrun (%)
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Date


Completion Date - Wind
y = -0,0208x + 49,556
R² = 3E-05
50
40
30
20
10
0
-10
-20
Cost overrun (%)
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Date

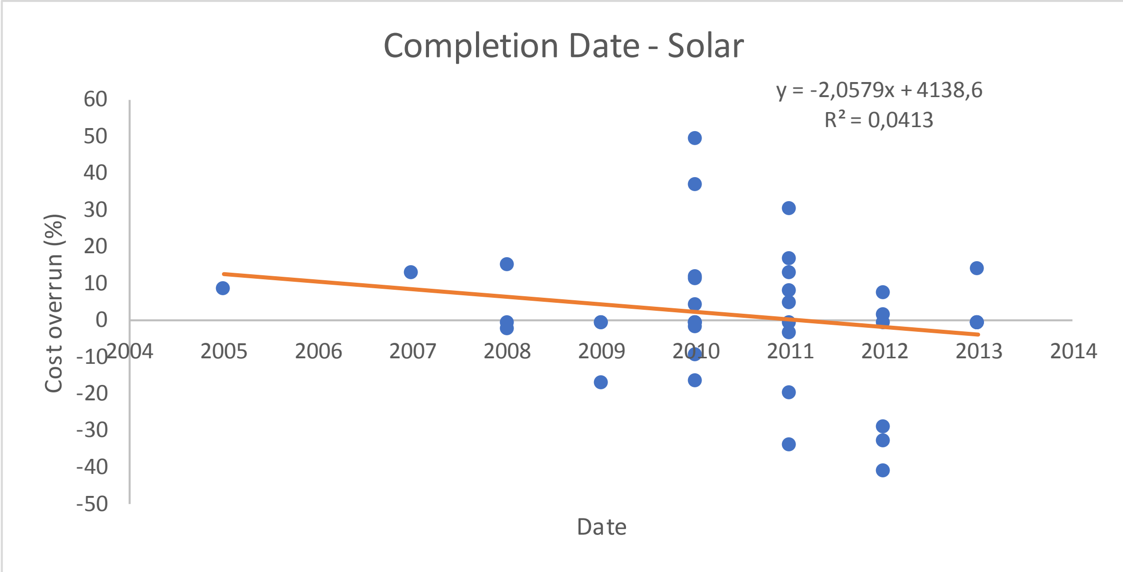


Figure 20: Linear trendlines showing the impact of completion date on cost overrun for each sector.

6.4.4 Proposed Time

Although not all projects that experience delays will experience cost overruns, it was the case for a significant number of projects in the dataset, see Table 23. This is natural, as the longer a project goes on, the costlier it gets. But what about the length of the initially proposed project time? Similar to the previous variables, longer time estimations could be a sign of uncertainty and/or complexity. Additionally, the longer a project goes on, even if it is within its estimated timeline, the more it is prone to being affected by outside factors. New rules and regulations, changes in markets, unfavourable currency fluctuations, etc., could cause or exacerbate cost overruns.

Table 23: The impact of time overrun on cost overrun for each sector.

	R2	P-value	Beta1	Beta0
Nuclear	0,310	0,000	1,609	17,163
Hydro	0,486	0,000	1,088	8,764
Oil and Gas	-	-	-	-
Wind	0,110	0,178	0,151	3,691
Solar	0,024	0,481	0,296	4,511

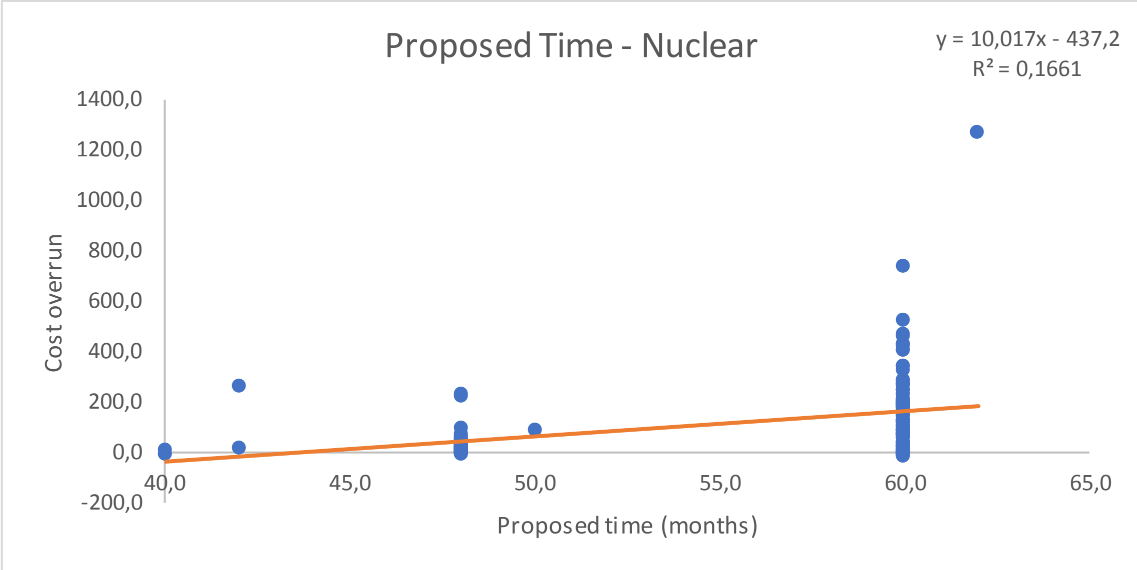
Data suggests that 16.6% of the variance in cost overruns in nuclear projects can be explained by the size of the initial proposed time, see Table 24. There are a few important facts to keep in mind however, while interpreting this result. One is the fact that the number of projects with five or more years of proposed time make up almost 63% of the sample size, and the other is that there is very little variation in these estimations. The majority of the estimations fall exactly on 60 months, see Figure 21. The strong R^2 result suggest that at least some of the variations in cost overruns can be explained by high proposed time, but the unusually low variation in size of these estimations suggest that they may have been intentionally or unintentionally downplayed in order to fit inside the accepted time schedule. Widespread deception or biases in this sector may affect the size of these estimations, as nuclear projects have historically high cost overruns and difficulty obtaining investors [39]. In other words, downplaying the size and length of some of these estimations may be necessary to get project approval. This makes it difficult to make any sort of conclusive statements about the effect of proposed time on cost overrun in this sector.

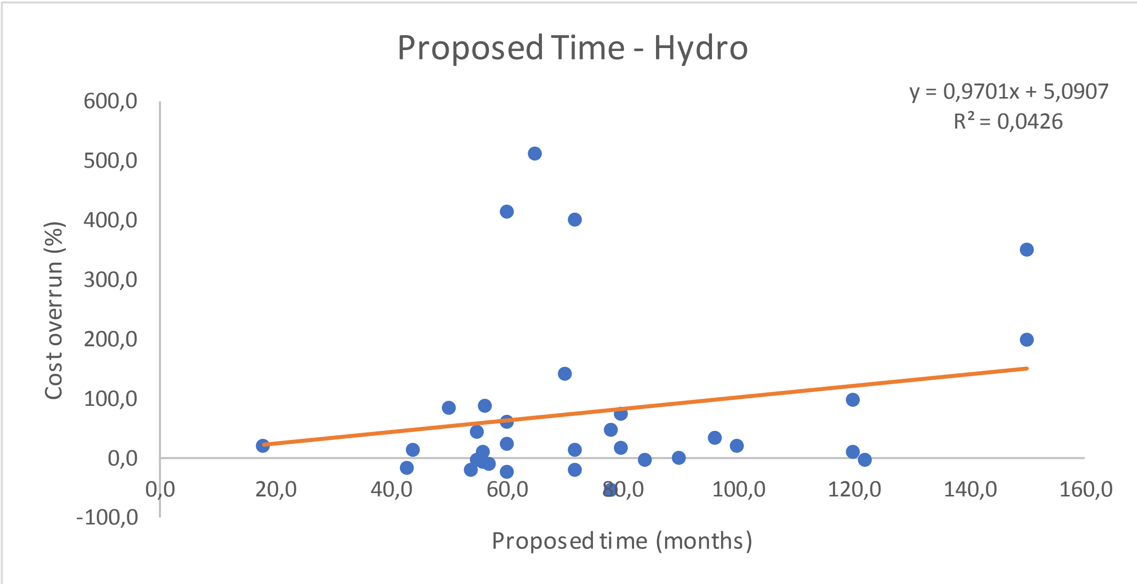
Hydro projects also exhibit the same behaviour, although to a much lesser degree (4.26%), and with a much larger p-value, 0.249. The results could be affected by outliers, as previously mentioned, so this topic needs a deeper discussion. See chapter 7.5.2 for the discussion on project duration in the construction of hydroelectric dams.

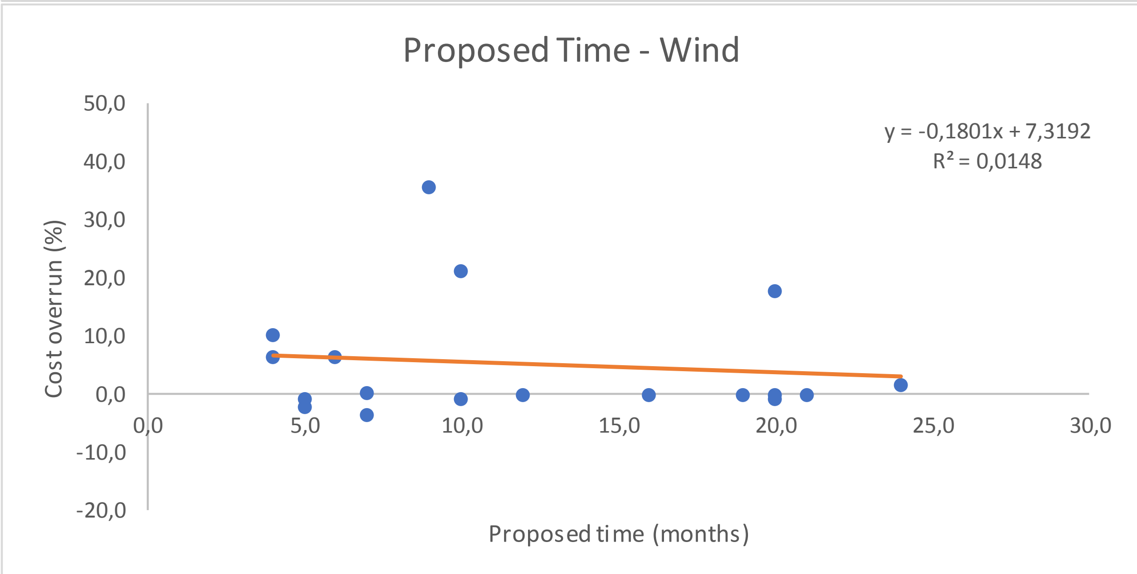
There seems to be no effect of proposed time on wind and solar projects. This is perhaps caused by their relatively accurate estimations regarding project time, as one saw earlier.

Table 24: The impact of proposed time on cost overrun for each sector.

	R2	P-value	Beta1	Beta0
Nuclear	0,166	0,000	10,017	-437,000
Hydro	0,043	0,249	0,970	5,091
Oil and Gas	-	-	-	-
Wind	0,015	0,631	-0,180	7,319
Solar	0,000	0,990	0,004	4,356


Proposed Time - Nuclear
y = 10,017x - 437,2
R² = 0,1661
1400,0
1200,0
1000,0
800,0
600,0
400,0
200,0
0,0
-200,0
40,0
45,0
50,0
55,0
60,0
65,0
Cost overrun
Proposed time (months)


Proposed Time - Hydro
y = 0,9701x + 5,0907
R² = 0,0426
600,0
500,0
400,0
300,0
200,0
100,0
0,0
-100,0
0,0
20,0
40,0
60,0
80,0
100,0
120,0
140,0
160,0
Cost overrun (%)
Proposed time (months)


Proposed Time - Wind
y = -0,1801x + 7,3192
R² = 0,0148
50,0
40,0
30,0
20,0
10,0
0,0
-10,0
-20,0
0,0
5,0
10,0
15,0
20,0
25,0
30,0
Cost overrun (%)
Proposed time (months)

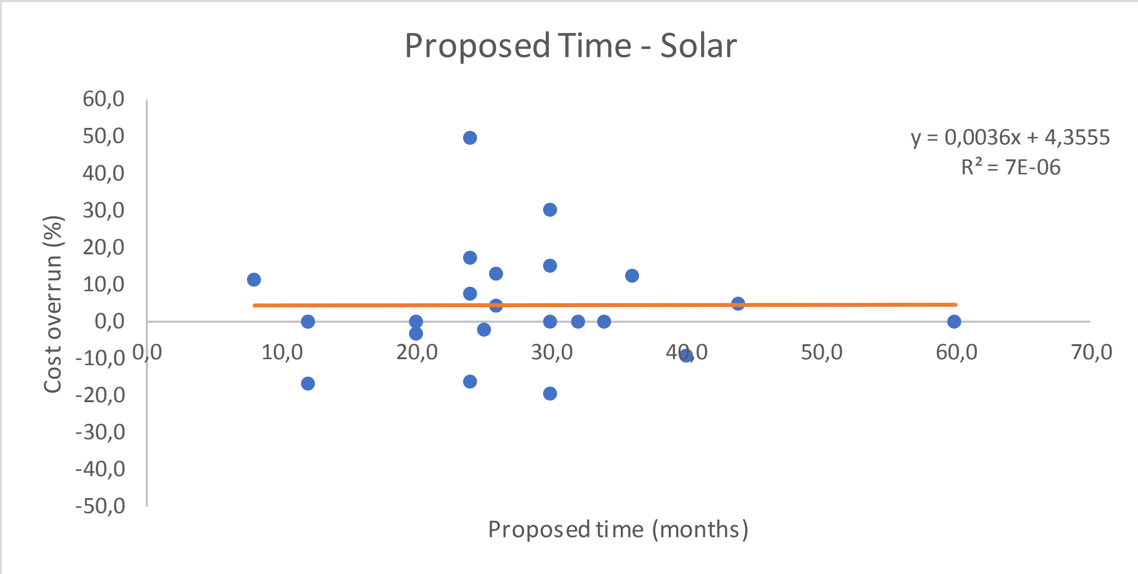


Figure 21: Linear trendlines showing the impact of proposed project time on cost overrun for each sector.

7 Discussion

This chapter is an amalgamation of the different data collection methods. One subchapter is dedicated to each sector, with sections within them discussing all the relevant findings.

7.1 Oil and Gas

This subchapter looks at the different projects from the study done by the Norwegian Petroleum Directorate; *Assessment of completed projects on the Norwegian Continental Shelf* [20]. These projects will be discussed in reference to Lorentzen et al's study; *Pro-Cyclical Petroleum Investments and Cost Overruns in Norway* [21]. They are then put in a wider context at the end of the subchapter by comparing them to EY's 2014 report; *Spotlight on oil and gas megaprojects* [4], the study by The Investment Committee; *Analysis of investment trends on the continental shelf* [22], and the relevant findings from chapter 6. In Table 25, one can see a summary of the projects' size and cost overrun relative to average oil and gas projects from the dataset. In the next section, one can see a short description of each project.

Table 25: The projects, and their relative initial budget and cost overruns.

Project name	Initial budget - relative to the average	Cost overrun
Gjøa	198%	12%
Skarv	222%	32%
Tyrihans	47%	18%
Valhall Videreutvikling (VRD)	46%	62%
Yme	-54%	136%

7.1.1 About the Projects

Gjøa was a relatively big (198% greater estimated costs than average), but still successful project. It had very little time delays and a 12% cost overrun, which was within the 20% safety margin. Extractable reserves in the PDO were estimated at 13.2 MSm^3 oil and condensate and 39.7 GSm^3 gas. The application of the PDO was delivered at the end of 2006 and approved mid-2007. It entered production start-up in 2010 as planned.

Skarv was another big project (222% greater estimated costs than average), with a cost overrun of 32%. Extractable reserves were estimated to be 43.4 GSm^3 gas, and 15.5 MSm^3 oil and 5.6 million tonnes NGL. The application of the PDO was delivered mid-2007 and approved at the end of 2007. Drilling of production wells started in 2010. The production vessel was completed and installed on the field in august 2011. Production start-up was planned to take place in August 2011, but due to major time overruns, start-up was delayed until the end of 2012.

Tyrihans' actual costs were within the 20% safety margin. Extractable reserves in the PDO was estimated to be 29 MSm^3 oil and 34.8 GSm^3 gas. The Tyrihans field was developed with an underwater production plant connected to Kristin for the processing of the well flow and Åsgard B for the import of gas to gas injection. The application of the PDO was delivered mid-2005 and approved at the end of 2005. Production start-up took place mid-2009 as planned.

The first platforms on the Valhall field were installed in 1981 and started production in 1982. The field was later expanded upon in several phases. The further development of the field, which was officially named *Valhall VRD*, is made up of the installation of a new processing platform and extensive modification work on the existing platforms for extended operations and future production on the field. The remaining reserves on the field was estimated to be 41.5 MSm^3 oil, 6.9 GSm^3 gas and 2.2 million tons NGL. The application for the PDO was delivered in March of 2007 and was approved in May of same year. After considerable cost and time overruns, the production started at the start of 2013.

Yme was first developed and operated by Statoil until 2001 when production was completed. It was intended to be the first field to be reopened on the NCS. The application for the PDO was delivered at the start of 2007 and was approved in May of same year. Due to several problems with the project, it will never be realised the way it was proposed in the PDO in 2007.

7.1.2 Optimism Bias and Inadequate Planning

The most important take-away from project *Yme* is related to the decision-making early in the project. One of the key criteria for choosing a construction/development solution in this project was the possibility for well intervention. An EPCIC contract was signed with Single Buoy Moorings Inc (SBM). Their solutions with MOPU (mobile production unit with storage) was considered more attractive than other rental solutions. The concept was used by Statoil, and the company had experience with several shipyards in Asia. Based on this information, a great deal of confidence was put on SBM being able to deliver according to the tender they received, even though they lacked experience with bigger construction projects and construction in accordance with Norwegian laws and requirements. Even though the licensees identified the contractor's inexperience with Norwegian offshore projects as a risk, important questions around this issue were ignored by the licensees when choosing contractors. The project started out poorly, which then resulted in major resources being invested in trying to salvage it. The operator suggests greater effort in the early phase of the project. One of the suggestions is to have an internal system to secure maturity and quality towards final project sanctioning. Another suggestion is to plan sufficient time for the completion of the FEED-phase (Front-End Engineering Design), before delivering PDO and detail engineering. And lastly, to put proper effort towards reviewing quality, experience and expertise of contractors is suggested by the operator.

Several other projects on the NCS suffered from similar problems. With project Tyrihans, there was underestimation of the understanding and maturity of modification projects, which deserved more attention. They should also have guaranteed that suppliers had enough personnel before signing contracts.

Some of Gjøa's cost overruns were due to optimistic time estimates in several areas of the project. Drilling and completion were estimated to take much shorter time than the actual time due to necessary design changes along the way.

Another project with optimistic time estimations was Valhall VRD. Too little time was estimated for the early phase of the project. In the early phase, new results from Valhall's reservoir review/study was received. The conclusion stated that the future potential of the field was far less than presumed. The study states that they should have gathered new reservoir information and conducted a new design review. This could have resulted in changes in topside weight, size, design life requirements, number of change orders and offshore assembly. The project was forced to follow the plan that was made from the start, rather than adjusting it, which had major consequences further into the project.

7.1.3 Economic Activity

Recapping the effects of economic activity found in Lorentzen et al's study [2]: An increase in economic activity usually means fiercer competition for rigs and qualified personnel, which in turn leads to higher rig rates and lower availability in qualified personnel, resulting in higher costs and time delays.

In Lorentzen et al's study, the explanatory variable "employment surprise" is defined as *"the relative change between the number of employees on the oil and gas sector on the NCS in the current year and at the time of project sanction*". This variable shows a statistically significant positive effect on cost overrun, which was especially relevant for both Gjøa and Valhall VRD. Both projects experienced a low supply of qualified personnel for hire, and Gjøa experienced difficulty coordinating between the project teams in Norway and India as a result. They also experienced low supply of resources which further amplified the cost overruns.

7.1.4 Contract Management and Strategy

The study states that several subcontractors of the Gjøa project stressed to deliver within the time and cost estimates. This led to an inadequate focus on weight estimates and a weight increase of topside, which had to be compensated in other ways. Later in the project's lifetime, pipe components of sub-optimal quality were discovered. The subcontractor was over-booked, so they decided to oversimplify and violate established procedures for heat-treating the pipes. The pipes had to be replaced due to their poor quality, which caused project delays. The subcontractors were chosen through a prequalification. Through the use of incentives, further delays were avoided.

Perhaps a new prequalification of subcontractors was due. Having said that, that might not have made a difference if the operator did not factor in price trends and economic activity during evaluation, since the underlying reason for the sub-optimal quality of the pipes was an overbooked subcontractor. Even if the operator did factor in personnel capacity and equipment availability, the subcontractor could still have been reporting unrealistic schedules and cost estimates, in order to be awarded the contract. This goes to show that proper contract management alone is not a guarantee for avoiding delays and cost overruns.

Even though some subcontractors could not deliver on their promises, proper contract and change management seems to have kept the costs from escalating beyond the safety margin. The importance of contract and change management were perhaps best demonstrated when constructing the substructure/hull of the platform in South Korea. The contractor had a comprehensive overview of the scope of work as well as the Norwegian laws and regulations. Having a well-defined scope of work, and therefore low uncertainty, meant few changes. Whenever changes occurred, they were properly handled by having the right personnel in the right places to detect problems, communicate it with the stakeholders and make changes early. The operator's own team of commercial and technical experts, as well as an external local firm in South Korea, followed up on the contractor.

Similar to Gjøa, both Skarv and Valhall VRD experienced several challenges with the quality of the equipment packages. For both projects, the study suggests that the operator should have more direct oversight of the fabrication of equipment packages, including the work done by the subcontractors. It is important to follow up on the deliverables with regards to time, cost and quality.

Furthermore, a great amount of the delays and cost overruns on Skarv was due to the vessels failing. More time put into prequalification of contractors and quality control of vessels would have likely avoided many of the problems. Furthermore, some suppliers could not deliver on their promises, which led to a change of suppliers. Without this change, the project could have experienced even more delays and cost overruns. It was an important learning experience for the operator. On the other hand, putting all the marine operations into a single contract proved itself to be successful. Having a single supplier simplified the complex coordination of many interdependent activities. There were a lot of instances of change orders during the construction phase of the platform. A strong commercial team on the construction site communicating these orders early avoided many of the delays and kept the cost overruns relatively low.

Underwater construction in project Tyrihans went relatively smoothly. This was due to the well-defined scope of work. Another aspect that was well planned was the early identification of risks in the project. The use of new technology was recognized as the biggest risk factor, which is why the operator chose to manage the choice of new technologies themselves and handled all the contracts of new technologies with the suppliers directly.

7.1.5 Project Management

It can be important to involve operations personnel when making decisions throughout a project. This was the case for project Skarv. The operator involved operations personnel in the earlier phases but did not continue including them in the construction phase. This led to the personnel's desires in the construction phase not to be materialised by the project managers, which resulted in more work and cost overruns.

For Tyrihans, there were challenges regarding prioritization of personnel and accommodation capacity offshore. It is important to have good interaction with all the different stakeholders of the project.

7.1.6 Complexity

Valhall VRD was complex with the inclusion of its new buildings, a significant modification of its existing plant, and the use of new technology for the transition of electrical power from land. In addition, it was assumed that the project would be carried out without halting the operation on the existing plant. The project experienced challenges regarding modification work, hook-up, completion and start-up of new construction/plant while operating existing plants. The complexity of it all was underestimated. The increase in well costs was due to the lack of understanding in reservoir development and a much higher well requirement than assumed by the PDO, while the costs for drilling and completion of the individual wells were higher than expected. The project team underestimated the challenge of operating existing facilities while performing offshore connections, testing and start-up. Simultaneous operation also made all the necessary modification work on existing facilities considerably more challenging than assumed in the PDO.

For the Tyrihans project, the cost overruns on the Kristin modifications were caused partly by the need for a higher than assumed number of engineering hours, and the fact that the weight was increased by two times the original estimate. Originally, the modification of Kristin was not considered to be a risky endeavour, which is why this work was not assumed to be on a critical path. Later, the operator realized that the scope and complexity was underestimated and that it should have started earlier. The simultaneous modification work and operation of Kristin proved to be more complex than presumed.

7.1.7 The Wider Context

All in all, oil and gas projects had a 12% average cost overrun in which 66% of the 109 projects in the dataset experienced cost overruns. From the normality tests and summary statistics, one can see a non-normal distribution, with high kurtosis and skewness values. Outliers, like the Valhall VRD, can somewhat explain these results. This sector also saw no improvement in forecasting abilities as time went on. As mentioned before, increasing oil prices may have masked some of the shortcomings in this area of projects.

The findings of MPE coincide with the findings from the study done by the Investment Committee back in 1999 [22]. This, and the results from chapter 6, suggest that no improvements have been made in this sector regarding cost estimation for more than 20 years, thereby indicating that strategic misreporting to be a wide-spread issue on the NCS. Unrealistic expectations, not accounting for economic activity, a lack of understanding of risk and too little time spent in the planning phase of projects were once again pointed out as determinants of cost overrun on the NCS.

Interestingly enough, issues observed in the five projects of MPE's study are also present in Ernst & Young's (EY) report on oil and gas megaprojects [4]. In fact, EY's findings, regarding root causes of cost overruns within project development and delivery, almost fully coincide with the findings from MPE's study, see Figure 22. This means that the shortcomings of the projects on the NCS can be found in oil and gas projects globally.

According to EY, there are a number of challenges that need to be considered before initiating a project. The first being the complexity of joint ventures. These agreements can be organizationally complex, and delivery issues are often exacerbated by the difference in investment rationale, project assessment criteria and tolerance for project risk between partners. The second being access to funding; or a lack thereof. And lastly, portfolio management and project selection. Poorly defined company strategy and project selection criteria leads to companies developing overly diverse and poorly aligned project portfolios.

Consequently, this leads to worse resource management, higher portfolio risk and lower potential value of synergy between projects.

There are also a number of external factors that can lead to overruns, according to EY. These relate to regulatory and geopolitical challenges, like regulatory delays and policy uncertainties, inadequate infrastructure, diplomatic and security issues, and financial and supplier market uncertainties.

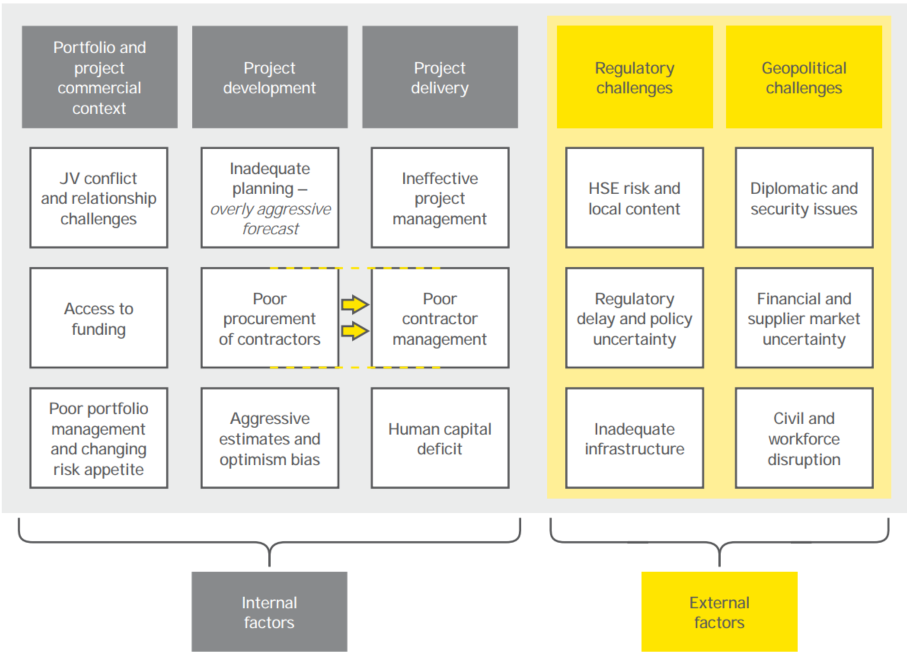


Figure 22: Factors responsible for cost overruns and delays in the oil and gas sector, according to a report from 2014 by Ernst & Young.

7.2 Nuclear

The results from chapter 6 show nuclear projects to have some of the worst cost estimation performance of any sector regarding cost estimation. This subchapter aims to identify some of the main determinants of these results.

In today's world, some researchers argue that nuclear technology is our best bet against mitigating global climate change. It is being promoted as a clean and reliable energy source. With the recent technological advances in nuclear technology, it is also being promoted as a safer option compared to previous models of nuclear reactors [47].

Indeed, this idea has gained a sizeable audience, promising a solution to climate change without hindering economic growth. And the idea is not without merit. Nuclear power plants (NPP) have enormous potential in terms of power generation while producing little to no climate gas emissions. Chapter 6 showed that NPPs have an average capacity of almost 1 GW while also having the best cost/kW numbers. On the other hand, some scientists and economists have expressed doubts on these promises with uncertainty around its environmental effects, technological maturity and financial viability [34].

Before moving on to the potential determinants of cost overruns in this sector, the author wants to focus on a specific project in the dataset; the development of phase II for the Tarapur Atomic Power Station (T.A.P.S.) This project represents the addition of two new units, Tarapur III and IV. Tarapur I and II were boiling water reactors (BWR) and were a part of phase I of the development of T.A.P.S. in the 1960's, while Tarapur III and IV were added in the mid 2000's and use pressurized heavy water reactors (PHWR). There are two reasons as to why this project deserves particular focus; the first is for it being the most recently commissioned NPP in the dataset, and the second is for the claims that were made of the project's performance regarding costs.

The project, or phase II, were said to have finished "*seven months ahead of schedule, at a cost much lower than the original estimate*", according to the Nuclear Power Corporation of India Limited (NPCIL) [33]. However, according to Sovacool et al's dataset, the project experienced a cost overrun of 151% and a time overrun of 92%. In hopes of finding a third party to confirm either side, the author came across two sources also stating that a cost overrun of over 150% (151% [34], and 165% [35]), took place in the project's development.

Note that one of the numbers from these sources may have been the source for Sovacool et al's numbers in their dataset. Sadly, the author found no statements about the project's duration.

Before explaining why this claim is troublesome, an alternative claim, which would not have raised so many questions, will be presented. NPCIL could have claimed the project as being within the *latest* estimates. This usually indicates that analysts or promoters changed their estimates during the project's lifetime, to claim a cost underrun or being on budget. There are several underlying reasons for changing cost estimates during a project's lifetime, like the need for scope changes, uncovering of new information, random errors, etc., as is often the case with nuclear projects. The problems with changing estimates during a project's lifetime was touched upon in chapter 1. Although there is nothing inherently wrong with changing estimates mid-project, big changes often indicate that a project had wildly inaccurate estimations regarding the cost or scope of the project. It could also mean that a company was trying to protect its renomme by retroactively matching the estimates to the actual final cost. But, since NPCIL claimed the project as being within the "*original"* estimates, it opens up for a more interesting discussion.

The statement from NPCIL is in stark contrast with what the independent sources are claiming. Project analysts often make several estimates, and one could perhaps argue about which of these represent the initial one. Otherwise, there is not much room for different interpretations of this statement; either the project cost was "*much lower than the original estimate*" like NPCIL claims, or much higher like the independent sources claim. It is impossible to know with absolute certainty which sources are correct in this situation without having access to the actual numbers from the project. With that said, it is important to note that companies and government officials in charge of these projects have great incentives to put their projects in a more positive light, in the hopes of getting future funding, among many other reasons.

Even if the claims of Tarapur III and IV being much lower than the original estimates were true, it would be the exception and not the rule, according to the results from chapter 6. Indeed, the results showed an average cost overrun of 117% for nuclear projects, the highest one in the dataset. In fact, it is very difficult to find a project with no cost overrun, as projects with cost overruns make up over 97% of the total nuclear projects. Why is it then that the nuclear energy sector is plagued with these enormous cost overruns?

7.2.1 Strategic Misreporting and Optimism Bias

The average estimated budget of nuclear projects in the dataset is around $1.3 billion, see Table 9 from chapter 6. Like with oil and gas, Flyvbjerg names optimism bias as one of the key reasons for cost overruns in megaprojects [36]. As stated earlier, nuclear technology has gained a lot of traction in the public eye as our best option against climate change. Planners paint nuclear energy as a source leading to economic revitalization, progress, and the possibility of a better future [48].

If optimism bias was the only cause, one could argue that the initial estimates should get more accurate with time, as the human psychology would correct this bias with repeated tries. However, as the results from regression analysis suggests, this is not the case with nuclear projects, see Figure 20. One reason for this could be the uniqueness and complexity surrounding nuclear projects, which is discussed in the next section of this subchapter. Another reason could be strategic misreporting, i.e. deception or lying, as mentioned before. Motivations for strategic misreporting can be many. Teams often compete with each other for funding from an organization's limited resource pool. There are also many others who benefit from the approval of a big project. The various stakeholders can be landowners, construction companies, lawyers, politicians, etc [36]. If deception is as widespread as the results suggest, it would help explain why the distribution of the relative cost overruns have such high standard deviation, kurtosis and skewness, as it would be difficult to make informed decisions for the approval of projects.

With the risks inherent in operations (equipment failures and outages), power plant projects pose considerable financial risks to investors [49] [38] [39]. Because of the high construction costs and complex nature, a high discount rate has handicapped nuclear compared to the other sectors of energy [50]. Funding of nuclear power plants have historically been heavily dependent on government investment and subsidies, in order to mitigate some of the great risks of these ventures have on the plant owners [51] [48].

7.2.2 Learning

The construction of an NPP is not only capital intensive, but also technically and organizationally complex. Advancements in nuclear technology has led to the nuclear sector experiencing rapidly evolving technology with high replacement frequency [15]. Simultaneously, delays and cost overruns have shown to be frequent throughout the years. In fact, this sector has shown negative learning, meaning that cost overruns have increased with the years, although slightly ($R^2 = 0.04$). At best, no improvement has taken place. Highly unique, non-standardized designs and the use of technology with high replacement frequency could be the underlying reasons for this development.

Furthermore, the long history of nuclear accidents show why NPPs are exposed to very strict and unique regulations. As Wong puts it:

"Components fail, systems do not function as planned and organisational cultures breed latent risks… no matter how well a plant or an operational manual is designed. In short, the processes of nature, technologies and organisations can take on a life of their own and humans are not always in control [37]*."*

The construction of NPPs experience project delays not only because of engineering challenges, which points to technical complexity, but also public opposition and changes in regulations, i.e. organizational complexity. These regulations play a big part in increasing the complexity and cost of the supply chain. The strong legal, political, financial, social, and environmental implications from performing the projects can create several stakeholders with wildly different expectations and needs, which only adds to the organisational complexity. [15]

7.2.3 Duration

Nuclear projects seem to run into cost overruns regardless of the size of their initial budgets and capacities. On the other hand, from Table 24 one can see a statistically significant impact of proposed project time on cost overrun ($R^2 = 0.166$). Proposed construction lead time was on average 55 months for the projects in the dataset, while the actual construction lead time was on average 91 months. As mentioned before, the longer a project continues after its proposed finish time, the more it is going to cost. And often times, a longer estimated project duration indicates higher project uncertainty, since projects with long development times are more prone to being affected by outside factors.

Chernobyl and Three Mile Island accidents drastically changed regulations for ongoing projects in the 1980s. This is likely the reason why there is a visible “spike” in the dataset for nuclear projects completed in this time space, see Figure 20. These regulations affected several projects mid-construction, which impacted the projects’ equipment needs, construction design, labour and materials. Modifying projects to incorporate these new changes led to severe cost and time overruns [45] [52]. This development could somewhat explain why the distribution of relative cost overruns is heavy tailed in this sector.

7.3 Wind

From the 35 wind projects in the dataset, one can see an average cost overrun of 7,7%, see Figure 4. This is the second lowest of all the sectors, only beaten by solar.

Wind projects had a standard deviation of relative cost overrun of just 13.1, the lowest compared to the other sectors, see Table 12. This suggests that wind developers have some of the most reliable forecasting abilities and it makes investing in wind farms some of the least risky ventures in comparison [45].

7.3.1 Manufacturing

Reasons for the low numbers for cost overrun and standard deviation could be linked to how mass production, pre-assembly and testing take place in wind turbine manufacturing. Major turbine manufacturers put great effort into streamlining the installation process by assembling as much as possible of the turbine's nacelle in their own offsite facilities [45]. A turbine nacelle contains the majority of the complicated components, see Figure 23. More and more items have been designed for pre-assembly, which used to be done on the field [53]. A more streamlined installation process also allows for an improved quality of work, since most of the assembly is being done in manufacturer's own controlled facilities. They can also do simulation and testing of performance before turbines are shipped for installation.

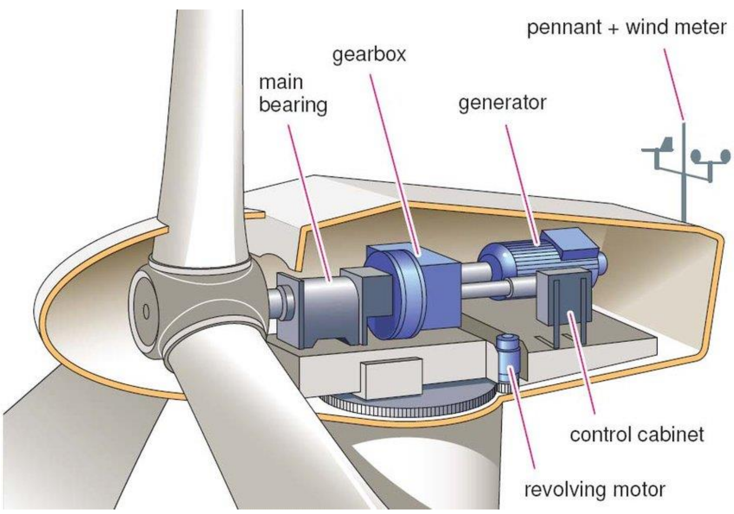


Figure 23: Components of a turbine's nacelle.

7.3.2 Duration

Wind projects also have the shortest average project lead time, which could be another explanation for the accurate estimates. Faster construction lead times reduce the risks of construction costs rising due to political events, tax changes, and other exogenous factors [45].

The short project lead times, in addition to the highly standardized manufacturing processes, suggest a much lower uncertainty and complexity in these projects. As a side note, the stakeholders could simply be content with these results, since cost estimation performance in the wind sector has not improved over the years.

7.4 Solar

The 39 PV (photovoltaic) and CSP (concentrated solar power) plants in the dataset outputs a total power of 2.37 GW from a total of $16.5 billion investment. We see exceptionally low numbers for time and cost overruns, with a 1.3% average cost overrun and a -0.2% average time overrun. These are the lowest average cost and time overrun results in the dataset. Furthermore, solar also stood for the lowest standard deviation for relative time overruns at 8.0, see Table 13.

7.4.1 Innovation

PV modules have experienced rapid cost declines since the 1970s, see Figure 19. Rapid innovation and increasing economies of scale has led to reduced prices. Increased module efficiency declines in the costs of both non-Si (silicon) and Si materials are some of the biggest reasons for the lower costs. Coupled with increasing manufacturing plant sizes leading to shared infrastructure, reduced labour requirements, higher yield, and better quality-control, it could explain why PV power plants have gotten cheaper over the years. Average plant size has grown from 1 MW in the 1980s to 1 GW in 2012 [46]. This explanation is supported, although very slightly (R^2 = 2.88%), by Figure 16. Another explanation could be overcapacity or overproduction. Government supported manufacturing has led to a 50% fall in global prices over the course of 2011 [44] [45], which is another development that might partially explain the negative relationship between completion date and cost overrun for solar projects in Figure 20 (R^2 = 4.13%). However, these results are accompanied with a high p-value (0.214), which somewhat undermines the strength of the relationship.

7.4.2 Learning

But what about CSP plants? CSP has been experiencing a resurgence recently. There was a 15-year period that saw no new installations of CSP plants, but this has changed significantly since 2006. The CSP market has been dominated by only two countries, Spain and USA. Of the 4 GW installed global capacity, half of it was installed by only three companies (Abengoa, Acciona and Cobra), which also make up 72% of the projects in this dataset. This suggests that the few countries and companies who make up the bulk of the installations have led to significant gains in experience and learning, and consequently, lower costs in most projects in this sector. Increased productivity and efficiency of activities, effectivity of teams, etc., could be the reason why actual costs were lower than expected, albeit slightly. This is supported by the fact that companies have done duplicates of projects (Andasol-1, Andasol-2, Andasol-3 and the likes), that saw less cost overruns with their successors than the original projects, see Table 22. This is also supported by the dataset, Figure 20.

7.5 Hydro

The dataset consists of 61 dams with a total capacity of 114 GW and $123 billion in construction costs. The actual total construction costs came at around $275 billion, resulting in a cost overrun of over $148 billion. The average cost overrun was 70.6%, and 75% of the projects experienced cost overruns. In absolute terms, hydroelectricity projects experienced the largest average cost and time overruns. They also had the longest average construction time with 118,4 months.

7.5.1 Outliers

In the dataset, there is a skewed distribution of project cost overruns due to 5 projects. These 5 projects stood for 36% of the total capacity, while making up over 70% of the total cost overruns [45]. They were massive in scale, between 2.7 to 22.5 GW, compared to the rest of the projects in this sector. These projects are likely why standard deviation, skewness and kurtosis of absolute cost overruns are the highest of any sector. The Three Gorges Dam alone make up 32% of the cost overruns, with an outstanding $47 billion over estimated costs, making it the largest cost overrun of any source by a large margin.

7.5.2 Duration

The average construction lead time was estimated to be 75 months, while the actual average construction lead time was 118 months, or almost 10 years. As stated earlier, this is the longest in any sector, and it equals nuclear in average time delays with 64%. Running regression analysis between cost overrun and proposed time shows some statistical significance (R^2 = 4.26%), but the p-value (0.249) states otherwise. However, long lead times in this context can still signify high uncertainty in estimations regarding internal factors, which will be discussed in the following section of this subchapter.

On the other hand, the longer a project is estimated to take, the more prone it is to be affected by external factors. These could be changes in demand, interest rates, availability of materials, exchange rates, severe weather, labour strikes, and sometimes even war. For the projects in the dataset, unexpected price increases, inflation, unfavourable currency devaluation, tax changes and political events have all proved to be common and significant causes of overruns [45].

There are several reasons for why construction lead times of dams are typically higher than the other sectors. One is that they are more material intensive on per MW basis. The other, given by The World Commission on Dams, is that there are elements of construction unique to dams. There can be the need to build coffer dams, excavate large amounts of subsurface rocks, and/or meet multiple purposes with the same project, such as a dam that simultaneously provides flood control, irrigation, and electricity [40] [45].

7.5.3 Uncertainty

The time delays can be explained by the great amount of uncertainty in the planning phase. With the explorations methods available today, planners are experiencing difficulties in detecting "*the presence of lenses made of soft material, highly compressible areas and pockets of high pore pressure, which can cause faulting in the rock mass* [41]."

Continuous work in the monitoring and control phase of the projects is mandatory, because "*the process of refining the geological model is an endless activity*". Even after extensive exploration, events like landslides, induced seismicity, cave-ins while tunnelling and finding different formations than expected can occur [41]. Changes in scope are therefore both unique to and a common cause of cost overrun for hydroelectric projects.

7.5.4 Size

Both in terms of capacity and initial budget, there are statistically significant results suggesting that the size of these project can explain some of their cost overruns (R^2 = 22.0% and R^2 = 5.83%, respectively). Hydro projects also show statistically significant positive relationship between completion date and cost overrun (R^2 = 6.91%), giving some legitimacy to the low-hanging fruit theory and strategic misreporting.

8 Conclusion

Let us bring back the research question before drawing conclusions; what are the determinants of cost overruns in energy projects? The author has analysed 424 projects, mixed with reports, articles, interviews, etc., and found that cost overruns are still a prevalent problem within the energy industry, extending the previous claims about projects showing no improvement in the last 70 years, made by Flyvbjerg et al [1], to 90 years. However, the findings are more nuanced than this, as there are big differences depending on the sectors. While some determinants of cost overruns seem to be universal, others are sector specific. For some sectors, the results suggest that a set of circumstances need to be in place in order to experience a cost overrun, suggesting major potential for improvements. Meanwhile, other sectors, or arguably a single sector, seem to experience cost overruns regardless of the circumstances, suggesting a more fundamental, sector-wide change is needed in order to improve forecasting performance.

8.1 What We Know So Far

One way of interpreting the results of this thesis is perhaps to conclude that most energy projects are inherently risky ventures. But as mentioned above, looking at the sectors individually paints a different picture. The nuclear sector stood out in this regard by producing the worst results. These projects seem to run into cost overruns regardless of size (capacity, budget), time of completion or length of proposed time. No doubt that some determinants of cost overrun can be, and often is, prevalent in multiple sectors. In the nuclear sector however, these only seem to exacerbate the situation and not necessarily be the root cause of cost overruns in the first place.

Four key factors seem to be causing cost overruns in nuclear projects, the first being complexity. Nuclear technology is complex, and NPPs pose a great risk to the environment in the case of an accident. This makes both the development and governance of NPPs incredibly complex. Uniqueness of projects adds another layer of complexity to them, since the technology has rapid replacement frequency. The financial, political, social and environmental aspects of nuclear technology also seem to be constantly changing. These make both technological and organizational learning from previous projects more challenging than in other sectors. The second factor could be optimism bias. As Flyvbjerg et al found in their 2005 paper, the projects that are sanctioned are not necessarily the ones with the best chances of succeeding, but the ones that overestimate the benefits while underestimating the risks [54]. NPPs have enormous potential, as evidenced by their cost/kW results, low emissions, high average capacity, etc. These, and the constantly changing technology that promises improvements compared to earlier projects, can cause analysts to make overly optimistic estimates. Furthermore, there is strategic misreporting, which could also explain why this sector has consistently experienced high levels of cost overruns throughout time. Coupled with complexity, it could make hiding or intentionally downplaying the risks while overstating the benefits an easier endeavour. Lastly, the project duration could be having a strong impact on cost overrun. Nuclear projects have high proposed times, an explanatory variable used in regression analysis, while experiencing the joint-highest relative time overruns. This explanatory variable certainly shows a strong impact on cost overrun. However, the low variation in these estimates could mean that projects, which were originally estimated to take longer time, have been intentionally downplayed to fit into a five-year window. In other words, some of the strength of the relationship between proposed time and cost overrun is likely due to strategic misreporting.

These factors likely exist in other sectors as well, but there are far fewer signs of them. In the hydro sector, budget and capacity, which are variables indicating the size of a project, both produce statistically significant positive impact on cost overrun. The results also show a positive impact of the length of time on cost overrun. This can be explained by the fact that projects with long lead times are generally more prone to being affected by outside factors. There were also some outliers, like the Three Gorges Dam, that negatively affect the performance numbers for this sector. Furthermore, completion date also shows a statistically significant positive impact on cost overrun, lending some legitimacy to the low-hanging fruit theory and strategic misreporting. While projects in some sectors can be approved for construction in many different locations and on different surfaces, hydro-electric dams are much more limited in their construction regarding location, suggesting that more complex projects are due with time, according to the low-hanging fruit theory. Interestingly enough, there was a statistically significant impact of completion date on capacity, suggesting an increase in size with time, which further supports the theory that hydro projects are getting more complex with time. Lastly, some planners state that a great amount of data is inaccessible before project sanctioning, and that continuous monitoring is needed to refine the geological model in the monitor and control phases. This suggests that hydro project planners operate with high degrees of uncertainty, which understandably would lead to strong deviations from the estimates.

Oil and gas had fewer variables for the statistical testing part of this thesis. However, reading detailed studies/reports about specific projects and about the sector in general revealed a great deal of information. Apart from complexity, determinants of cost overruns in the oil and gas sector seem to be optimism bias, poor contract and project management, and high economic activity. These problems appeared in other reports as well, showing that they are both prevalent and have been consistent for decades. Many of the problems categorized as optimism bias over the decades have been highly similar, suggesting that optimism bias alone is not a sufficient answer for the research question. Much like the nuclear and hydro sectors, the results suggest that strategic misreporting and increasing complexity of projects have impacts as well. As EY mentioned in their report, the era of "easy oil" is coming to an end. This is forcing businesses to pursue alternative and/or more complex opportunities while arranging joint ventures to fund these technically complex projects, which increases the organizational complexity as well.

However, not every sector produced poor results. Wind shows that short project lead times and highly standardized manufacturing processes can simplify forecasting, thereby making it more accurate. Solar projects produced even better results, most likely by exploiting the positive aspects of completing several similar projects, and projects undertaken by the same countries and companies, for improved learning. These seem to have played a major role in reducing complexity and uncertainty in solar projects. The solar sector was also subject to falling material prices and economies of scale, so some of the relatively good results are likely explained by this factor as well.

The hypotheses, like the ones relating to initial budget and capacity, were only validated for a single sector each. The author expected a much stronger relationship between these variables and cost overrun, but this was not the case. This was also one of the factors leading to a mixed-method approach for this topic, as the chosen statistical methods alone did not reveal enough information to answer the research question.

8.2 How to Improve

To improve the accuracy of cost estimations, a number of steps and changes need to be made. First, more time needs to be spent in the early phases of the projects, including feasibility studies, considering the availability of resources, among others. The importance of the early phase work is commonly overlooked and can lead to under-performance and changes in scope [55]. Furthermore, it is important to create a well-defined project plan. It is important for planners and managers to do their due diligence in this regard, and more clearly define all the activities necessary to successfully implement the project. It is also important to create well-defined success criteria to go along with it.

Secondly, more transparency is needed, something which is severely lacking in the energy industry. This can be achieved in several ways. One way would be to enact policies similar to the policies that are in place for the oil and gas projects on the NCS. Publicly available estimations and results throughout a project's lifetime would help decision-makers attain information more easily for the aid in the decisions of future projects. It would also increase accountability and effectivity in identification of issues. In the case of an operator-contractor relationship, the author suggests that the operator should improve their programs for the follow-up of contractors by implementing systems for retrieving weekly/monthly reports on the progress of their projects. Operators can also send out multi-disciplinary teams with company representatives to project sites, or alternatively, use an independent third-party company for this job. There was the case of an operator using both internal and external experts to follow-up on contractors with high levels of success, detailed in chapter 7.1.4. These steps would make it easier to identify risk areas of projects, relating to cost, time and changes, earlier.

Third would be to have a proper risk and scope change management plan to anticipate and manage deviations. These would need to be combined with the measures for more transparency in projects to be effective, as detecting risks too late would somewhat undermine the efforts.

Fourth is to take an outside view by taking use of a reference class forecasting method, which is detailed in Flyvbjerg et al's paper, *Curbing Optimism Bias and Strategic Misrepresentation in Planning: Reference Class Forecasting in Practice* [19]. But, as they mention in that paper, the incentives to use better forecasting methods are low if the forecasters or promoters are engaging in strategic misreporting. In order to improve under these circumstances, they suggest taking measures which would reward good performance and punish bad performance to limit the occurrence of optimism bias and strategic misreporting in the industry.

8.3 Further Research

This thesis' main focus has been on identifying as many determinants of cost overrun as accurately as possible. The suggestions to improve forecasting have mostly been derived from these findings, meaning that more work can be focused on how to improve.

Furthermore, the use of more sophisticated statistical methods to research this topic is in order. These would include the use of different and more advanced forms of regression analysis, including regression with multiple variables and testing without outliers, simulations, etc.

Although Sovacool et al found cost overruns to be agnostic to geography, or location, there were still some differences based on location. A deeper look at how geography and culture affect cost overrun could be in order.

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