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The Potential of Nuclear SMR in the Norwegian Energy Mix

Economic and financial analysis of SMRs in Norway

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Executive summary

The primary purpose of this thesis is to determine the feasibility of incorporating small modular reactors (SMR) into the Norwegian energy mix, considering Norway's role in a larger integrated power market with direct grid connections to several European countries. Three analyzes were conducted to evaluate this: Initially, we conducted a literature review to determine if there is room for nuclear energy in the Norwegian energy mix and to compare nuclear energy with other relevant sources on a variety of financial and socioeconomic metrics to determine its potential value relative to relevant alternatives. Finally, we conducted a profitability analysis to determine the potential value creation of an SMR project. This approach aims to provide a nuanced perspective on the potential of allowing nuclear energy production in Norway.

The primary findings suggest that SMR technology has significant potential in the Norwegian energy mix. With the green transition, the market analysis predicts a substantial increase in energy demand through 2050. In addition, the energy prices observed over the past few years are likely to decrease by 2030. With the current energy policies, however, there is a substantial risk of deviations between demand and supply, thereby severely jeopardizing the power balance and causing volatile power prices. Potentially resolvable by the addition of a stable and to a large extent dispatchable energy source, such as SMR. The comparative analysis demonstrates that nuclear energy has acquired an undeservedly negative reputation, despite appearing to be one of, if not the most environmentally friendly and secure energy source available today. In addition to being highly cost-competitive with sources such as offshore wind and solar, especially when the need for energy storage and external costs is considered.

Our analysis of profitability is based on several assumptions. Seeing as SMR is a new and untested technology, its validity is difficult to assess. Nevertheless, based on these assumptions, our findings indicate that SMR projects would require reasonable financing in order to create shareholder value due to their substantial initial investment. With the long and stable cash flow, however, our base case estimates indicate that a project could achieve a payback period of approximately 20 years, with an accumulated positive net cash flow of between 60 and 70 billion NOK. Which, with discounting effects included, results in a net present enterprise value of 2-3 billion NOK. In addition, a levelized cost of electricity of around 65 øre/Kwh is achieved, which is particularly competitive compared to offshore wind.

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1. Introduction

1.1 Actualization and background

Energy has always played a vital role in human prosperity. It has been one of the most powerful forces for evolution and growth throughout our history. Since the discovery of fire, new technologies and understandings of how energy functions have contributed to human progress (Smil, 2004, pp. 549-561). We know that there is a strong correlation between access to affordable and reliable energy and economic growth. This relationship became increasingly apparent during the industrial revolution when the British began using coal in iron production and subsequently witnessed an exponential increase in production and economic growth (Jack, 2022). Since then, hydrocarbons have been the world's primary energy source.

Human activity is almost universally acknowledged as the main cause of global warming. Along with that, we must reduce our greenhouse gas emissions to mitigate the effects of climate change. Energy is by far the biggest contributor to global warming. It accounts for roughly 73% of human-caused greenhouse gas emissions, while only 17% of the world's energy production is derived from renewable sources (UNDP, n.d.). The transition to a zero-emissions economy by 2050 will require a substantial adjustment. Whereas, on the one hand, we must transition away from a society that is primarily powered by hydrocarbons. On the other hand, energy security is one of the most crucial determinants of economic growth and human prosperity. The present energy crisis illustrates the difficulty of achieving this balance. We are experiencing unsustainable high and volatile energy prices. In addition, there is a potential deficit in Europe's energy balance, which made the appearance of energy blackouts a possibility during the winters of 22-23. During the Texas power crisis in 2021, for example, over 100 people died as a direct result of a blackout (HSDL, 2021), demonstrating the significance of reliable energy access. Clearly indicating that energy security cannot be sacrificed for the green transition.

To achieve this balance, the majority of western nations have made substantial investments in renewable energies, primarily solar and wind. Consequently, creating an energy balance in the future that is highly dependent on specific weather conditions, also known as variable renewable energy (VRE). Moreover, if we consider the European countries closest to Norway, a significant portion of this production is expected to be located in the North Sea. Therefore, we are not only dependent on the same source but also on that source's ability to produce in the same location. Consequently, the future energy portfolio is not very diverse. While this is in the works, an increasing number of nations, such as Germany, are shutting down their hydrocarbon-fueled dispatchable sources and nuclear power plants (Paddison et al., 2023). Thus, eliminating stored and dispatchable power that can cover energy demand during periods of unfavorable weather.

Additionally, it is essential to keep in mind the use of resources during the transition to a renewable economy. Both in terms of sustainability and monetary value. In terms of sustainability, earth overshoot day is the date at which humanity's demand for ecological resources and services exceeds what the planet can regenerate in a given year. The date was July 28th. In 2022. Which is roughly two months earlier than the corresponding date in 2000 (EOD, n.d.). Which demonstrates the significance of resource efficiency. In addition, since 2004, the world has invested approximately 6,7 trillion USD in the green transition (Bullard, 2023), which is equivalent to almost five times the amount of the Norwegian Government Pension Funds (NBIM, n.d.-a), while annual CO2 emissions have increased by approximately 30% during the same period (OWD, n.d.-b). Insinuating that something has gone wrong, either through inefficient use or poor organization of resources.

In the postwar period, Norway was a major contributor to the nuclear power research community. Still, we never established a commercial nuclear power industry (Hofstad, 2019). This is most likely because we are largely self-sufficient in renewable energy thanks to hydropower, rendering a nuclear source unnecessary. Nonetheless, the energy demand will increase in the future, necessitating investment in new production sources while maintaining energy security. Consequently, it is paradoxical that nuclear power faces so much political opposition that the current administration is unwilling to investigate the potential benefits of including nuclear power in the energy mix. In particular, small modular reactors (SMR) appear to be a highly relevant possibility by delivering safe, reliable, and clean energy. This becomes increasingly intriguing with Norsk Kjernekraft AS (NKK) asserting that they can make it economically feasible within a reasonable timeframe, even without government subsidies.

Despite considerable political opposition, nuclear power has become more accepted and highly debated in recent months, with several political parties advocating for its exploration (Aas, 2023). Despite this, it appears to be few nuanced perspectives in this debate, with the majority of participants being either extremely pro- or anti-nuclear power, reflecting the debate's highly contradictory arguments. On the one hand, nuclear power is viewed as a dangerous energy source, while on the other, it is viewed as the superior energy source. This has made it difficult to determine the true benefits and drawbacks of the energy sources anticipated to meet our future energy needs.

1.2 Subject and problem

> "*Can nuclear small modular reactors (SMR) be economically and financially feasible alternatives to the long-term energy challenges, and represent a positive societal contribution to the Norwegian energy mix?*"

Norway along with the rest of the world faces long-term challenges in transitioning into a sustainable economy, and especially relevant for our thesis, the transition into sustainable energy while also securing energy supply. Nuclear power, and in particular SMRs, could potentially play an important part of the solution to this problem. However, this is an enormously complex problem and question.

Norway has never had commercial power production of nuclear energy, and there are still political barriers that need to be handled and a regulatory framework to get in place before we can even consider investing in nuclear power. Additionally, SMR technology is still in the developing stages, and although there has been a lot of progress in recent years, it is not commercially available yet. Consequentially, it is impossible to give a quality prediction as to whether an SMR project would be profitable, simply because an SMR project in Norway is not possible today. However, there are substantial amounts of data and literature on both SMRs and comparable nuclear power production, which we can analyze.

The wording "can" in our problem is deliberately vague. Our thesis will not investigate whether to invest or not, but rather if there are potential for SMRs to be profitable or at least economically and financially feasible option. Everything is relative, and to assess SMRs, we need to review them against the relevant alternative energy sources for Norway. However, these are not mutually exclusive, and beyond simple comparison, we investigate how they can work in coexistence. Additionally, we investigate the subject beyond isolated projects, also accounting for effects on society with external costs and benefits. Ultimately looking into how SMRs potentially could fit into and contribute to the Norwegian and Nordic energy mix.

In conclusion, our goal is to give an objective analysis and insight into the potential of SMRs in Norway, and in the process, try to give some conclusion as to whether this should be considered a relevant alternative. To do so we review the market and need for added energy production in the future, analyze and compare relevant alternatives, and lastly model a potential SMR investment to assess the economic and financial aspects of it. Which in turn will create a comprehensive insight and understanding of our problem.

1.3 Limitations and scope

The subject of current and future energy markets is very broad and highly complex. We must balance the thesis to comprehensively cover the subject while maintaining the quality of our analysis. Therefore, it is essential that we limit the scope of this thesis. We divide the thesis into three parts. Firstly, we review the literature and build our perspectives on the research of others. By doing so, gain an understanding of the future energy market and fundamental differences between the possible alternatives, potential socioeconomic benefits, and challenges. The second section of this master's thesis consists of financial models of a potential SMR investment in Norway, where we analyze the economic and financial viability of SMRs in Norway. Together, these two approaches provide a comprehensive overview of how a potential SMR would fit into Norway's energy mix.

In the financial section of this thesis, operational profitability, and financing of a potential SMR project are emphasized. Estimations of various macroeconomic factors, such as market prices, are included to a limited extent in this thesis, as performing such a complex task would constitute its own master's thesis. Due to the long duration of this project, any results derived from such estimates are likely to be highly unreliable. Furthermore, we have only scratched the surface of the numerous social implications and effects a nuclear power plant would have on the power market and grid. External analysis and existing literature are used to gather information about this topic.

We have no technical prerequisites to question whether SMR is a viable technology or estimating probabilities that the obtained SMR estimates, and prognosis are correct. As a result, the vendor's and our cooperation partner's SMR-specifics are assumed to be applicable. Any uncertainties are then captured using scenario analysis and sensitivities. As a result, we implicitly assume that SMR technology development will be successful, and that commercialization will be feasible within the next 5 to 15 years.

2. Nuclear power

Before we can start to analyze the potential of SMRs in Norway, it is important to understand what it is. Firstly, by gaining a fundamental understanding of nuclear energy production, and then secondly, how SMRs differentiate from traditional nuclear power plants. Additionally, we need to understand operational challenges, especially regarding the handling of nuclear waste, which could be extremely harmful if not dealt with appropriately.

Nuclear power is a technology that utilizes the energy produced when atomic nuclei are split, a process known as fission. Uranium 235, the most commonly used nuclear fuel, is a substance with large atomic nuclei that can be split by sending neutrons in its direction. When this occurs, the uranium core releases new neutrons, which split a new uranium core, etc. In this chain reaction, tremendous amounts of energy are released as heat. In a nuclear power plant, the heat generated by atomic fission is typically transferred to water-based coolant. The water is heated to generate steam, which then drives a turbine, which in turn drives a generator to produce emission-free electricity. (Stensrud, 2019)

SMR is a nuclear technology that has emerged in recent years. This is an advanced nuclear technology with a power output of up to 300 MWe per unit, which is the equivalent of the power needed by around 180.000 households (Fjordkraft, n.d.). Compared to conventional nuclear reactors, this is approximately one-third of the capacity (Liou, 2021). As their names imply, these reactors are significantly smaller than conventional reactors, and they are modular, meaning that systems and components can be produced in a factory and transported to a site for assembly and installation. This design resembles a Lego set in that all components are manufactured in a factory, transported to the construction site, and only require assembly, as opposed to conventional reactors where almost every plant is a custom design (Liou, 2021). This may reduce construction duration and expenses. Moreover, due to their smaller size and capacity, SMRs can potentially be located in rural areas and provide clean, reliable energy to smaller towns or power-intensive industries without costly transmission grid upgrades. In addition, SMRs are typically simpler, and their safety features rely more on passive systems than conventional reactors. This reduces the likelihood of human error and makes system shutdown easier and quicker, thereby reducing the potential for radioactive releases into the environment and the public in the event of an accident (Liou, 2021).

Nuclear energy is a massive source of energy, with uranium-235 having nearly 71.000 times the energy density of natural gas (Energy Education, n.d.-b). Nonetheless, as with all sources, it has both advantages and disadvantages. A significant amount of nuclear waste is generated by production. A waste that must be handled properly because it is extremely harmful to both the environment and the public. Prior to use, nuclear fuel is stored as metal rods with very low radioactivity. After use, these fuel rods become highly radioactive and are placed in a pool to contain the radiation and cool them down. After about a year, these rods are removed and stored in metal containers to prevent external influence and accidents and to contain the radiation. The rods will be stored in these containers for 30 to 40 years, during which time approximately 99,9% of the radiation will be removed. The nuclear waste is then placed in cobber capsules that are lined with cast iron. These capsules are then transported four to five hundred meters into the bedrock and deposited in so-called landfills. The space between these capsules and the mountain is then sealed using a water-resistant and soft clay called bentonite, which is soft enough to absorb any radioactive particles from a potential leak while protecting the capsules from any movement in the mountain. Since 1983, extensive research and testing has been conducted on this method. And in this way, nuclear waste is safely stored away from any potential ground-level incidents, while also protecting the environment from any radiation (Rose et al., 2023).

3. Power Market and grid

3.1 Definition of the relevant energy markets

It is critical to understand the potential markets in which an energy producer will operate and sell its power. In the case of a nuclear power plant, this energy would be electricity and excess heat from the electricity production. The electricity market and the market for district heating are therefore the relevant markets to study further. However, electricity and district heat can largely be seen as substitutes, which in turn implies high similarity in the markets.

Electrical power differs from other commodities in that there are no efficient, large-scale storage options. As a result, there must always be an exact balance of production and consumption (Energifakta Norge, n.d.-a). This is when the power market comes into play. The power market is a complex system designed to ensure that resources are used efficiently, that supply security is maintained, and that power is not produced more expensive than necessary (Energifakta Norge, n.d.-a). Norway is part of an integrated power market with direct links to Sweden, Denmark, Finland, the UK, the Netherlands, Germany, and Russia, however, we will not include Russia for this analysis which we will explain in Chapter 6. Furthermore, the Norwegian market is divided into five price zones, each representing a different region of the Norwegian mainland (Energifakta Norge, n.d.-a).

The various regions and nations are linked by the electricity grid. The Norwegian grid has three levels: distribution, regional, and transmission. The transmission grid is made up of a nationwide network that spans approximately 11.000 kilometers and connects the largest producers with consumers as well as international connections. The regional grid, which is approximately 19.000 km long, connects the transmission grid to the distribution grid. The distribution grid is the local power grid that connects smaller consumers and common households to the power grid. It is about 100.000 kilometers long (Energifakta Norge, n.d.-b).

Because of the nature of a power grid, each region has only one provider. Statnett regulates the transmission grid and requires new power producers to have a minimum output of 300 MWe for connection (Statnett, 2023a). All new power producers must plan, construct, and operate an overhead line or underground cable in order for their output to reach the network facility with the appropriate capacity that is closest to them. Due to this requirement, direct sales of electricity with physical delivery are prohibited in Norway (NVE, 2018, p. 3).

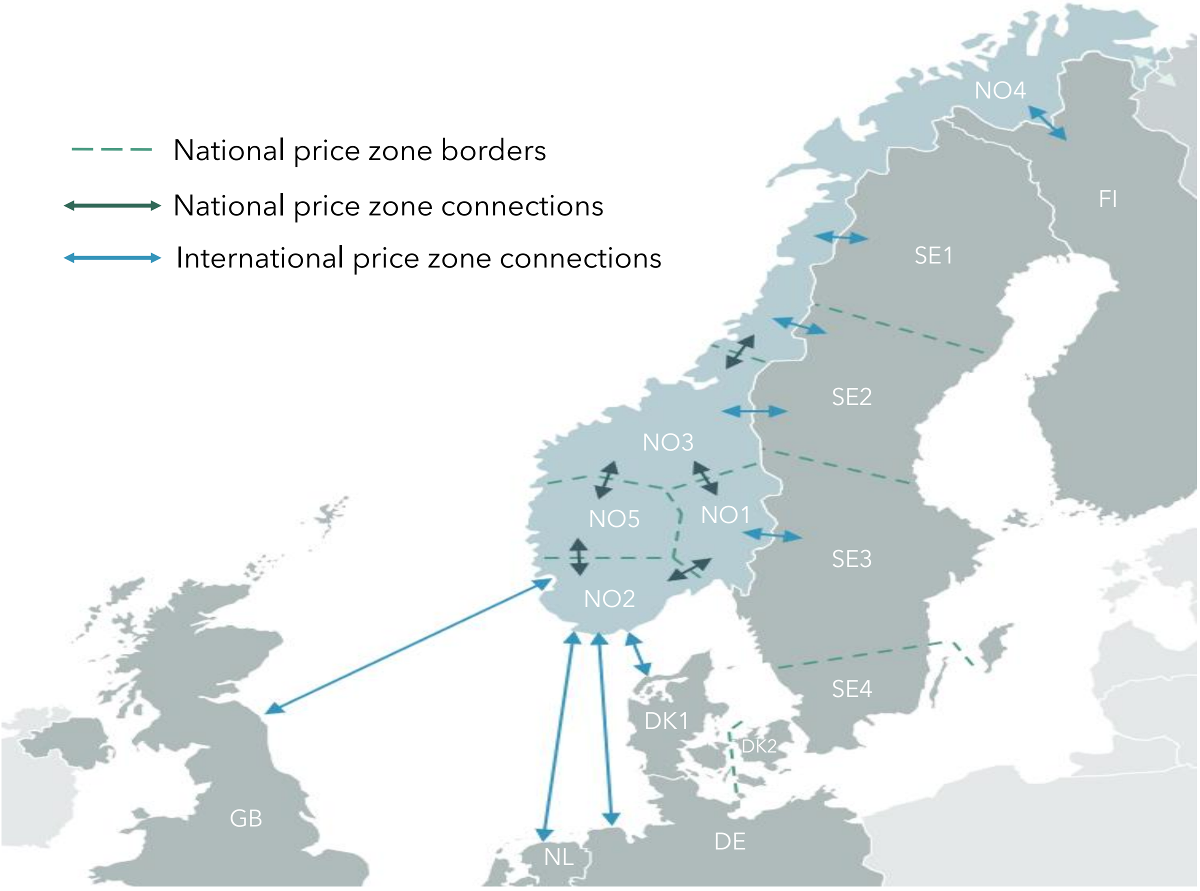


Figure 3.1: Illustration of the price zones and connections - Nordic power market Based on (Statnett, n.d.)

Compared to the market for electricity, the market for district heat is relatively small, covering only about 3% of the energy consumption on the Norwegian mainland and being concentrated in cities. Nonetheless, it could still make a significant contribution, potentially covering 25% of Oslo's momentary energy requirements (Energifakta, n.d.-c). Using district heat, industrial plants, and other heat-generating sources, such as waste incinerators and a nuclear power plant, can sell their excess heat to a market. The heat is used to heat water, which is then transported via insulated pipes to customers (Norsk Fjernvarme, n.d.). The price of district heat is governed by the Norwegian energy law, which states that the price of district heat cannot exceed the local market (spot) price of electricity plus various surcharges and taxes, which will be discussed in greater detail later. The price for industrial customers will include a power term, which is a surcharge for reserving capacity, and a volume term, which represents the amount of water flowing through the customer's system (Statkraft, n.d.-b).

The electricity market is divided into two segments: the wholesale market and the end-user market (Energifakta, n.d.-a). The wholesale market is where large-scale electricity transactions take place. The key participants in this market are producers, brokers, large industrial customers, and suppliers. The suppliers carry out transactions on behalf of the end user market, which consists of small and medium-sized end-users as well as small businesses and industries. The figure below depicts this procedure.

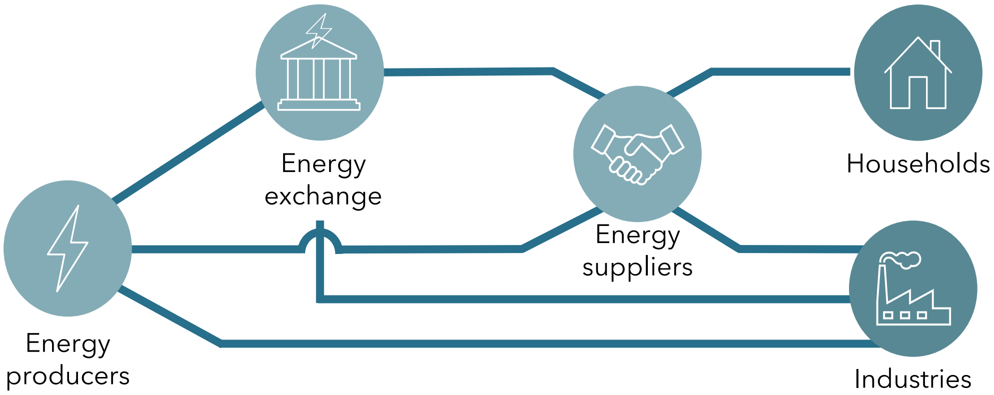


Figure 3.2: Illustration of power market organization and trade
Based on (Energifakta, n.d.-a)

3.2 Wholesale market

The wholesale market consists of several organized markets where participants submit bids and where prices are determined (Energifakta, n.d.-a). The markets are:

3.2.1 Day ahead market:

In Norway, the two licensed market operators are Nord Pool and EPEX SPOT. These businesses collaborate to provide a marketplace for power trading. The primary market, where the majority of volumes are traded, is the day-ahead market. It is an hour-by-hour contract market for physical power delivery the following day. Market participants submit sales and purchase bids to the power exchange's trading system between 08:00 and 12:00 (Energifakta, n.d.-a). Transmission System Operator (TSO), Statnett in Norway, provides transmission capacity to the market for each bidding area before 10:00. When the auction closes at 12:00, the prices for each hour of the following day are calculated based on the received purchase and sale bids and the available transmission (Energifakta, n.d.-a).

3.2.2 Intraday market:

Even though the majority of the supply-demand balance is secured in the day-ahead market, unforeseen events such as changing weather forecasts occur, altering power producers' actual production or consumers' actual consumption. This imbalance is corrected in the continuous intraday market, where participants can buy or sell power up to one hour before the operating hour (Energifakta, n.d.-a).

3.2.3 Balance market:

Although the intraday and day-ahead markets are designed to create a balance between production and consumption, there will always be incidents that can disrupt this balance during operating hours. To address this, the TSO purchases primary, secondary, and tertiary reserves, which are activated based on the length of the imbalance. These reserves are purchased through the tertiary reserves option market (RKOM), a market in which providers are compensated to guarantee available power regardless of whether such an imbalance occurs or not (Energifakta, n.d.-a).

3.2.4 Price mechanisms

The system price is the initial price calculated when determining the price of electricity. This is a theoretical price based on market supply and demand, disregarding the possibility of grid bottlenecks (Energifakta, n.d.-a). On the day-ahead market, producers inform the market of the amount of electricity they can and are willing to produce at a particular price, which largely reflects the variable cost of producing said electricity. The end-users then communicate to the market the quantity they are willing to consume at the given prices. The equilibrium between supply and demand then determines the system price for the following day. In market equilibrium, the price will be determined by the marginal cost of electricity. Thus, the cheapest energy resources are consumed first, ensuring that society's power demand is met at the lowest possible cost (Energifakta, n.d.-a).

As mentioned, the price is determined by supply and demand. Because hydropower is a substantial part of the production mix in Norway and Sweden, changes in water reservoir inflow have a significant impact on Nordic price fluctuations. During periods of high inflow, there is a large supply of electricity, causing prices to fall, and vice versa (Energifakta, n.d.-a). Similarly, temperature fluctuations affect the price because they affect the demand for electricity to heat homes. Moreover, due to the high exchange capacity between Norway and other European nations, domestic price levels are heavily influenced by the costs of producing electricity in these countries, which are largely dependent on thermal power plants, such as coal and gas. However, renewable energies such as wind and solar continue to make up a larger portion of the energy mix in these nations, making the price more weather-dependent (Energifakta, n.d.-a).

3.3 Price zones

In addition to the system price, Nord Pool calculates a price for each region, where each region corresponds to the aforementioned price zones. This price is designed to account for potential grid bottlenecks. And it is precisely these bottlenecks that account for the substantial price disparity between the five regions (Energifakta.n.d.-a). These bottlenecks are the result of substantial regional disparities in the demand and supply of electricity. One region may have an energy surplus while others experience a deficit. This deficit necessitates the import of power to meet demand, whereas the surplus necessitates the export of power. When there is insufficient transmission capacity on the grid, we experience what is known as a bottleneck, and in extreme cases of surplus, regions may experience negative electricity prices. However, this division into regions does not necessarily imply that prices will vary across each region. If there are no transmission bottlenecks, all Nordic regions will experience the same price, known as the system price (Energifakta, n.d.-a).

These regions define a market area on each side of bottlenecks. This creates the possibility that regions with a deficit will pay a higher price for electricity than regions with a surplus. The power flows from regions with a low price to regions with a high price, thereby increasing the power supply in regions where it is most needed. In addition, regional prices signal to market participants where it is most profitable to increase or decrease production and consumption. In regions with a power shortage, production would be increased while consumption decreased, thereby improving power access and supply security. Furthermore, this division into area prices helps to highlight the need for longer-term power system measures. The regional prices signal to producers and consumers where it would be most profitable to locate new production or large consumption (Energifakta, n.d.-a).

3.4 End-user market and electricity prices

The end-user market consists of consumers who purchase electricity for their own use. End-users in Norway are free to choose their electricity supplier. Small end-users typically purchase power from a power supplier, whereas larger end-users, such as large industrial companies, frequently choose to purchase power directly on the wholesale power market or through a bilateral agreement with a power producer (Energifakta.n.d.-a).

With more than 100 suppliers (Nettavisen Strøm, n.d.), the market for electricity suppliers in Norway is extremely competitive. Since electricity is a homogeneous product, the only way for suppliers to differentiate themselves is by offering electricity contracts with different terms. In general, there are three types: contracts with a fixed price, contracts with a standard variable price, and contracts based on the market price with a markup, also known as a spot price agreement. The price for the end user will then include the electricity price, which is determined by the terms of the agreement, grid rental for the connection to the power grid, a consumption tax, a value-added tax, a surcharge designated for the Energy Fund (Enova), and payment for electricity certificates (Energifakta, n.d.-a).

3.5 Financial power trading

An additional component of the power exchange is the financial market. It is a market for financial instruments used for risk management and speculation in which all contracts are settled financially. This allows market participants to hedge against market volatility for up to six years by locking in a fixed price for their power demand or supply. We should also note that traders play an important role in leveling out price levels, as argued by Thore Johnsen, Professor Emeritus at NHH. To simply explain his argument, “an efficient trader buys on low price levels and sells on high price levels, all else equal, the effect of this is reduced variations in the market”. (Johnsen, 2023). The financial instruments consist of futures and forward contracts, electricity price differentials (EPAD), and options. Future and forward contracts are agreements for the financial settlement of a predetermined amount of energy at a predetermined price over a predetermined period. Forwards are not standardized, so their prices and other terms can vary from contract to contract while futures contracts are standardized. Moreover, settlement for futures contracts occurs during both the trading and delivery periods, whereas settlement for forwards occurs at the contract's expiration date. The majority of Nordic financial power trades occur on Nasdaq OMX Commodities AS. They perform settlements as the counterpart, mitigating the counterpart risk associated with a counterpart's delivery during a settlement. However, even bilateral agreements that do not directly include a power exchange can be cleared and settled (Energifakta, n.d.-a).

3.5.1 PPA

Price purchasing agreements (PPA) have emerged in recent years as a new risk management instrument in the power market. This can be a contract for the delivery of both financial and physical power. A PPA is a long-term contract between an energy project and a power buyer in which the buyer agrees to purchase the project's energy at a fixed price for the duration of the contract (UrbanGrid, 2019). The long-term nature of PPAs distinguishes them from other financial instruments, and they are frequently used to hedge prices up to ten years in advance. This makes them a valuable risk management tool for renewable energy projects and other new power producers.

There are numerous varieties of PPAs, but we distinguish between two: the virtual or synthetic PPA and the Retail PPA. A virtual PPA is a financial product in which the power producer and consumer sell and purchase their electricity to the grid at market prices. The parties then settle their financial obligations in accordance with the predetermined price, but without any actual transfer of power (EPA, n.d.). Thus, a power producer can be certain of the selling price prior to launching a new project, and a consumer can hedge against volatile market prices. The retail PPA or direct PPA is a contract between a producer and consumer for the sale of a physical quantity of energy at a predetermined price at a future date (EPA, n.d.). However, due to the physical delivery requirements of this contract, it is not possible in the Norwegian market. In general, PPAs can be structured in a variety of ways that all function as a hedge against volatile market prices for both the project owner and the power consumer.

4. Theoretical review

In this thesis, several hypotheses and conclusions are supported by theoretical approaches derived from research papers and other literature. This chapter will provide a theoretical overview of this topic. Initially, we will describe how our approach to profitability analysis with certain investment rules highlights the potential profitability of NKK's project in various ways. We will then present the chosen theoretical method for estimating the appropriate cost of capital for discounting future cash flows. Then, we will introduce the reader to EROI and LCOE, two highly contested energy research metrics that can be used to compare the resource intensity and potential economic viability of energy-producing infrastructure. This theoretical review will provide the reader with an understanding of the grounds upon which our discussion and conclusions are based.

4.1 Investment and profitability analysis

Prior to making any investments, it is necessary to conduct a thorough the investment and its profitability. This procedure involves evaluating the financial viability and expected returns of a proposed investment. In this undertaking, it is essential to comprehend the project's potential value. This is typically achieved using a discounted cash flow model. This model uses the time value of money and risk compensation to compute the present value of the future cash flows of a prospective investment. In this chapter, we will discuss the various theories utilized to assess the prospective value of an SMR in Norway. In addition, we will explain how we assess risk and incorporate it into our model, as well as various investment decision rules.

When deciding whether to proceed with an investment, one must consider several rules. This paper employs three rules: the Net present value, the internal rate of return, and the payback rule. In the absence of alternative projects, the NPV rule states that any project with an NPV greater than zero should be accepted. The IRR rule is to approve any project with an IRR that exceeds the cost of capital. Lastly, the payback rule entails accepting any project that can return the initial investment within a reasonable time frame (Berk & DeMarzo, 2014, pp. 207-215). The most common rule is the net present value rule, which provides both a qualitative measure of whether the project should be accepted or not and an absolute measurement of the increase in market value resulting from accepting a project. This is not the case with IRR and the payback rule, both of which provide only a qualitative measure. Moreover, additional disadvantages of these solutions include the possibility that IRR may be absent in certain circumstances or that multiple IRRs may be obtained. In addition, the payback period disregards the time value of money, resulting in skewed results for projects requiring a substantial initial investment and a long-term cash flow (Berk & DeMarzo, 2014, pp. 207-215). Even though the NPV rule may be more applicable when choosing between multiple projects, in this case where there is only one project, each of these investment rules provides valuable insight into the economic viability of the project, from different perspectives.

$$NPV = -I_0 + \sum_{t=0}^{n} \frac{CF_t}{(1+r_t)^t}$$

$$IRR{:}\, I_0 = \sum_{t=0}^{n} \frac{CF_t}{(1+r_t)^t}$$

Where:
$I_0 = The\ initial\ investment$
$CF_t = Cash\ flow\ at\ time\ t$
$r_t = The\ discount\ rate\ at\ time\ t$
$n = projects\ life\ time$

4.1.1 Capital cost

WACC

To determine the appropriate discount factor, we use the weighted average cost of capital (WACC), which, as its name implies, is the weighted average of the after-tax cost of debt and cost of equity. The weighted average cost of capital (WACC) is the rate of return that all investors, both equity and debt holders, in a company, expect to earn for investing their funds in a particular business as opposed to others with comparable risk (Mckinsey et al., 2020, p. 321). It is comprised of three primary elements: the cost of equity, the cost of debt, which we set equal to the yield to maturity of debt, and the target capital structure of the company. The use of WACC necessitates several assumptions, including market weights for equity and debt and a stable capital structure.

$$WACC = \frac{D}{V} * k_d * (1 - T_m) + \frac{E}{V} * k_e$$

Where:
D/V = target level of debt to value using market-based values
E/V = target level of equity to value using market-based values
k_d = cost of debt
k_e = cost of equity
T_m = company´s marginal tax rate on income

Required return on equity (CAPM)

As a measurement for the cost of equity we utilize the Capital Asset Pricing Model (CAPM), it is a financial model that postulates that the expected return on any security equals the risk-free rate plus the beta of the security multiplied by the market risk premium. “In the model, the risk-free interest rate and the market risk premium, which is defined as the difference between the expected return of a market portfolio and the risk-free interest rate, are macroeconomic factors and are therefore the same for all companies” (McKinsey, et al. 2020, p. 331) So, to account for company-specific risk, we need to estimate the beta (McKinsey et al., 2020. p. 322) The CAPM formula is:

$$E(R_i) = r_f + \beta_i[E(R_m) - r_f]$$

Where:
$E(R_i) = expected\ retrn\ of\ security\ i$
$r_f = \text{risk-free rate}$
$\beta_E = security\ i's\ sensitivity\ to\ the\ market\ portfolio$
$E(rm) = Expected\ return\ of\ the\ market\ portfolio$

Beta

As stated, to account for company-specific risk, the beta must be estimated. The beta value indicates the covariance between a stock's return and the market's return, i.e., how the value of an asset fluctuates in response to changes in market prices, thus indicating a stock's sensitivity to market fluctuations (Berk & DeMarzo, 2014, p. 337). A stock with zero systematic risk would have a beta value of zero. The beta can be estimated by regressing the return of a stock against the return of the market. However, as NKK is not a publicly traded company, this strategy is inapplicable. In addition, research indicates that “individual company betas can be heavily influenced by nonrepeatable events” (McKinsey et al., 2020, p. 332), which argues for using the median or average of industry peers rather than the beta measured historically for the company in question. The beta formula is as follows:

$$\beta_i = \frac{Cov(r_i, r_m)}{Var(r_m)}$$

Where:
$\beta_i = The\ beta\ of\ the\ investment$
$Cov(r_i, r_m) = Covariance\ between\ investments\ returns\ and\ market\ returns$
$Var(r_m) = Market\ return\ variance$

When estimating the beta, there are four factors that must be considered: the number of years over which data should be collected, as well as whether daily, weekly, or monthly intervals should be used, the number of companies that should be used to estimate the industry beta, and the market index (McKinsey et al., 2020, p. 333). We utilize monthly data from the past five years because it strikes a balance between sufficient data points and data relevance. This is because a company changes over its lifetime, rendering too long data sets unable to accurately reflect the current company and short intervals can result in a significant bias towards companies with high turnover, causing companies with low turnover to receive a beta that is lower than it should be and companies with high turnover to receive a beta that is higher than it should be (McKinsey et al., 2020, p. 332). Regarding the number of companies, there is a trade-off between more data points providing a more precise industry measurement and the degree to which the companies resemble NKK. The index is meant to be a proxy for the market index, so large value-weighted indices like the S&P 500 and MSCI World Index are suitable alternatives.

In addition, this estimation yields a so-called levered beta, which is a function of both the operating risk and financial risk of the comparable companies (McKinsey et al., 2020, p. 335). Thus, we must use the theories of Miller and Modigliani, which state that the weighted average risk of a company's financial claims equals the weighted average risk of a company's economic assets, to undo the effect of leverage (McKinsey et al., 2020, p. 335). By assuming a debt beta of zero for comparable companies, we can obtain the unlevered beta (Equation 1) by multiplying the acquired equity (levered) beta by the market share of the equity. Take the average of the unlevered betas of comparable companies and then “re-lever” the equity beta using equation 2 to reflect our company's corporate structure.

$$(1)\ \beta_u = \beta_e * \frac{E}{D+E} + \beta_d * \frac{D}{D+E}$$

$$(2)\ \beta_e = \beta_u + \frac{D}{E}(\beta_u - \beta_d)$$

Market risk premium

The risk premium is the difference between the expected market portfolio return and the risk-free rate. It is the additional return required for undertaking risk. This value is estimated based on the historical excess return on the market portfolio over treasury bills, it then reflects an estimate of the market's future risk premium. This is accurate only to the extent that the past can accurately predict the future. Additionally, this will vary from country to country. In any case, by analyzing historical returns for the global market from 1900 to 2022, we can determine that the risk premium on equities has been approximately 4,6% (Dimson et al., 2023, p. 15). Furthermore, if one looks at the United States, this premium has been approximately 5%, which is comparable to the market risk premium found by PwC and FFN (2022) in their annual survey for the Norwegian market.

Risk-free interest rate

As its name suggests, the risk-free rate is the interest rate at which there is no risk, meaning that the return is equal to the expected return and there is no variance. To qualify as a risk-free interest rate, there must be no default risk, no uncertainty regarding reinvestment rates, and no currency risk. In practice, this implies that we must use an interest rate on a government-issued bond, preferably one denominated in the same currency as the investor, and that the bond's maturity must be long, ideally as long as the cash flows we are analyzing (Damodaran, n.d.).

Cost of debt

One alternative method for calculating the cost of debt is to use the yield to maturity (YTM) as the cost of debt. This strategy is appropriate in situations where the risk of default is minimal. However, if there is a substantial risk of default, this method will overestimate the expected return for debtholders. Consequently, it is crucial to understand the relationship between a debt's yield, which is the promised return, and its expected return, which considers the probability of default and the expected loss if default occurs. So, the CAPM can be utilized to estimate the expected return on debt. As debt betas are not as easily observable on the market as equity betas, estimates of bond index betas by credit rating are frequently used (Berk & DeMarzo, 2014, pp. 411-414). Where higher credit ratings and shorter maturities result in lower betas, and vice versa. There is no credit rating for NKK, and performing a credit rating accurately is beyond the scope of this thesis. *Figure 4.1* nonetheless illustrates how S&P approximates a credit rating.

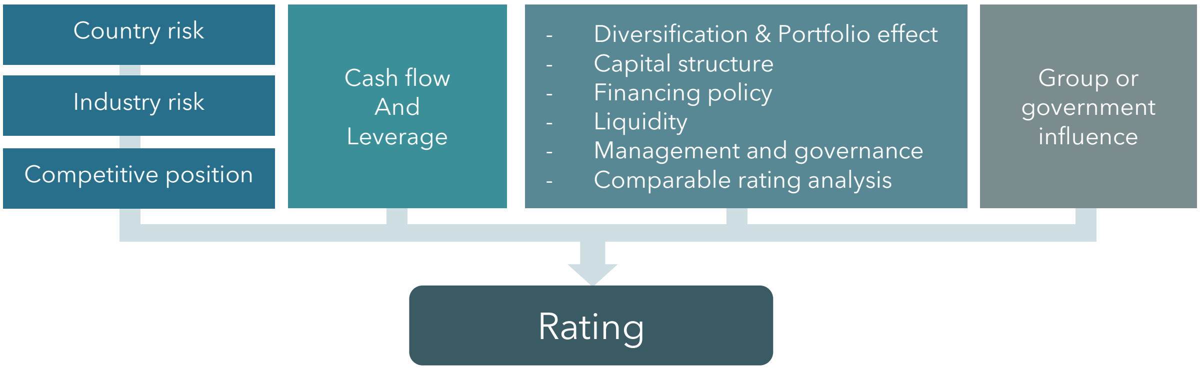


Figure 4.1: Illustrative model of credit rating guide.
Based on model from (S&P Global, n.d.).

4.2 Comparative multiples for energy sources

4.2.1 EROI

Energy return on investment, also known as energy return on invested energy, is a ratio that compares the amount of energy produced to the amount of energy invested (Hayes, n.d.). In the case of a nuclear power plant, this ratio would illustrate how much energy is used to extract materials, construct the plant, and produce usable energy versus how much energy is produced. This means that a ratio above 1 indicates a source that provides more energy than is required to create said energy, while a ratio below 1 indicates a source that loses energy (Hayes, n.d.). Clearly, a higher EROI translates directly into a greater energy supply for society and a more economically viable energy source. Moreover, some researchers on this subject suggest that there is a minimum EROI required to sustain a modern society and promote economic growth. Based on the fact that there is a strong correlation between energy consumption and the human development index (Pahud & de Temmerman, 2022), this statement appears to be reliable. In this paper, an economically viable threshold of 7 is utilized (Hayes, n.d.).

$$EROI = \frac{\sum Energy\ output\ over\ lifetime}{\sum Energy\ input}$$

During the transition from hydrocarbons to renewable energy sources, the use of EROI as a metric has grown in popularity. However, the precise method for calculating EROI varies considerably. While the majority of energy output is straightforward to calculate, the energy input is complex, and it is debatable how far back in the value chain one should look. Moreover, the ratio of EROI would vary significantly depending on the location of production, particularly for VRE (Pahud & de Temmerman, 2022). Putting a solar panel in a location with poor sun conditions, for instance, would naturally reduce the energy output compared to a location with better sun conditions, while the input would likely remain the same. When viewed as a whole, this creates a bias toward VRE sources; however, when viewed from a different angle, it may also provide insight into suitable locations for various energy sources. EROI is unquestionably a controversial ratio, but it provides insight into the efficiency of various energy sources.

4.2.2 LCOE

The levelized cost of energy (LCOE) is the average total cost of building and operating an energy-generating asset per unit of total energy generated over its assumed lifetime. Therefore, it is a theoretical price at which the generated electricity must be sold for the asset to break even at the end of its lifetime (CFI, 2023). It is a common metric for comparing the economic viability of various alternative energy sources. However, the LCOE does not consider non-financial factors such as environmental damage and other social disadvantages. In addition, LCOE only considers production and lifetime costs, ignoring the economic value of flexibility from dispatchable and reliable energy sources relative to VRE as well as costs incurred beyond theoretically isolated production, like system costs in the grid or added costs for storage (Aldersey-Willimas & Rubert, 2019 pp. 170-179). Nevertheless, it provides valuable insight into the potential economic profitability of an energy-generating asset. LCOE can be computed using the following formula (Papapetrou & Kosmidakis, 2022):

$$LCOE = \frac{\sum_{t=0}^{n} \frac{(I_t + M_t)}{(1+r)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+r)^t}}$$

Where:
$t = year$
$n = plant\ life\ time$
$I_t = Investment\ expenditures\ in\ year\ t$
$M_t = The\ running\ cost\ (fixed\ and\ variable) in\ year\ t$
$E_t = Electricity\ generation$
$r = the\ discount\ rate$

5. Data and methodology

“Research methodology is the specific procedures or techniques used to identify, select, process, and analyze information about a topic” (University of the Witwatersrand, n.d.). The research question is complex and requires multiple different analyzes, which in sum will answer the question at hand. With the different nature, complexity, and data availability of the different aspects of our analysis, the methodology will also differ. As a basis we will analyze the current situation and outlook for the energy market, to understand the need for future development. Following that we will analyze comparative differences between different energy sources, with implications on how that will fit in the Norwegian energy mix and Nordic energy markets. For these parts of the analysis, we have collected and analyzed both quantitative and qualitative data to the extent possible within the limitations of the scope of the thesis and the availability of data. In addition, on more complex matters we have seen it as suitable to review existing literature. The last part will be an analysis of the profitability and economic feasibility of a potential investment in nuclear SMR in Norway, using quantitative and qualitative data to model DCF and LCOE.

5.1 Data collection

As part of answering our research question, we must gather data that is both relevant and reliable. When collecting this information, it is common to distinguish between primary and secondary data sources. The former is data collected directly by us in and used to answer our specific question. The latter is data collected by others in a different context and likely with some difference in purpose (Taherdoost, 2021). We have collected both primary and secondary data, where primary data are more prevalent in the financial analysis, and secondary data are more prevalent in the market and comparative analysis.

As part of our data collection efforts, we distinguish between quantitative and qualitative methods of data collection. With quantitative method, the emphasis lies on counting phenomena and mapping their prevalence. Qualitative methods focus on describing events and understanding why things happen rather than just simply occurring (Taherdoost, 2021). Each in its own way contributes to better comprehension and are tools to help us answer our research question. Throughout our analysis, we have used quantitative data showing the phenomenon, complemented by qualitative data to create a better comprehension.

5.2 Overview of collection and analysis of data

To give a comprehensible insight into how data and information are collected, and which data is used, we find it suitable to explain the different types of data which is included in the analysis. This lays the foundation for how analyses are shaped and carried out. Additionally, we can provide insight into the underlying data and assumptions used to get our output. *Table 5.1.* illustrates all the different types of data collected and used in our analysis. In subsequent sections, each type of data will be discussed further regarding its collection and utilization, along with any assumptions or prerequisites required.

	Primary data	Secondary data
Quantitative data	Estimates and analyses	Economic data Financial data Research and reports
Qualitative data	Meetings and conversations	Research and reports Articles

Table 5.1: Descriptive matrix of collected data.

Meetings and conversations

We have had several meetings and conversations with the cooperating company, Norsk Kjernekraft AS (NKK), mainly providing us with qualitative information, especially to better understand the underlying problems and operational aspects of nuclear power production. The purpose of the first meetings was to align ideas and wanted outcome of the cooperation. We also got introduced to a lot of important aspects of the energy problem and how nuclear power could be a suitable alternative for Norway. Furthermore, we discussed possible opportunities, uncertainties, and possible strategies and plans. Additionally, we have gotten answers to uncertainties that arose during the process. Lastly, towards the end of the process, we had a meeting to address some of the uncertainties we had with our models, where we got feedback on some parts of the collection and usage of data, in addition to the reliability of our assumptions and prerequisites.

Estimates and analyses

In addition to meetings and conversations, NKK has provided us with different estimates and analyses, both produced by the company internally and received from suppliers. The content includes technical input in the financial analysis regarding production capacity and volume, fuel usage and costs, time aspects of construction and operations, and investment costs. Additionally, we have received internal cost and profitability analysis which we have used to control our estimates. Lastly, we have received documents containing qualitative information about the relevant SMR, which have been an important basis to understand and be able to model potential projects.

Economic data

We have collected economic data from several sources and on several matters. More specifically, we have collected data on the production, consumption, and demand of both electricity and primary energy, import and export of electricity, and emissions from energy production, for different energy sources and relevant countries. Additionally, we have collected information from data on hydro reservoir levels and data on power output. This data is mostly used in the market analysis, but daily production volumes are also used in the comparative analysis.

Financial data

Financial data have been collected from multiple sources and on multiple topics. Firstly, we have collected power prices for different bidding zones used in the market analysis. Additionally, we have collected exchange rates between different currencies, used in all parts of the analysis to collate data in a comparable currency. To estimate the cost of capital we have collected and analyzed historical data on stock prices and indexes, financial reports to comparable companies, interest rates, credit risk, and tax rates. The tax rate is also used directly in both the DCF and LCOE model. Furthermore, we have collected future electricity price estimates for the Norwegian power zones, used in the market analysis and as a basis to find price scenarios in the financial analysis.

Research and reports

We have used external research, reports, and analyses throughout the analysis, both through collected quantitative data to use directly in our analysis and qualitative data to support and add comprehension to our analysis. The market analysis includes material on the power market, effects of high and volatile power markets, climate plans, economic development and future energy prices, production, and consumption. In the comparative analysis, we have collected and reviewed content on the potential future capacity and feasibility of different energy sources. Furthermore, we have used cost estimates with LCOE for the energy sources, in addition to external costs for the energy system and grid. We have also collected and used literature on environmental and social matters, including safety, environmental impact, and resource usage of different energy sources, in addition to the ease-of-doing-business-rankings for Norway. Lastly, we have used estimates on fuel costs and O&M costs to be used as a basis for scenarios and variables in the financial analysis.

Articles

This includes data and information found in articles, press releases, factsheets, and websites, where we have collected quantitative and qualitative data, used mainly to support and further understand the market and comparative analysis. The content includes an analysis of the power markets, numbers on EU gas imports, EU emission targets, information about the domestic power cables, press releases, and Norwegian laws, all used in the market analysis. In the comparative analysis, we have used different articles, websites, press releases, and court rulings containing qualitative data describing the political situation and other aspects regarding nuclear power and other potential energy sources in Norway, and knowledge and experience with nuclear energy in Norway. In situations where there have been limited research and analysis publicly available, we have collected different ratios and key numbers as substitutes from what we have evaluated as reliable sources.

5.3 Data usage and methodology

To create a comprehensive understanding of the use of data and methodology, we will describe how we have used all data. We use the same segmentations as in the analysis as the methodology also differs from the three parts of the overall analysis. Both the market and comparative analysis is mainly based on external data and analyses which we have reviewed, whereas the financial analysis is independent. For all parts, we have illustrated the data usage with an illustrative model, followed by a description of data usage and methodology.

5.3.1 Market analysis

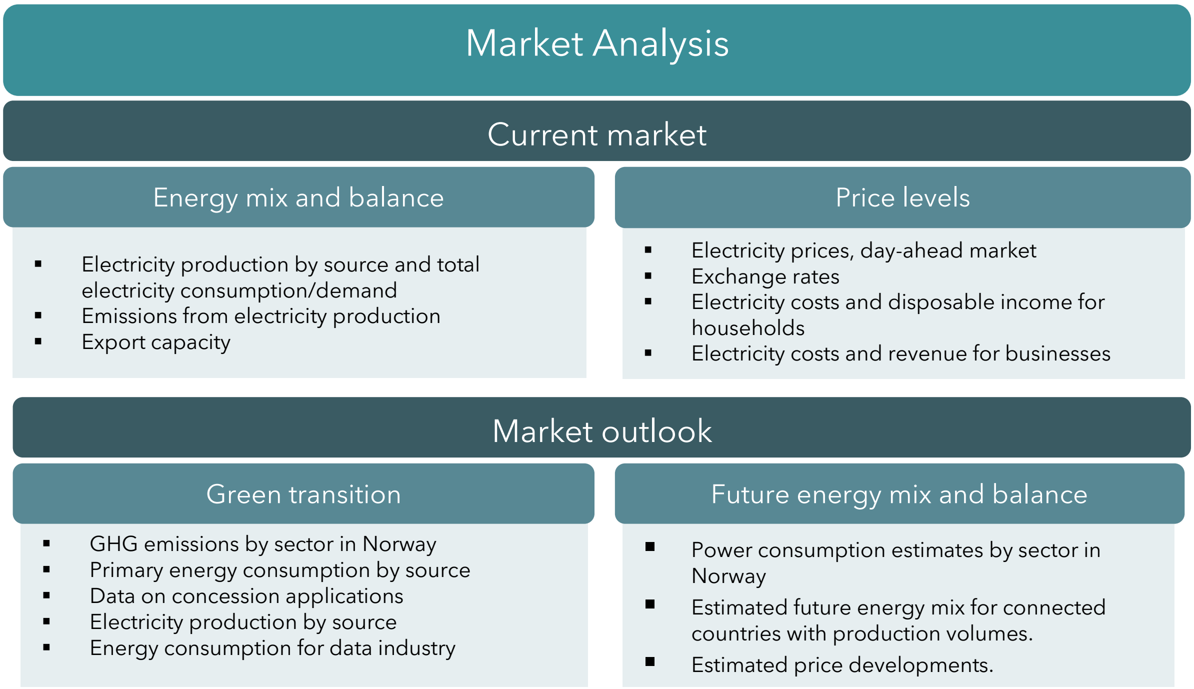


Figure 5.1: Descriptive figure of data usage and methodology for the market analysis

Current markets

In the first section of the current market analysis, we have collected data from Our World in Data, based on collected data from several sources, on production, consumption, demand, net export, and emissions for different energy sources across different countries, for both electricity and primary energy. Additionally, we have collected electricity trade data from a factsheet produced by SSB, based on different statistics also from SSB, both in time series for total numbers and numbers by trade country in 2021. To further add to this, we have gathered information on export capacity and how it has developed over the last years, published by the Norwegian Ministry of Petroleum and Energy through their information site, Energy Facts Norway.

In the second section of the analysis, we have collected price data from the day-ahead market for all price zones in Norway. We have collected hourly prices from the European Network of Transmission System Operators for Electricity (Entso-e). To consolidate all price data in the same currency and time, the monthly average price in øre per KWh, we have collected monthly average exchange rates for relevant currencies from Eurostat and calculated monthly average prices for the daily data from Entso-e. Additionally, we have found effects on private households and businesses from high electricity prices, based on two different analyzes from Statistics Norway (SSB). For the effects on households, we have collected and illustrated the data directly. For the effect on businesses, we hate gathered data on revenue in 2020 and estimated electricity costs for different sectors in 2019, 2020, and 2021 and used that to calculate estimated electricity costs as a percentage of revenue in 2020.

We have collected, organized, filtered out, and consolidated specific data which are used in graphs or tables, placed in the analysis, or explained in text in this paper. Additionally, we have done some calculations, as explained above. The data we have used is mostly historical in combination with some future estimates, which in general, we believe to be less complicated measurements, minimizing the risk of potential measurement errors. The majority of data is collected from reliable sources, where most of it is either directly from or based on governmental organizations or international cooperations. However, we should note that the dataset from Our World in Data collects and consolidates data from multiple sources, including BP, which also collects its data from multiple sources. Additionally, it’s not necessarily straight forward to track where energy comes from once it is in the market, meaning that there are some estimates used in the dataset. Consequentially, the data may have some errors and be less reliable. Moreover, SSB estimates based on 2020 could be somewhat different from the current situation, thereby not being perfectly representable for the current situation. However, in the totality of things, we believe that the potential errors would be minor, and misrepresentations would not significantly affect the conclusions we draw in the analysis, as they are general conclusions less focused on detailed numbers.

Market outlook

In the first section of our market outlook, we define the green transition and its implications. This section is primarily based on data from SSB and Our World in Data. The latter is the data collected and used in the current market section of the market analysis. The second part of our market outlook analysis entails determining how the future energy mix is anticipated to look and which energy sources countries with a direct grid connection to Norway will rely on primarily, in the future. In this paper, our analysis is mainly based on Statnett's "long-term market analysis” and other reports published by both NVE and Statnett. These sources are quite credible; however, as mentioned about the collected data from Our World in Data in an earlier section, there are possibilities of errors and the data being less reliable. Moreover, because Statnett is owned by the Norwegian government, they have an incentive to focus their reports primarily on the energy sources specified by current energy policies.

The collected data has been utilized primarily for the creation of illustrations and graphs to provide insight into the current energy mix and consumption. For instance, data from SSB on GHG emissions by source in Norway has been depicted in an area graph, which has been extrapolated into 2030 and then 2050 with the average annual reduction in emissions required to meet the Paris Agreement's objectives. The information regarding the future energy mix is based on simulations conducted by Statnett. Even though Statnett is a reputable source, the results of these simulations are only estimates and in does not provide a precise picture of future demand, consumption, or prices. Nonetheless, these reports provide an understanding of the potential future of the energy markets.

5.3.2 Comparative analysis

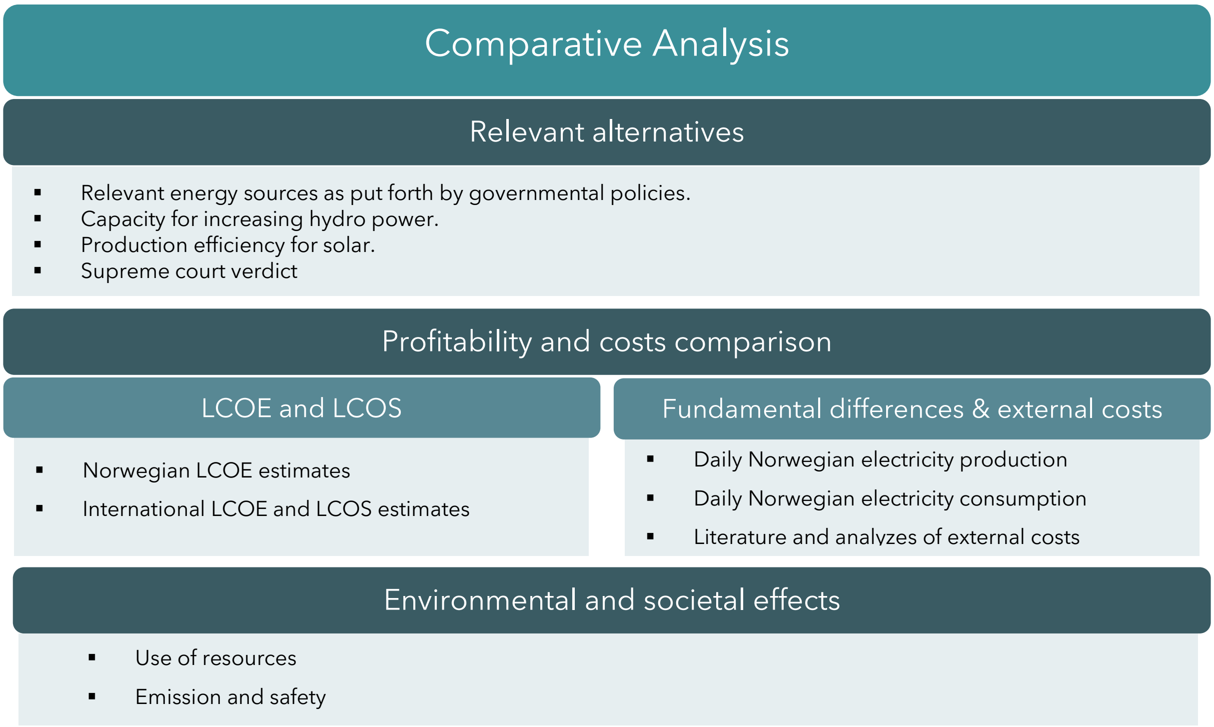


Figure 5.2: Descriptive figure of data usage and methodology for the comparative analysis

Relevant alternatives

We largely based our assumptions on the energi21 strategy report, which outlines six investment areas for environmentally friendly energy sources: hydropower, offshore wind, solar, hydrogen, batteries, and CO2 handling, when determining which alternatives were relevant for nuclear power plant comparisons. In addition, we have used a variety of government and Statnett articles and reports to assess the potential for increased development of each source, where the potential for increased effect and production capacity for hydropower has been visualized using data from an NVE report. The other sources have been discussed using qualitative data and reasoning derived from news articles and reports on their technical capacity.

Profitability and costs comparison

To compare cost levels, we have collected LCOE estimates for Norway from an analysis conducted by NVE, in addition to estimates on LCOE and LCOS, which is. The LCOE of storage, from a more comprehensive and international analysis from the international energy agency (IEA). For the latter, we have calculated the estimates from USD to NOK, using the yearly average USD/NOK for 2021 from the central bank of Norway (Norges Bank). Also, we have excluded extreme datapoints with unusually high deviation from the rest of the sample, this includes two datapoints from Italy on run of river hydro and onshore wind with an LCOE of 409 and 896 USD/MWh respectively. To show the fundamental difference in production levels, we have collected and compiled daily production data for all relevant sources and compared it to daily total consumption, for all Norwegian price zones, from Elhub.

The abovementioned data is collected, organized, filtered, and compiled to get the wanted data, which is then used in graphs in the analysis. Costs estimates from both sources contain a high level of uncertainty and will vary greatly depending on the underlying data and assumptions used in their analysis. To address this problem, we have included comprehensive discussions of the underlying assumptions for the numbers in the analysis, to showcase potential variations. This, combined with using two different reliable sources, creates a strong ground on which to showcase overall trends and comparative connections. The production and consumption data are historical data, measured and calculated by Elhub, which we argue is a reliable source. Elhub is a centralized system for streamlining and measuring the power market and is owned by Statnett, the government-owned Norwegian power grid operator. The data will most likely include some measurement errors, which Elhub also informs. However, since we are most interested in the general variations and trends, we argue that the errors are not significant in the high-level conclusion we draw from the analysis.

Social and environmental effects

To estimate the social and environmental impacts of energy sources, one must conduct a life cycle analysis. This would be a difficult task that would likely require the equivalent of multiple master's theses. Our data for this section of our master's thesis is based on the work of the EU, the UN, and the IEA. EU and UN conducted two distinct analyses to estimate the life cycle environmental impact of various energy sources. Both of these credible sources reach the same conclusion, with comparable estimates for all sources.

In the subsections about safety, emissions, and land use, EU and UN reports are used to illustrate the impact of various sources on these metrics. No adjustments have been made to the data, with the exception of the emission data, which has been extracted from graphs. In these estimates, the data represent the mean of the worst- and best-case scenarios. Therefore, the true average is not presented. Nevertheless, based on these graphs, our average appears comparable to the averages presented in EU and UN reports which are not possible to extract as it is only presented visually. The majority of the data in the section on the use of resources is derived from IEA publications and is used directly to construct graphs illustrating the mineral intensity of various resources. There are no obvious incentives for these three credible sources to present other sources as inferior or superior on these metrics. Consequently, we have no reason to question the accuracy of their estimates.

5.3.3 Financial analysis

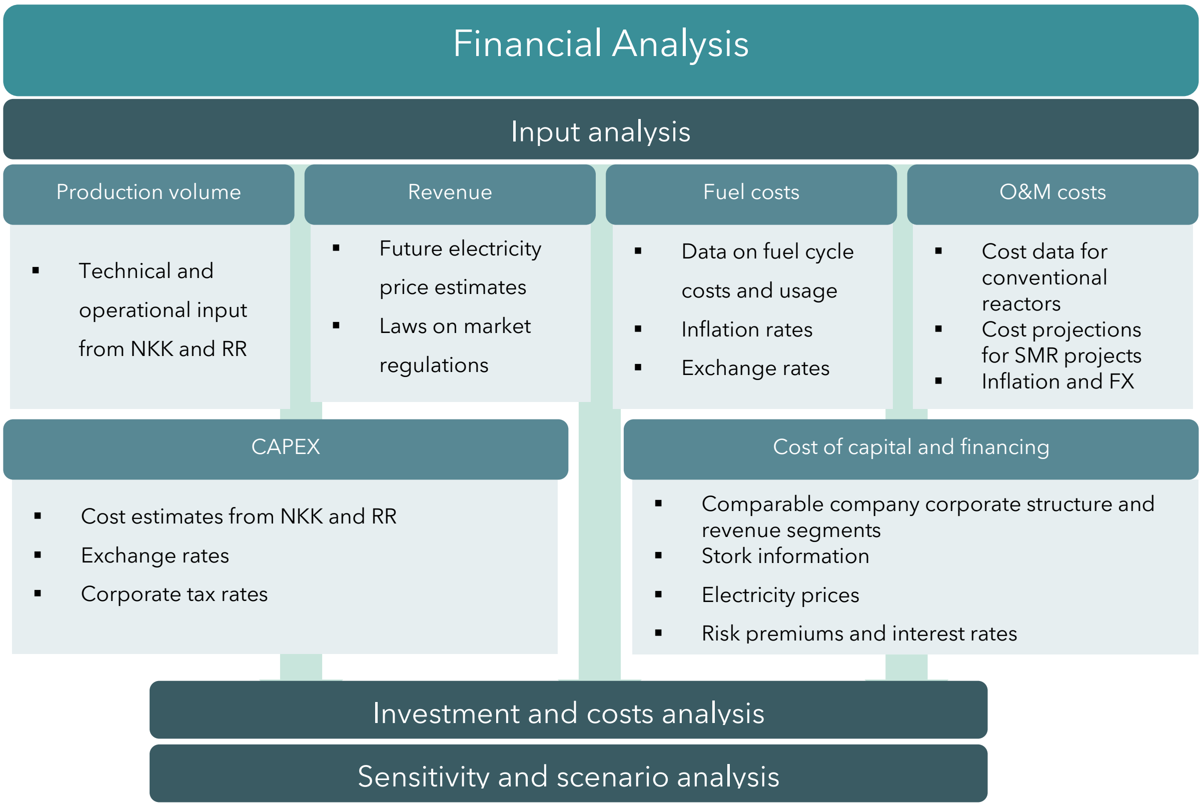


Figure 5.3: Descriptive figure of data usage and methodology for the financial analysis

As illustrated in *Figure 5.3*, the input we use in our models is the foundation of our financial analysis. More specifically, the input is the base of both DCF and LCOE models in the investment and cost analysis, which again is the base of the sensitivity and scenario analysis. Consequentially, the focus has been on the input, which this section will reflect.

Explanation of our models with underlying assumptions and limitations

Before looking at the input, we will go over the general methodology of the models with underlying assumptions, prerequisites, and simplifications, seeing as that is a deciding factor in how we find the input. As the scope and limitations of this thesis state, investment in an SMR project is only a potential possibility several years into the future. Therefore, by limitations, we simplify the analysis by modeling a fictional SMR investment, without taking project-specific elements or the exact time at which the project will start into account.

Besides depreciation and connected tax effect, we ignore accruals and treat all items with a cash-flow effect in the period they accrue. Furthermore, we simplify the model by using fixed average price levels, thereby not capturing risks and uncertainties with inflation, market conditions, and price fluctuations.

Input analysis

Used input, both fixed and variable input are presented in the *Table 5.2* and *5.3* below. This is followed by sections explaining where and how the underlying data is collected, and applied methods to estimate the input, for all categories of input used in our analysis.

Fixed input	Value	*Source and comment*
Thermal capacity	1.358 MWth	*Based on estimates from RR*
Electric capacity	470MWe	*Based on estimates from RR*
Operational lifetime	60 years	*Based on estimates from RR*
Operational hours in a year	8.760 h	*Assumed to have constant operations*
District heat relative to electricity price	100 %	*Assumed based on market regulations*
Required fuel inventory	75 KgU/MWe	*Based on estimates from WNA*
Exchange rate – USD/NOK	10,31	*Based on 2023 avg. from Norges Bank*
Exchange rate – GBP/NOK	12,44	*Based on 2023 avg. from Norges Bank*
Market risk premium	5 %	*Based on reports from PWC and FFN*
Risk-free interest rate	3,10 %	*Based on 10-year government bonds*
Nominal tax rate	22 %	*Based on Regjeringen.no*

Table 5.2: Table of underlying fixed input to models used in the financial analysis.

Variable scenarios	Low case	Base case	High case	*Source and comment*
Capacity factor	85 %	90 %	95 %	*Assumed and calculated based on estimates from RR*
Thermal capacity	0 %	10 %	20 %	*Assumed and calculated based on estimates from NKK and assumptions*
Energy price	50 øre/KWh	70 øre/KWh	80 øre/KWh	*Assumed and calculated based on estimates from Statnett*
Fuel usage factor	2,50 %	2,70 %	3 %	*Assumed and calculated based on estimates from WNA*
Fuel cycle cost	20.000 Kr	25.000 Kr	30.000 Kr	*Assumed and calculated based on estimates from WNA*
O&M costs	13,01 øre/kWh	17,1 øre/kWh	22,7 øre/kWh	*Calculated 25th, median, and 75th percentile based on NEA*
Preparation (CAPEX)	2.000″ Kr	2.250″ Kr	3.000″ Kr	*Assumed and calculated based on supplier target*
Construction (CAPEX)	22.388″ Kr	23.632″ Kr	31.095″ Kr	*Assumed and calculated based on supplier target*
Construction time	3 Years	4 Year	6 Years	*Assumed and calculated based on supplier target*
Down payment structure	All after construction	Equally distributed	All upfront	*Assumed arbitrary down payment structures*
WACC	3,50 %	4,50 %	5,50 %	*Calculations based on financial data from Yahoo Finance and financial reports*

Table 5.3: Underlying variable scenarios to models used in the financial analysis.

Production volume

Production volume consists of two parts. Mainly it is the electricity produced by converting the thermal energy produced from the nuclear reactor, additionally, after this process, there is still excess thermal energy that can be used as district heat. We have received the necessary specifications and estimates from NKK and RR and retrieved public estimates from RR.

As fixed input, we have received thermal and electric capacity for the SMR with an implied conversion rate from thermal to electric energy. Additionally, we have received estimates on capacity factor and excess thermal energy capacity from RR and NKK respectively. To account for uncertainty in both numbers, we have used them as variables with different scenarios. The capacity factor account for downtime with refueling, controlling, maintenance, and similar, and describes the relative amount of electricity produced from the reactor's electric capacity. Excess thermal energy capacity is an estimate of the amount of excess heat available to be sold as a percentage of electricity production. We have shown calculations of annual production volume in the formulas below.

$$\mathit{Electricity\ production}:$$

$$\underbrace{470}_{\mathit{Electrical\ capacity}(MW)} * \underbrace{90\%}_{\mathit{Capacity\ factor}} * \underbrace{8760}_{\mathit{Hours\ in\ a\ year}}$$

$$\mathit{Excess\ thermal\ energy\ production}:$$

$$\underbrace{470}_{\mathit{Electrical\ capacity}(MW)} * \underbrace{90\%}_{\mathit{Capacity\ factor}} * \underbrace{8760}_{\mathit{Hours\ in\ a\ year}} * \underbrace{10\%}_{\substack{\mathit{Excess\ thermal}\\ \mathit{energy\ capcity}}}$$

Revenue

Revenue is simply a product of production volume and the energy price. We use the electricity price estimates to calculate revenue from electricity sold, and as a base for district heat with a factor for electricity price to district heat price from excess heat sold. The factor between electricity price and district heat price is based on laws and regulations in addition to conversations with NKK. The electricity price is based on price prognoses from Statnett, which is also presented in the market analysis. To calculate the price we use high, base, and low scenarios for NO1, NO2, and NO5 to calculate average scenarios for Southern Norway for all future periods. Then, for each scenario, we calculate the average price based on all data points for future periods, rounded up to the nearest 10 øre, to get three fixed average future price scenarios.

Fuel costs

Fuel costs in this case refer to the front-end cycle of fuel used in the nuclear power plant, as the back-end costs are captured in O&M costs, as explained in the section below. The fuel cost is a product of fuel cycle cost and fuel usage which is based on the production volume, as fuel usage is a direct variable cost. We have retrieved estimates from the World Nuclear Association (WNA), as suggested by NKK, used to estimate fuel costs. The numbers retrieved are 27 in fuel usage in tonnes uranium per gigawatt of electric capacity, and 75 tonnes of uranium containment per gigawatt in electric capacity (WNA, 2021). Furthermore, we have retrieved front end fuel cycle cost of 1.663 USD per kg uranium used as fuel (WNA, 2022b). Additionally, we have retrieved yearly US inflation rates from the World Bank (n.d.-b), and monthly average exchange rates from USD to NOK from Norges Bank(n.d.-b).

Fuel usage consists of two parts, the first fuelling of the reactor and fuel usage during production. Both are found by using high-level estimates on fuel containment and fuel usage in traditional nuclear reactors, retrieved from WNA, which is then scaled down to the capacity of the SMR. To find the relative front-end fuel cycle cost for each unit of fuel, we have retrieved high-level estimates from WNA. The numbers retrieved are presented in 2021 USD, which have been adjusted for inflation using US inflation rates from 2021-2023, amounting to an adjustment of around a 13% increase. Additionally, this number is then converted from USD to NOK using the average USD/NOK in 2023, which is 10,31. The calculation of fuel cost for the first fuelling and annual fuel usage is shown in the formulas below.

$$Fuel\ costs\ at\ first\ fuelling:$$

$$\underbrace{75}_{Fuel\ containment\ (KgU\ per\ MWe)} \quad * \quad \underbrace{470}_{Reactor\ capacity\ (MWe)} \quad * \quad \underbrace{25.000}_{Fuel\ cycle\ costs\ (Nok\ per\ KgU)}$$

$$Yearly\ fuel\ costs:$$

$$\underbrace{3.705.480}_{Yearly\ electricity\ production\ (MWh)} \quad * \quad \underbrace{0{,}003}_{Fuel\ usage\ facor\ (KgU\ per\ MWh)} \quad * \quad \underbrace{25.000}_{Fuel\ cycle\ costs\ (Nok\ per\ KgU)}$$

O&M costs

O&M expenses consist of daily production, refurbishment costs, back-end fuel cycle expenses, as well as decommissioning and dismantling costs, which accrue in operational years. We obtained data from the Nuclear Energy Agency's (NEA, 2016; NEA,2022) published reports on several conventional nuclear power plants. Like fuel costs, we use inflation and exchange rates from the World Bank and Norges Bank respectively. We developed three potential scenarios: high, medium, and low. Where the O&M costs for each scenario correspond to the 75th, median, and 25th percentiles, respectively, of the collected data. Accordingly, we are operating with O&M costs of 17,1 øre/KWh.

As stated, we gathered our data for this estimate from two NEA reports. This data was originally presented in 2016 USD and has been adjusted for inflation, which, according to our data, was approximately 26% between 2016 and 2023. In addition, it has been converted from USD to NOK using the average exchange rate in 2023, which is 10,31 USD/NOK. In addition, one of the datasets excluded refurbishment, decommissioning, and dismantling costs, while the other included them. Consequently, we needed to add these costs to obtain total O&M expenses. In addition, to separate the O&M costs into fixed and variable costs, percentages from a projected SMR project that will be operational in 2028 were utilized. This results in approximately 78% fixed costs and 22% variable costs for total O&M expenses. To convert 17,1 øre/KWh to total O&M costs, we use the formula below.

$Operations\ and\ maintance\ cost$:

$$\underbrace{470}_{Electrical\ capacity} * \underbrace{10}_{\frac{\text{Øre}}{KWh}\rightarrow\frac{NOK}{MWh}} * \underbrace{8760}_{Hours\ in\ a\ year} * \underbrace{1 * 78{,}3\%}_{If\ fixed} * \underbrace{21{,}7\%}_{If\ variable} * \underbrace{95\%}_{Capacity\ factor}$$

CAPEX

We've decided to divide the CAPEX into two parts. The first component consists of costs associated with project preparations, such as license applications, impact assessment, design, procurement, and training. The second component of CAPEX is the construction expenses associated with the SMR itself. The cost of project preparation is estimated to be 2,25 billion NOK in year 0. In addition, the estimated cost of the SMR is 2 billion GBP, which, at the average exchange rate for 2023 of 12,44, is equivalent to 23,6 billion NOK. For both of these components, we primarily employ the low, base, and high scenarios.

In addition, numerous past projects experienced construction delays, making the construction duration uncertain. To account for this uncertainty, we employ comparable scenarios to those presented for the various cost scenarios. The base case is four years. Additionally, we employ various down payment structures, which are hypothetical and serve only to illustrate the potential effects of different down payments on the total NPV. Thus, we employ three distinct structures: evenly distributed, all up front, and all after construction.

Cost of Capital & Financing

As described in the section on theoretical review, we have adopted the industry peer approach and collected data on six energy companies that produce nuclear power. Evergy Inc, Xcel Energy, Fortum, Entergy corporation, Electricité de France (EDF), and Excelon corporation are these companies. Due to the minor share of nuclear energy in Evergy and Xcel's energy portfolios, we decided to exclude these from our calculations. To calculate the cost of capital, we retrieved data from Yahoo Finance on stock returns and computed the beta for these companies relative to the MSCI world index. In addition, we have accounted for differences in capital structure, as shown in the theoretical review chapter, using Yahoo Finance market weights. The average beta for the industry was 0,21, resulting in an equity beta for NKK of 0,54. In addition, we used CAPM to calculate the equity cost of capital, using a risk-free interest rate collected from Norges Bank for 10-year government bonds of approximately 3%. Additionally, we employ a 5% premium for market risk, as estimated by PWC and NFF.

To estimate the cost of debt, we utilized the CAPM with a debt beta of 0,2, which corresponds to a credit rating between BB and CCC, obtained from (Berk & Demarzo, 2014, p. 412). This resulted in a cost of debt of approximately 4,1%, which is significantly lower than corporate bonds with a CCC rating in the United States. With our estimated market weights of 50/50 debt and equity for NKK, we calculate our after-tax WACC using the cost of debt and equity and a nominal tax rate of 22%. This amounts to approximately 4,5%.

6. Market analysis

The energy market is a complex and interconnected system that operates under various regulations and requires cooperation among different players. To assess whether it makes sense to invest in SMR technology, one must gain a comprehensive understanding of the market. This chapter will cover key aspects of both the current market and the market outlook, looking at challenges and opportunities, with the perspectives of all relevant stakeholders.

6.1 Current Markets

As a solid foundation, we start by looking at the current state of the relevant markets. This involves assessing countries' energy mix and balance as well as understanding the market prices and volatility with underlying drivers. Therefore, this section seeks to analyze these elements to provide an extensive overview of the current state of Nordic and Northern European electricity markets, with a particular focus on the Norwegian markets.

6.1.1 Energy Mix and balance

Norway

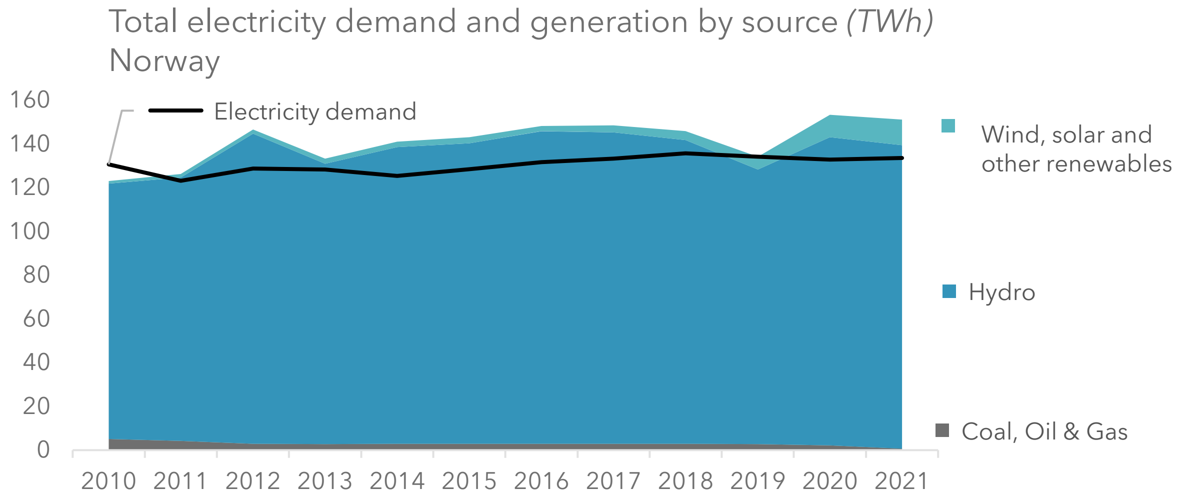


Figure 6.1: Average yearly data on demand and production of electricity in Norway Based on consolidated data retrieved from (Ritchie et al., 2022, Our World in Data-Energy data)

There are some key aspects we can observe from *Figure 6.1*. Firstly, the demand has generally been stable over the last decade, with some increase from 2011. Secondly, supply has been high due to extensive capacity from hydropower plants across the country. For most years the supply is higher than the demand, implying that Norway is a net exporter of electricity. The energy mix has mostly stayed the same, with hydropower almost making up all supply. In addition, we have nearly phased out fossil fuel electricity generation, and have increased non-hydro renewables over the last years, where most of the increase comes from wind energy.

Norway has vast amounts of water resources which they have capitalized on with high electricity production capacity from hydropower plants across the country. This capacity gives Norway sufficient electricity supply to cover internal demand, with dispatchable power, meaning that it can be produced on-demand, bringing balance to the power grid. Furthermore, besides very small proportions of electricity generation from gas and coal, the electricity mix is renewable, with low emissions. To put it into perspective, Norway had an average emission of 26 g of CO2 per KWh. in 2021, which is around 10% of the average emissions from all countries connected to the Norwegian power grid (Ritchie e al., 2022). The low proportion of gas and coal in the electricity mix also mitigates supply and price exposure to the gas and coal market, if we look at Norway in isolation. However, the large proportion of hydro also creates a high exposure to variations in levels of rain and water reservoirs, and the increase in wind energy increases exposure to variations in wind levels.

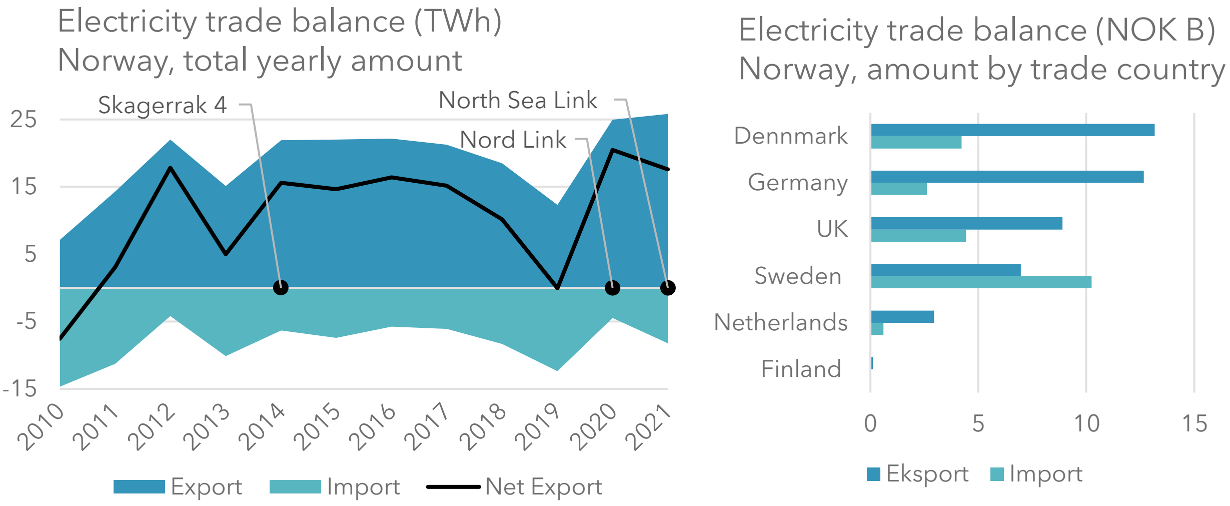


Figure 6.2: Norwegian trade of electricity, by yearly amounts (left side) and by trade partner in 2021 (right side). Based on (SSB, n.d.-b; Energifakta, n.d.-b)

As we can observe from *Figure 6.2*, Norway is a net exporter of electricity most years. The exceptions are in 2010 and 2019. The former was mainly caused by low reservoirs and rain levels combined with cold winter, and problems importing and moving power across zones due to grid limitations (Willumsn et al., 2011). The latter was mainly due to high wind levels in connected countries, which made it possible to import cheap electricity, enabling us to save and build up water reservoirs (NVE, 2020). This reflects uncertainties connected to variations in production and capacity with renewable energy and its dependency on weather conditions.

Export varies from year to year, but over the last decade, Norwegian export of electricity has increased. It is also important to note that the export capacity also has increased significantly, which is a material driver of increased exports. We have increased our export capacity with 3.500 MW. over the last decade, with Skagerrak 4 to Denmark, Nord Link to Germany, and North Sea link to the UK, contributing respectively with 700, 1.400, and 1.400MW (Kampevoll & Lorch-Falch, 2022). The added capacity is a significant increase to the total export capacity of around 9.000 MW at the end of 2021 (Energifakta, n.d.-b), which is around 23% of the installed production capacity of 38.744 MW (Energifakta, n.d.-c). This translates to a theoretical yearly export capacity of around 78 TWh., assuming maximum usage of export capacity every hour of the year. It is by all likelihood impossible to export that large amount, however, it still highlights that we potentially could export a lot of electricity.

In 2021, Denmark and Germany imported the most electricity from Norway, followed by the UK and Sweden. On the contrary, Norway imported most electricity from Sweden, in addition to similar import levels from Denmark, Germany, and the UK in 2021. We should note however that this will vary over time, depending on the demand in the connected countries. Norway is also connected to Finland and Russia, however, levels to Finland are very small, and in 2021 there was no energy exchange with Russia due to the unfortunate war with Ukraine (NTB, 2022), which makes future trade uncertain. Therefore, we exclude Russia in further discussions.

Although Norway for most years produces more electricity than its domestic demand, we need to import electricity. We can't isolate Norway as a market, since the electricity grid is international and electricity is traded across borders through grid connections. Firstly, at times, Norway's electricity production may not be sufficient to meet demand or it may be more profitable to export it than use it domestically. Secondly, due to the grid being highly interconnected with other countries, the exchange of electricity is necessary to maintain grid stability and balance supply and demand. Both factors contribute to price convergence between connected power zones, within certain grid limitations. Therefore, we must understand the Norwegian electricity grid as part of a bigger electricity market with the countries that have direct grid connections.

To put it in perspective, as we can observe from *Figures 6.1* and *6.2*, in 2021 Norway produced about 150 TWh and had a demand of around 130 TWh, while also exporting around 25 TWh, meaning that they had to import to supply the national demand. Since the connected countries don't have excess production over demand, there is a strong demand for Norwegian electricity. It is both profitable for Norwegian power producers to export, and it is necessary for grid stability. This implies that Norway is not self-sufficient in electricity since it needs to export a lot of its production, and therefore needs to import to meet domestic demand.

Connected countries

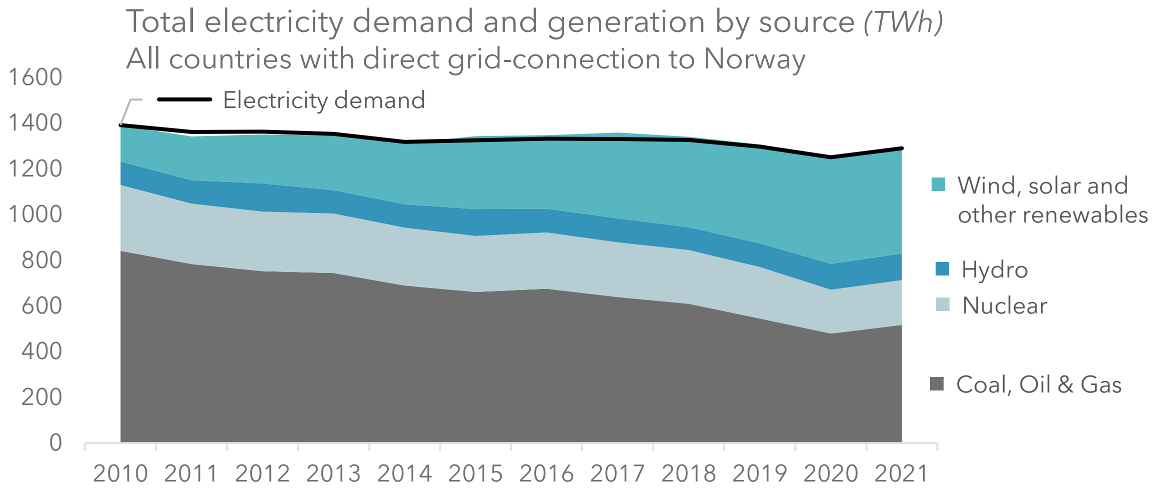


Figure 6.3: Electricity demand and production in connected countries
Based on consolidated data retrieved from
(Ritchie et al., 2022, Our World in Data-Energy data)

Figure 6.3 illustrates the electricity market for all countries that are directly connected to the Norwegian grid. Here we can see a significantly different situation compared to Norway. The electricity demand is much closer to production, and in total for all connected countries it varies from a net export of around 30 TWh to a net import of around 20 TWh in the period from 2010 to 2021. With a total yearly demand of around 1.300-1.400TWh, the net import or export is minuscule and in total these countries just about produce enough electricity. This implies a higher dependency on production from their connected countries, which naturally includes a dependency on Norwegian production.

Moreover, the energy mix differs significantly from Norway. there has been a significant increase in renewable energy. This contributes to decreasing emissions from electricity production, but it also increases the exposure to variations in production levels due to weather variations. This variation needs to be balanced with dispatchable on-demand electricity production. A smaller part of that balance comes from hydro with a stable production amount over the last decade. The same goes for nuclear energy but with some decrease. However, the largest balance comes from a decreasing, but still, large amount of electricity generation from fossil fuels, creating a high exposure to coal and gas markets. Additionally, the production has a higher CO2 intensity, averaging an emission of 236 g of CO2 per KWh in 2021 (Ritchie et al., 2022). A large proportion of this needs to be replaced with green electricity to reach the EU's long-term goal of an economy with net-zero greenhouse gas emissions by 2050 (European Commission, n.d.-a). Although it would be a small proportion, Norway has an opportunity to be part of this green transition by for one exporting more green electricity to its connected countries. Additionally, Norway can contribute by exporting dispatchable on-demand energy to balance variations in renewable energy, which in turn also facilitates further investment and increase of renewable energy production.

6.1.2 Price levels and volatility

Overview

Over the last couple of years, Norwegian electricity markets have experienced very high prices and volatility. In addition, there have been increasing geographical price differences. The recent market development is especially extreme when compared to levels and development in the last decade, with stable and low-price levels in for the entire country. This creates a problem for both households and businesses and illustrates a demand for cheap and reliable electricity.

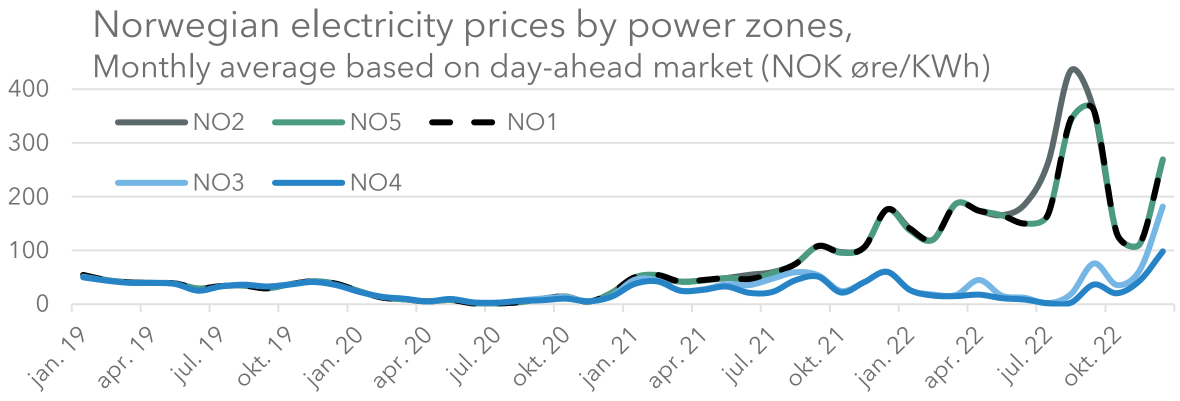


*Figure 6.4: Norwegian electricity prices om 2019-2020.
Based on hourly price data retrieved from (Entso-E, n.d.).*

	(Numbers in Øre/KWh)	NO2	NO5	NO1	NO3	NO4
2019-2020	Avg. monthly price	24	24	24	24	24
	Monthly std. dev.	16	16	16	15	15
2021-2022	Avg. monthly price	144	134	135	42	30
	Monthly std. dev.	100	86	87	34	20

Table 6.1: Norwegian monthly avg. electricity price levels and variations in 2019-2020. Based on hourly data retrieved from (Entso-E, n.d.).

As we can observe from *Figure 6.4* and *Table 6.1*, electricity prices have been extraordinarily high and volatile over the last couple of years. For all power zones in the period 2019-2020, the monthly average electricity price is low, never exceeding 55 øre/KWh and moving close to 0 øre/KWh for shorter periods. Additionally, the price is stable within that interval for all zones in Norway, with a standard deviation between 15 and 16 øre/KWh. Furthermore, there is almost no variation in prices or volatility between the power zones, which implies a balanced power market and a well-functioning power grid. We have collected price data from Nordpool (n.d.) back to 2012 and found similar trends and characteristics as in the period 2019-2020. Low market prices were largely driven by high amounts of rain, implying high reservoir capacity in 2020 (Aanensen, 2021), and high wind levels gave cheap energy from domestic production and import from connected countries combined with a warm winter 2019/20 (NVE, 2020).

Moving forward a couple of years, in the period 2021-2022, we can see a completely different picture for all zones. From *Figure 6.4* and *Table 6.1*, we can observe a rapid increase in prices, volatility, and differences between the zones increased from the start of 2021, before stabilizing somewhat towards the end of 2022. The average monthly prices, for the three most southern power zones in Norway, in the period 2021-2022 are around four times the average monthly prices in the period 2016-2020. Additionally, the standard deviation has seen a similar increase over the same period. A large cause of this is naturally the energy crisis in Europe. The situation is mainly caused by increasing prices of gas and coal, largely driven by the gradual loss of around 40% of the EU's imported natural gas from Russia from the start of 2021 (European Council, 2023). Additionally, increasing CO2 prices contributes to increasing gas and coal prices, and contributes as a driver to the green transition (Statnett, 2023a). We should also add that domestically, levels of water reservoirs have been lower than usual, especially for the end of 2021 and through 2022, this also limits Norway's capacity for hydro production, decreasing domestic supply (NVE, n.d.-b).

There is a clear distinction between the northern zones, NO4 and NO3, and the southern zones, NO1, NO2, and NO5. The former sees some effect, but not nearly to the extent that is seen in the latter. A key reason for the domestic difference is that the southern zones are affected by the energy crisis in Europe through its connection with NO2, and we see that the connected zones to NO1 and NO5 again are affected by the increase in NO2.

The economic effect of current markets

The extreme increase in price and volatility of electricity prices naturally has a significant economic effect on households and businesses. We should note, however, that we do not suggest the addition of SMR as a short-term solution to the current problems, seeing as it would be added energy supply several years into the future. Even so, the current situation highlights the potential risk of an unbalanced energy market. We argue that this risk with connected consequences is relevant currently, and in the decades to come, because of current and future challenges in balancing the energy market, as pointed out in this section, and as we will highlight even further in the next section.

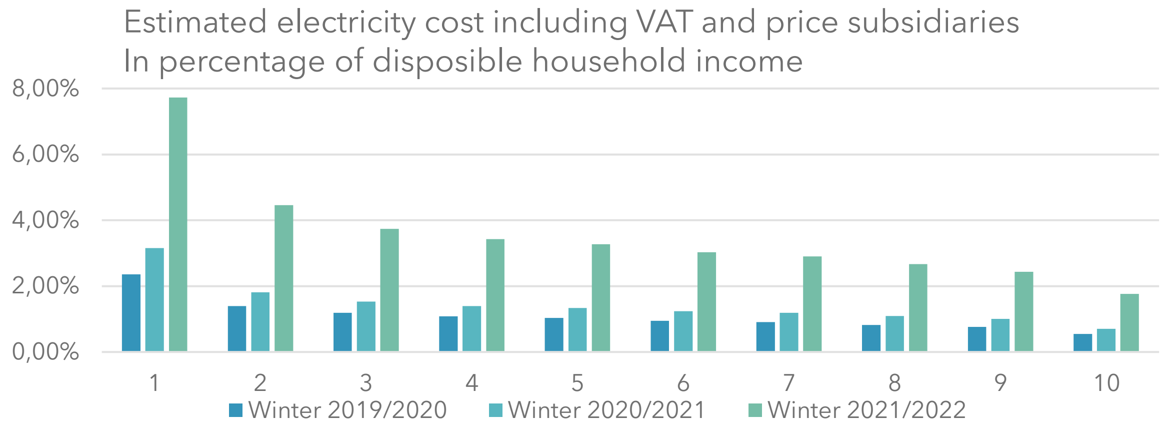


Figure 6.5: Economic effect of high electricity prices on Norwegian households
Based on data retrieved from (Halvorsen, 2022, (SSB))

As illustrated in *Figure 6.5*, despite price subsidies, there is a high increase in electricity costs for Norwegian households. The effects are especially challenging for the lower income households, having a considerably higher increase in electricity costs relative to disposable income. We should also bear in mind that lower-income households, that experience the most effects, already have a more limited budget and financial flexibility. There is a material effect for all households, and when observing the further increase in prices in the winter of 2022/2023, it is natural to assume that these challenges have remained, if not further increased.

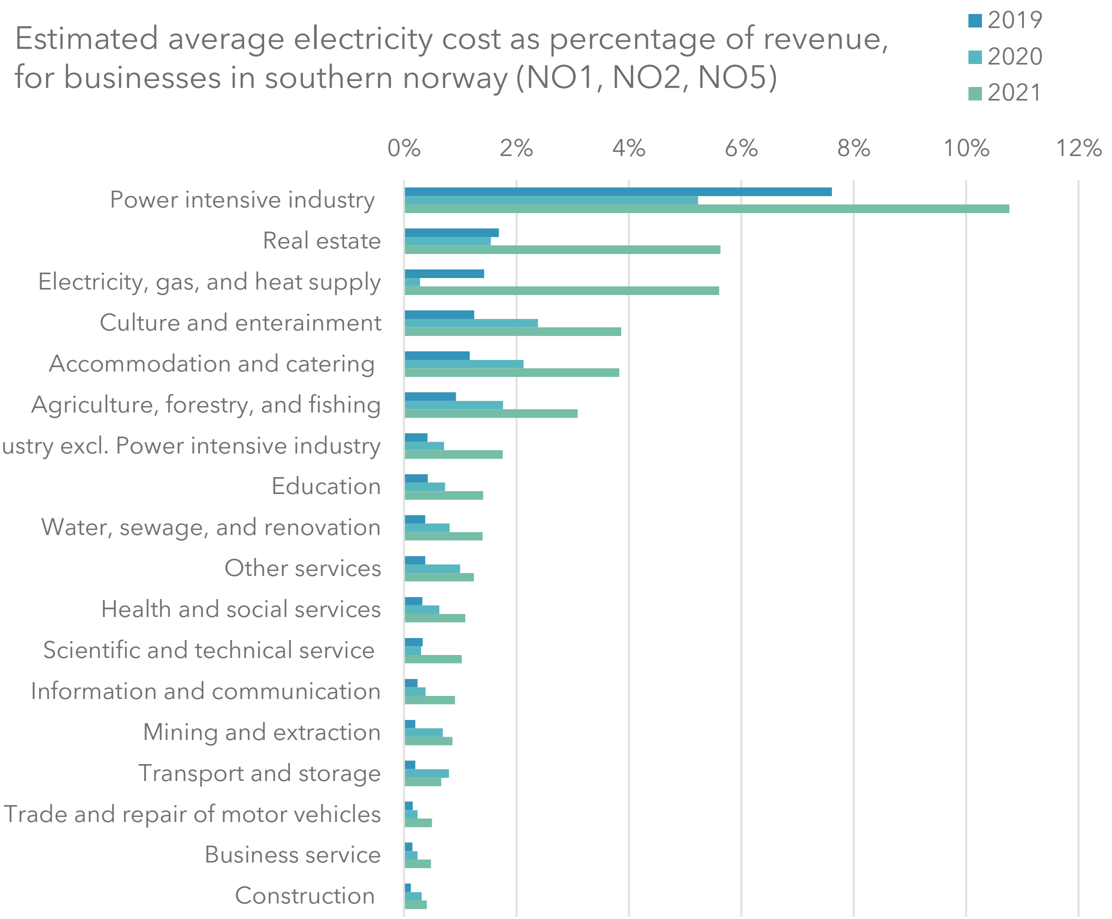


Figure 6.6: Economic effect of high electricity prices on Norwegian business sectors. Based on data retrieved from (Eika, 2022 (SSB))

Besides households, businesses make up the majority of Norwegian electricity consumption, where especially power-intensive industry contributes to the total consumption (SSB, n.d.-a). *Figure 6.6* illustrates estimates of how electricity costs have changed relative to revenue for different sectors. For all businesses, the estimated electricity cost is almost 7% in 2021, compared to around 4,5% and 3,5% in 2019 and 2020 respectively (Eika, 2022). However, as we can observe there is a large variation across sectors, and within sectors which the figure does not illustrate. For many of the sectors, the change is relatively small since only a small proportion of their cost base is electricity. However, in many sectors, the cost increases dramatically and the estimates show that electricity costs become dangerously large relative to revenue.

The effects of current market prices have illustrated a serious problem for both households and businesses, especially for lower-income households and businesses with high electricity intensity. We find it reasonable to argue that current levels are not sustainable over time. We should also note that we have not explicitly investigated variations within a year, which as shown in *Table 6.1* are large. Consequentially, simultaneously as extreme electricity price increases, electricity costs become largely unpredictable, making it difficult to manage costs for both households and businesses. Conclusively, this implies a need for cheap and reliable electricity. We are not suggesting that one or a few SMRs alone could solve the short-term problems of high prices and volatility, but it could be a positive contribution to a much larger effort in solving the long-term energy transition to a sustainable energy mix.

6.2 Market outlook

Now that we have highlighted the current state of the energy markets, we need to look at the market outlooks for the future. As a reminder, investments in energy addition are long-term projects, especially for nuclear power with a lifetime of several decades. The timeframe of such investment needs to be accordingly long-term. Therefore, this section seeks to give insight into the future of the relevant energy markets. Especially, with a focus on how current challenges possibly could evolve in the future, in combination with how other aspects might represent new challenges and opportunities.

6.2.1 Green transition

We can assign two properties to the green transition. The first element of the transition to sustainability is the reduction of greenhouse gas emissions (TGS, 2023,0:47:30). The aspect of emission reduction can be subdivided further into three categories: the first is electrification, or the transition from hydrocarbons to electricity use. The second aspect is the transition from mainly producing electricity with fossil fuels to primarily producing electricity with renewable energy sources. Thirdly, emission reduction includes energy-efficient measures such as technological advancement and home insulation. The green transition also necessitates the addition of new energy (TGS, 2023,0:47:30). This property entails population growth, economic development, and technological progress, all of which will increase the demand for clean energy.

Emission reduction

Reducing greenhouse gas emissions is essential for limiting global warming; therefore, the European Union has set a goal of reducing GHG emissions by 55% compared to 1990 levels by 2030 and by 95% by 2050. The Norwegian government has vowed to adhere to these objectives and stipulated them in the Climate Change Act (Climate Change Act, 2021, sections 3 & 4).

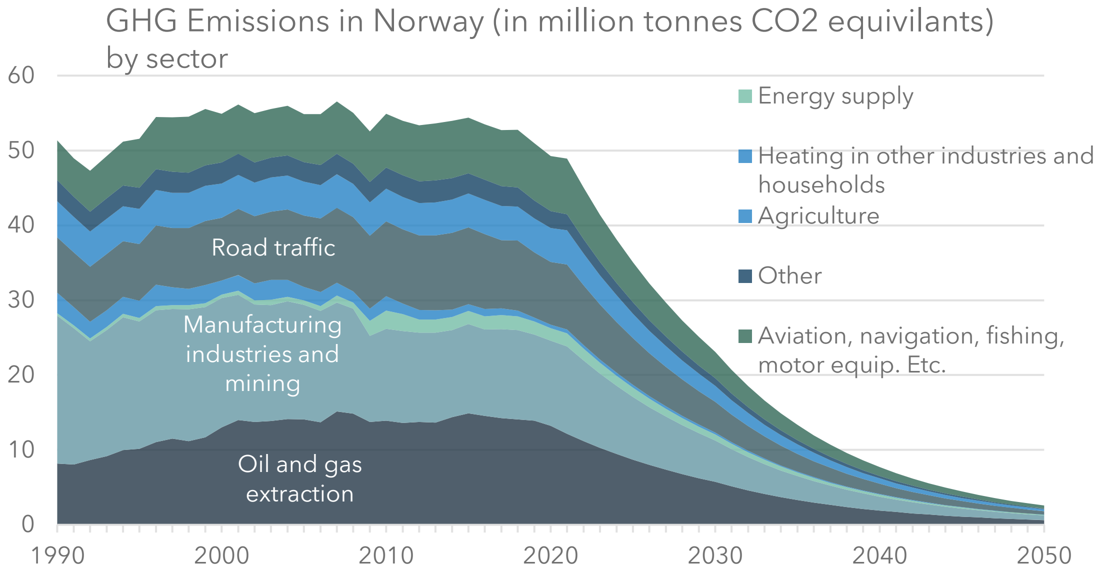


Figure 6.7: GHG emissions from Norwegian businesses. Based on (SSB, n.d.-c)

Although climate concerns have been on the agenda for many years and that Norway has pledged to contribute to the reduction of GHG emissions, the reduction has been minimal, as shown in *Figure 6.7*. As of 2021, greenhouse gas emissions have only decreased by 4,7% compared to 1990 levels. In order to reach the 2030 objectives, the reduction rate must be approximately 8% per year, and 10,4% per year after 2030 to reach the 2050 objectives. Clearly, Norway must undergo a massive restructuring to achieve its goals, and this restructuring will be the most essential factor for the development in Norwegian Power consumption (Christiansen et al., 2023, p. 9).

Electrification

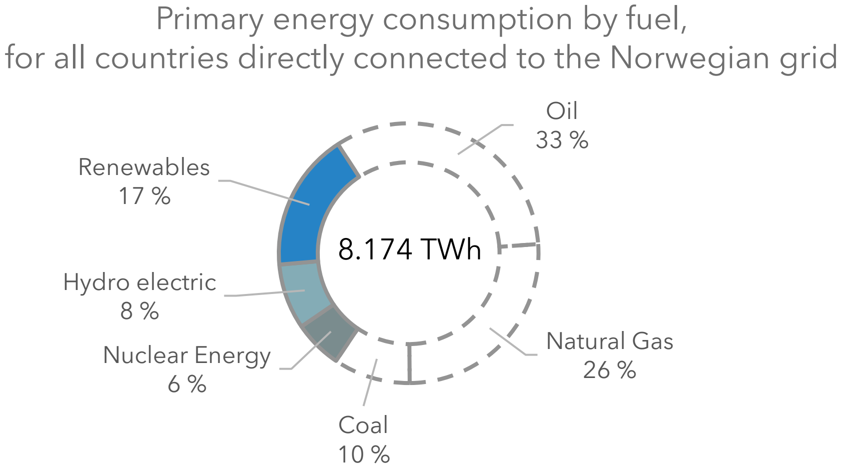


Figure 6.8:Primary energy consumption by fuel in connected countries. Based on (Ritchie et al., 2022, Our World in Data - Energy data)

When examining the aspect of emission reduction, the current energy mix provides valuable insight into the requirements for renewable energy. As shown in *Figure 6.8*, the current energy balance in the countries with a direct grid connection to Norway is dominated by hydrocarbons. This is due to the dependence on natural gas and coal-fired power plants, as well as the dependence of the transportation sector and energy-intensive industries on hydrocarbons. The total energy consumption in these nations is 8.174 TWh, of which 5.608 comes from fossil fuels. As previously stated, there are numerous elements of emission reduction, however, if we presume an emission-free energy sector in these countries by 2050, approximately 69% of the energy consumed by Norway and the connected countries will have to be replaced or otherwise reduced in the future.

Even though electrification is the chosen solution to the climate crisis, it is unrealistic to replace all energy as depicted in *Figure 6.8*. Large portions of the transportation sector, including shipping, and energy-intensive industries cannot replace hydrocarbons with electricity directly. However, carbon capture and the use of electricity to produce hydrogen could be potential solutions. Additionally, the transition from hydrocarbons to electricity reduces energy consumption as a result of increased efficiency (Statnett, 2019, p. 13). For instance, the efficiency of electric vehicles, allows them to use approximately half the energy required by a car powered by fossil fuels (NRDC, 2019). In an analysis conducted by Statnett, it was determined that replacing Norway's current use of fossil fuels would increase electricity consumption by 30 to 50 TWh, with an additional 40 TWh if the production of green hydrogen via electrolysis becomes feasible (Statnett, 2019, p. 13).

Electricity production

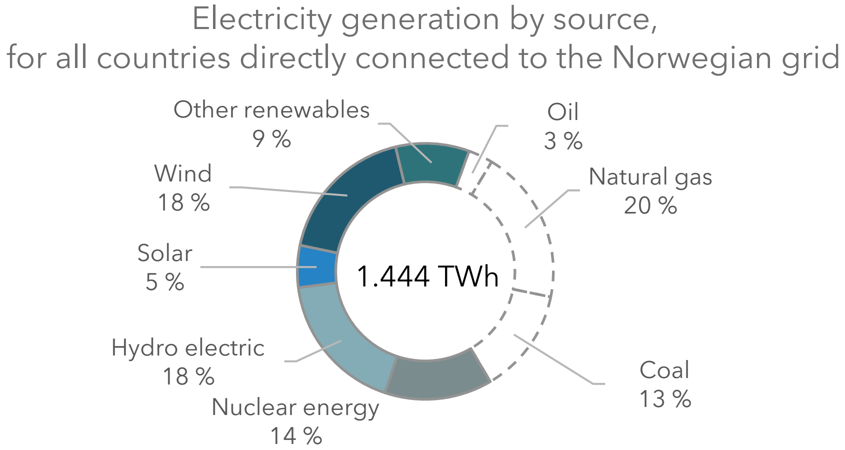


Figure 6.9: Electricity production by source in connected countries. Based on (Ritchie et al., 2022, Our World in Data - Energy data)

The second component of emission reduction is the shift in electricity production. As we can observe from *Figure 6.10*, in 2021, the total electricity production in Norway and the other connected countries was approximately 1.400 TWh. For electrification to have a significant impact on emission reduction, however, electricity must be generated from emission-free sources. Therefore, all electricity generated from hydrocarbons must be generated from alternative sources. This necessitates approximately 518 TWh of additional clean energy for these nations. However, as pointed out in a current market section, if we isolate Norway, virtually all national demand is supplied by renewable energy, predominantly hydro. This is essentially true for the remaining Nordic countries, including Sweden, which generates a great deal of emission-free electricity from hydro and nuclear power plants. On the other hand, Finland and Denmark continue to produce a considerable quantity of electricity using hydrocarbons, but they are relatively minor electricity producers, ensuring that the Nordic countries predominantly produce renewable electricity. However, due to connections with the United Kingdom, Germany, and the Netherlands, which produce more than twice as much electricity as the Nordics, approximately 36% of current electricity production still requires a transition within these countries.

Energy addition

As populations expand, economies develop, and technologies advance, it is natural for energy demand to increase. Consequentially, to balance the market, we are reliant on increasing the supply of energy. This is what we mean when we refer to the addition of energy. The industry that manufactures renewable energy infrastructure, such as solar panels and wind turbines, is one of these demand-increasing sources. Moreover, due to the variable nature of these weather-dependent energy sources, there is a growing demand for energy storage, resulting in an enormous need for battery and hydrogen production. In addition, as digitalization advances, the demand for data storage increases. As a result, the data center industry becomes significant, consuming between 220 and 320 TWh in 2021. This does not include cryptocurrency mining, which alone consumed between 100 and 140 TWh (Kamiya, 2022). These are some of the elements that will require more energy in the future, undoubtedly, new energy consumers will play a significant role in increasing the demand.

The quantity of new demand is contingent on several factors, but especially the availability of stable, low-cost energy. Consequently, if Norway can produce large quantities of electricity, resulting in lower electricity prices, more new or existing industries seeking to reduce emissions through electrification will likely locate here. In recent years, electricity prices have skyrocketed partially due to the green transition, which will be a key driver in the future. Because of its excess capacity, Norway has been able to maintain slightly lower prices than other European nations. This has created favorable conditions for the emergence of new industries in Norway. In the past four years, applications for approximately 30 GW of new consumption capacity have been submitted, amounting to approximately 150-200 TWh annually. The majority of this new capacity is located in price zone NO2 in southern Norway. Due to grid capacities, however, only 6,5 GW of the requested capacity has been reserved (Christiansen et al., 2023, pp. 11-12).

6.2.2 Future energy markets

Development in consumption and energy mix

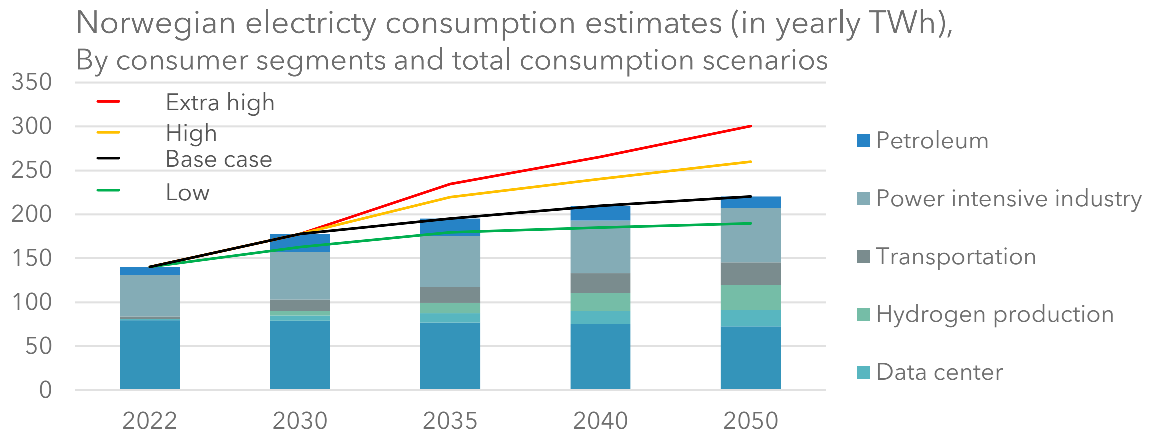


Figure 6.10: Future estimates on Norwegian electricity consumption. Based on (Statnett, 2023c, Excel file)

The consumption growth is primarily driven by energy addition and electrification. Statnett operates under four scenarios: high, extra high, base, and low, all of which are dependent on the available electricity price on the market, which is in turn are dependent on the production capacity. These scenarios can be seen in *Figure 6.11*. In the base scenario, it is assumed that both bottom-fixed and floating offshore wind farms contribute to meeting the demand for electricity alongside hydropower. Furthermore, numerous energy-saving measures, such as the renovation of older buildings and stricter building codes, will contribute to the reduction of future consumption. In addition, increased use of district heating will reduce consumption peaks. Lastly, the use of gas-produced hydrogen, also known as blue hydrogen, meets the energy demand in areas where electrification is inappropriate. In this scenario, Norway is projected to experience a deficit in its energy balance by 2027, which will be eliminated by 2035, and its annual energy consumption will reach 220 TWh by 2050 (Christiansen et al., 2023, p. 32). In the high scenario, offshore wind is implemented on a large scale, laying the groundwork for rapid consumption growth. In the Extra high scenario, the Norwegian government's offshore wind goal of 30 GW new effect by 2040 is fully realized. In addition, the high cases involve an increase in population growth as well as the production and export of hydrogen on a large scale (Christiansen et al., 2023, pp. 34-35). In the low scenario, offshore wind is constrained, and emission reduction is prioritized over new consumption, small-scale electrification, and the issuance of new permits for oil and gas exploration. In addition, this scenario assumes a significant emphasis on energy conservation measures, reducing future energy demand (Christiansen et al., 2023, p. 33).

The green transition in Norway cannot be viewed in isolation from the larger European market. A significant portion of the increase in domestic Norwegian power consumption is attributable to European industry, which will be powered by Norwegian energy in the future if Norwegian power production is sufficiently developed. This creates enormous opportunities for Norway, and even though the extra high scenario assumes a 300 TWh electricity demand in 2050, the future electricity demand could be viewed as virtually infinite (Christiansen et al., 2023, p. 12)

Energy mix

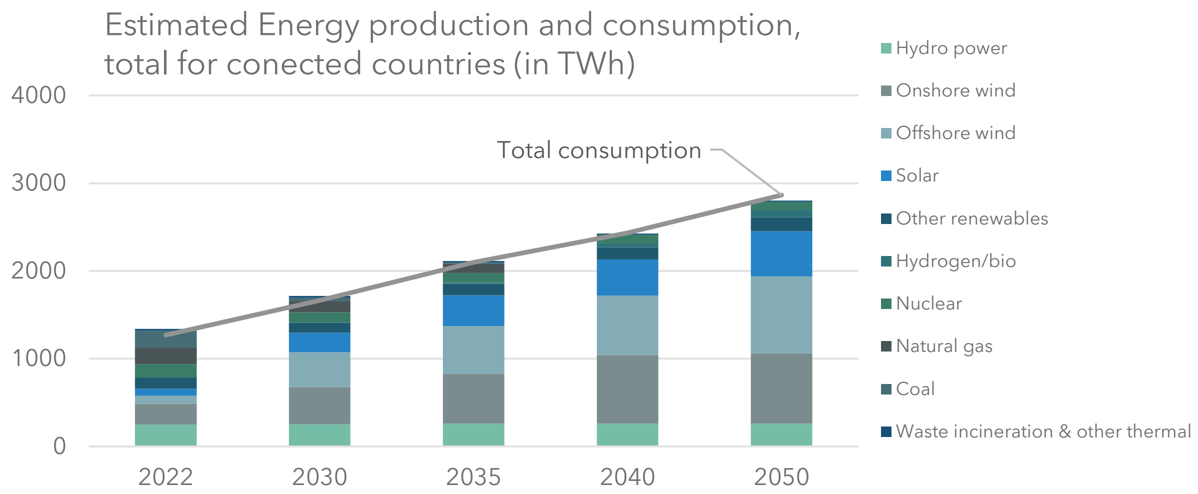


Figure 6.11: Future estimates on energy production and consumption – Norway and connected countries
Based on (Statnett, 2023c, Excel file)

Every energy consumer desires the freedom to consume at their convenience and at a low cost, they desire energy security. Here, the term energy mix becomes significant. The fortunate availability of hydropower in Norway is insufficient to meet future demand, so the Norwegian government and other connected countries have decided to invest heavily in the development of solar power and offshore and onshore wind farms. This is illustrated in *Figure 6.12*. These sources are referred to as variable renewable energy (VRE) because they depend on the weather. According to Statnett´s scenarios, approximately 78% of the production in the connected countries will come from these sources in 2050. Isolated, this could result in periods of enormous production that significantly exceed the transmission capacity of the grid and any momentary consumer demand, forcing the system operator to disconnect production from the power grid (Statnett, 2021, p. 17). For these sources to be viable alternatives that provide flexibility, they must be paired with energy storage capacities. Whereas the alternatives envisioned are batteries, pumped hydropower plants and hydrogen production via electrolysis (Gunnerød et al., 2023, pp. 23-27).

We argue that basing the energy mix on the previously mentioned VRE scale will, isolated, compromise energy security. To put it in perspective, if we assume a 55% capacity factor, 30 GW of offshore wind in the North Sea would result in a production of approximately 140 TWh annually, exceeding the current annual demand. Nevertheless, this does not account for the instantaneous power demand. By 2030, Norway's peak demand for instantaneous electricity is projected to reach 32 GWh, up from 25 GWh in 2022 (Statnett, 2022, p. 6). While momentary winter production will increase by only 0,6 GW over the same period due to the negative correlation between wind energy production and temperature in Norway (Buvik, et al., 2022; Gunnerød, 2023). It is then problematic that such consumption peaks are typically observed during the winter, as we will show later.

Moreover, the aforementioned deficit may be impossible or prohibitively expensive to cover through imports due to the transition of the rest of Europe to VRE. Many of the countries directly connected to Norway are planning to build large wind farms in the North Sea (Henley, 2023), where there is a strong correlation in wind energy production between the different areas (Birkeland et al., 2023). In addition, weather data has revealed a significant geographical correlation between solar and wind power production in Europe, meaning that high exposure to these two sources will result in extremely high production during some periods and extremely low production during others (Statnett, 2022). To counteract some of these issues Norway could build more offshore wind further north. However, in the North of Norway, there is already a surplus of electricity (Fornybar Norge, n.d.), resulting in the need for this production to be transmitted to other areas, on an already worn and limited transmission grid and exposing it to transmission grid losses.

Furthermore, it is not inconceivable that a lack of energy diversification will have a negative effect on the green transition. This could be seen in the primary energy consumption in 2021 when production from VRE decreased compared to 2020 and Russian gas was removed from the market, resulting in an increase in the use of hydrocarbons, particularly coal, to produce electricity. Demonstrating that we are unwilling to compromise energy security for the green transition. For the green transition to be truly realized, we can’t ignore grid capabilities and limitations, and in the process, expose ourselves to highly volatile markets. Therefore, we argue that a diversified portfolio of emission-free, reliable energy sources is required, not just more variable renewable energy as suggested by current policies.

The future will require both more dispatchable power and large-scale energy storage capacities, for which numerous alternatives have been proposed. However, these alternatives are not yet efficient enough, and technological advancement is necessary to both increase their efficiency and reduce their costs (Statnett, 2023, pp. 24-27). Since 2010, the average range capabilities of electric vehicles have increased by approximately 170% as a result of improvements in battery capacity (IEA, 2022). However, batteries are still inadequate for long-distance travel. Many believe that hydrogen will play a role in future energy consumption for this reason. During periods of peak VRE production, hydrogen will be produced, thereby storing energy. The issue with producing hydrogen via electrolysis and the solution of pumped hydro plants is that more energy is required than is returned, resulting in an energy loss (Horne & Hole, 2019, p. 2).

Price and volatility

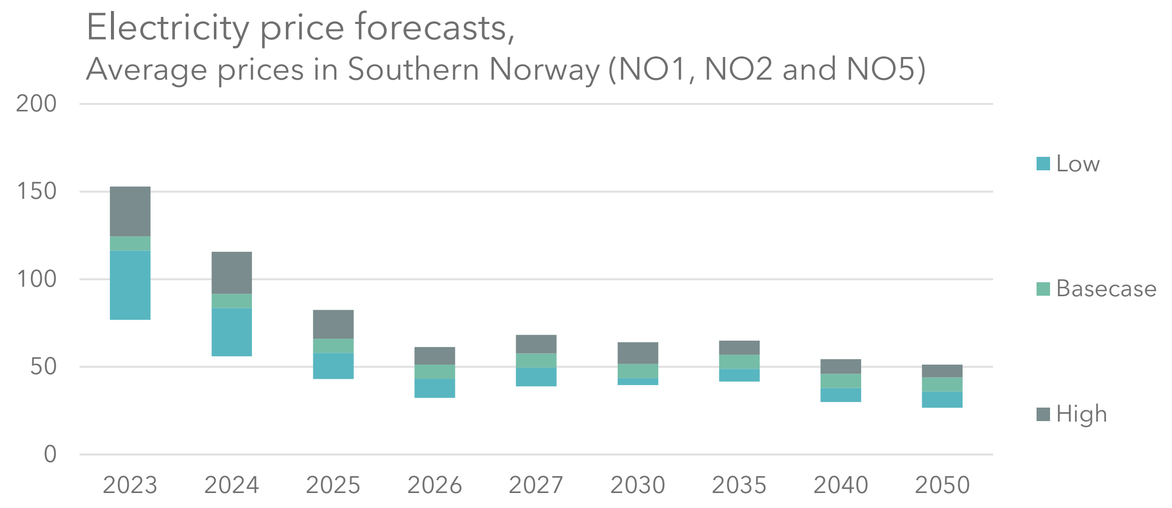


Figure 6.12: Electricity price forecast in southern Norway.
Based on (Statnett, 2023 c & d Excel files)

Multiple factors determine the price of electricity. We are fortunate in Norway to have a large hydro capacity, which provides us with excess electricity. As we have seen, however, this surplus is projected to decline and even become a deficit by 2027. This will, isolated, result in an increased price of electricity. Nonetheless, it is anticipated that electricity prices will decline and become more uniform across Norway's various price zones. This is due to the normalization of gas prices in the short term. In addition, the decreasing availability and rising cost of CO2 quotas, as well as the shift away from hydrocarbons, will reduce the correlation between gas and electricity, causing the price of electricity to be determined more by the cost of renewable energy production and energy storage (Gunnerød et al., 2022, p. 45). This is depicted in *Figure 6.13*, where the estimated price declines rapidly between now and 2026.

We should note, however, that the illustrated price prognoses in *Figure 6.13*, do not capture hourly, daily, and monthly variations, which is an important aspect for the consumers. Increasing VRE dependability will result in greater price volatility. Due to the zero marginal cost and the expansive development plans, electricity prices may fluctuate between close to 0 and up to 150 EUR/MWh during periods of low production (Gunnerød et al., 2023, p.48). In this manner, the development plans are virtually more susceptible to market variation. Moreover, as a result of the subsidies, a significant portion of the production will be conducted at significantly higher development costs than are economically viable given the market price that VRE creates. These government subsidies, which are likely to be financed through taxation, may be viewed as a reallocation of consumer expenditures rather than a reduction. On the one hand, the price of electricity is decreased, while on the other, taxes are raised to fund the development plans. Moreover, a low average price is deceptively positive, as the high variation is detrimental to consumers, such as power-intensive industries, and will likely make it less desirable for new businesses to locate here.

7. Comparative analysis of energy sources

From the last sections, we have established a substantial demand for increasing the production capacity of electricity over the next decades. More specifically, we need clean energy to keep up and contribute to the green transition, in addition to cheap and reliable energy to cater to consumer needs. With the challenge laid out, this brings us to the question of how to achieve the goal of added energy production. In this section, we will present a comparative analysis of the different energy sources, particularly focused on relevant alternatives to the future Norwegian energy mix.

We should note however that the energy sources are not mutually exclusive. On the contrary, they should be seen in connection with each other as a portfolio of energy sources that could make up the Norwegian energy mix. Therefore, the goal is not to establish the most desired energy source, but rather highlight and understand fundamental differences between the different alternatives. In doing so, we can better understand how nuclear energy potentially could fit into the energy mix, which in turn lays a good foundation for analyzing the economic and financial aspects of a potential investment.

7.1 Relevant alternatives for the Norwegian energy mix

We have previously discussed the anticipated future energy mix in Norway. In this section, we will examine in greater detail the relevant sources and the reasons why certain alternatives are more important for development than others. As clearly stated in earlier chapters, we already have a substantial amount of hydropower, which could potentially be increased. Other options include solar, onshore and offshore wind, and, as we argue, SMR nuclear power plants. In addition, the introduction of a substantial amount of VRE will result in a significant increase in storage opportunities, especially such as batteries and hydrogen.

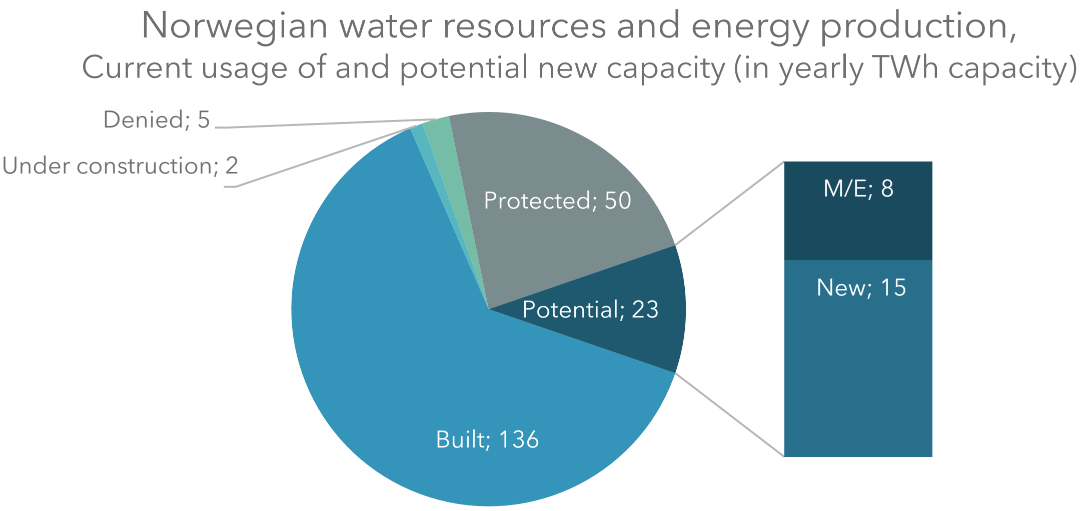


Figure 7.1: Norwegian water resources and energy production. Based on (Henriksen et al., 2020)

We are extremely fortunate in Norway to have access to clean, stable energy through our hydropower capabilities, which have a theoretical capacity of around 600 TWh. However, when both technical and economic factors are considered, the true capacity is approximately 216 TWh (Henriksen et al., 2020, p. 1). Nevertheless, as shown in *Figure 7.1*, roughly 50 TWh applies to protected waterways and 136 TWh has already been constructed, indicating that the potential for increased capacity is approximately 23 TWh. Where 8 TWh can be increased by the modernization and expansion of existing power plants, while 15 TWh could be generated by potential new power plants. Compared to the presented power consumption scenarios in which new energy consumption ranges from 40 to 50 TWh, it is apparent that new hydropower could play a significant role, but it is not sufficient for future power demand.

With solar power, there is a large potential to install high amounts of capacity. In an analysis done by Multiconsult they find a yearly production potential of 66 TWh on rooftops alone, and 199 TWh if we also include larger areas for utility solar plants (Mørk, 2022). However, as we will show later in this section, the output of solar power is highly variable and is mainly prevalent in the summer, because of long winters with limited sun in Norway. This, along with other factors, causes the average efficiency of solar panels to range between 16 and 20% (Otovo, 2023), which again makes it harder to achieve economically viable production, limiting the potential for solar power. Despite this, many homes and larger buildings have solar panels installed on their roofs, creating the potential for solar panels to play a significant role in the future energy mix.

It is anticipated that the majority of new electricity production will come from wind. However, as of now, only six wind power concessions are pending at NVE, which could produce 8-10 TWh. Four of these are located in Finnmark, where there is insufficient local demand, resulting in an excess of electricity with limited transmission capacity to other regions. Moreover, these concessions are for Sami reindeer herding areas (Finstad & Berglihn, 2023). This makes it less likely that they will be approved considering the recent supreme court ruling that the granted concession for the largest wind power plant in Europe (Statkraft, n.d.-b), Fosen Vind DA, was invalidated due to its violation of Sami rights (Norges Høysterett, 2021). Furthermore, according to NVE, there are not enough applications to meet the energy commission's 2030 goal (Finstad & Berglihn, 2023).

Since the expansion of onshore wind is limited, the government is heavily committed to facilitating the development of offshore wind (Regjeringen.no, 2022). For offshore wind, there are essentially two options: bottom fixed or floating, with bottom fixed being the more prevalent option. However, due to depth and bottom conditions, it is difficult or impossible to construct bottom-fixed wind turbines along the Norwegian continental shelf, necessitating the use of floating wind turbines for at least half of the planned offshore wind power development (Østenby, 2019, p. 2). This alternative is currently technologically immature and prohibitively expensive to build due to its need to withstand potentially severe weather conditions. Therefore, it requires subsidies from the government (Østenby, 2019, p. 4).

It is not surprising that the most discussed alternatives for the future energy mix are VRE, but for VRE to be sufficiently efficient, it will require storage capabilities or a substantial amount of new stable and adjustable electricity production. As previously stated, the most commonly discussed energy storage alternatives are batteries and hydrogen from electrolysis. Currently, two alternatives that are not economically viable on a commercial scale, which call for subsidies. Alternately, dispatchable power plants that can be turned on and off can be used to cover the power demand during periods of poor weather conditions. SMR could be a viable alternative, delivering safe, reliable, and clean energy; however, nuclear energy faces significant political opposition (Nyhus, 2023). We argue that this opposition is based on a flawed and overly simplistic understanding of nuclear power plants, and we will get deeper into this in the following section.

7.2 Profitability and cost comparison

After determining which energy sources will be important in the future energy mix of Norway, we can now try to understand the fundamental differences between them. It is critical to understand this in the challenge of the situation – energy planning should be long-term and try to optimize the use of limited resources. Furthermore, it's critical to consider this in the context of Norway and other connected nations, with both current and planned future energy infrastructure goals. Additionally, it is important to evaluate it in the context of the country's geography, society, and politics, as well as the resources it has access to. In this section, we will explore and compare these material aspects of various energy sources, particularly focusing on how nuclear energy and SMR compare to other relevant sources for the future Norwegian energy mix.

7.2.1 Levelised costs of electricity and storage (LCOE and LCOS)

A key part of the future energy transition is to achieve a sustainable energy mix. Naturally, this includes minimizing and at best eliminating negative environmental and societal externalities. However, we should also realize that for energy production to be sustainable, it needs to be financially viable over time. Therefore, as a good foundation, we can start to look at costs for different energy sources and technologies.

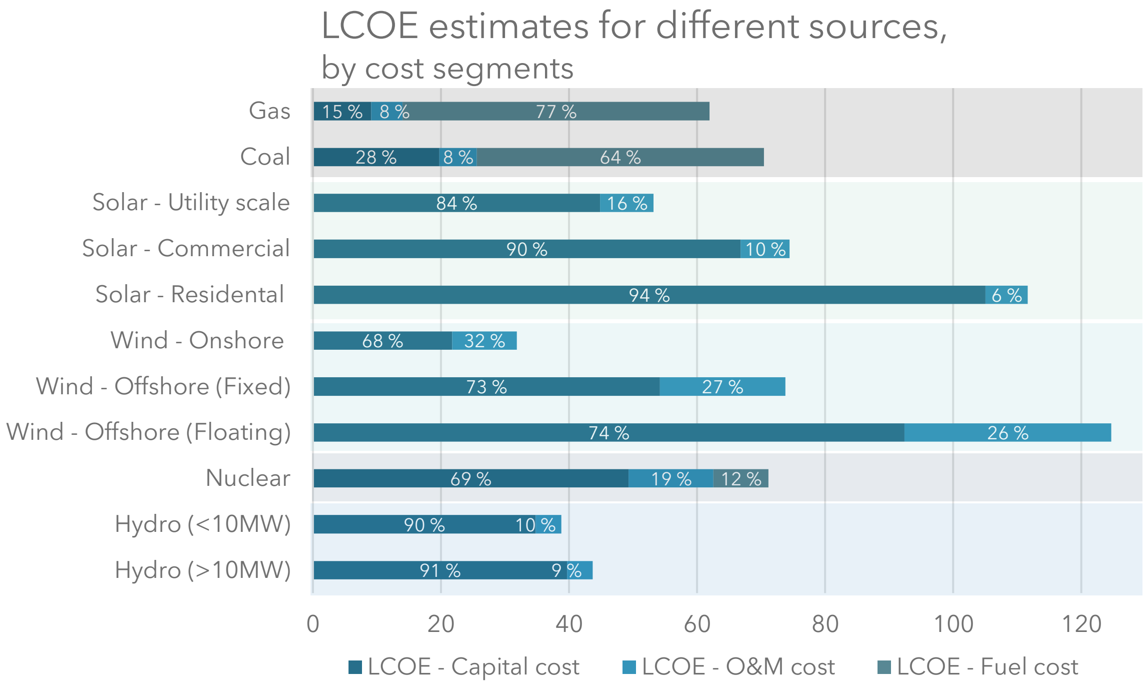


Figure 7.2: Norwegian LCOE estimates on different energy sources. Based on (NVE, 2021)

Figure 7.2 illustrates levelized cost of energy (LCOE) estimates by NVE for different energy sources, divided by cost segments. The estimates are meant to be representative of new builds. Additionally, we should note that these are estimates with high uncertainty and likely high deviations from actual projects. However, we argue that they give a high-level comparative insight into cost levels for isolated sources and technologies.

LCOE varies significantly between the energy sources. Overall, wind and solar energy seem to be at a similar or slightly higher cost level than nuclear power, while hydro reservoirs are overall lower than other relevant sustainable sources. Implying that by current NVE estimates, nuclear power is a cost-competitive alternative to solar and wind. Additionally, these estimates are for isolated projects and do not cover higher storage or system costs for solar and wind, which we will cover later in this chapter. In absolute numbers, the investment in nuclear power plants is larger, but because of high capacity and lifetime, relative to energy produced, investments are lower than most investments in solar and wind with varying capacity and expected lifetime of around 25-30 years. Besides a significant proportion of investment, the LCOE of nuclear has some operational costs in the form of O&M and fuel. On the contrary, solar and wind have no fuel costs. LCOE for wind generally has a larger proportion of O&M costs than solar, but a smaller proportion of investment. Hydro is similar to solar, with the LCOE mainly consisting of investments with some smaller proportion of O&M costs.

There are significant variations between different technologies of energy sources. For solar power, cost levels are reduced by increased scale which in turn would decrease relative investment by economies of scale. Residential and commercial solar PV are generally small-scale and assumed by NVE below 1 MW capacity, compared to utility-scale which is assumed to be 10 MW. Additionally, increased time of usage from optimizing utility-scale plants reduces LCOE. For wind power, the difference in LCOE between technologies is mainly driven by differences in investments and O&M levels, with onshore wind having significantly lower LCOE because of this. Offshore wind is a newer technology with a lot of development and technological advances still to come, driving levels of investment. In addition, we should note that it is naturally more challenging to access offshore turbines, also increasing O&M (Østenby, 2019, p. 4). Both aspects are key drivers of higher LCOE for offshore wind.

In NVE's report, they also have estimated LCOE in 2030. They estimate a cost reduction of around 30% for wind, with especially high reductions for floating offshore wind. Additionally, they estimate around 40% cost reduction for solar power (Buvik et al. 2019). Generally speaking, with increasing levels of investments, subsidies, and government support towards wind and solar projects, it is natural to expect technological advancement, economies of scale, increased knowledge, and competency among other factor driving cost reduction. However, these estimates are from 2021, which means that high prices and volatility in commodities and supplier markets in recent years are not reflected in the numbers above, as Buvik et al. (2019) explicitly state in NVE's analysis. This is especially relevant for energy sources that have a high intensity of materials, metals, minerals, and energy in high demand, such as solar and wind, as we will cover in a later section. There is also uncertainty within these cost reductions. As argued by associate professor at NTNU, Nøland (2023a), Norwegian floating offshore wind could remain expensive in the future, seeing as material sources of cost reductions in foundations and turbines are already developed technologies, through the development of foundations in offshore petroleum industries and turbines in onshore wind industries.

NVE has no cost reduction for nuclear power in their 2030 LCOE estimates. We should note that, in their analysis, NVE uses traditional large (1.600MW) nuclear power plants. Therefore, not capturing the potential cost reductions of new and smaller reactor technologies, such as SMR with a potential of cost reductions with research and development. Nuclear power consists of more established technology, especially compared to wind and solar, it is natural to assume a lower potential for advancements and cost reductions. However, there is still potential for improvements. Especially for a country such as Norway with limited experience, but only if investments are allowed and facilitated by the government. With no investment in nuclear power in Norway, there can be no advancement in technology, experience, and knowledge.

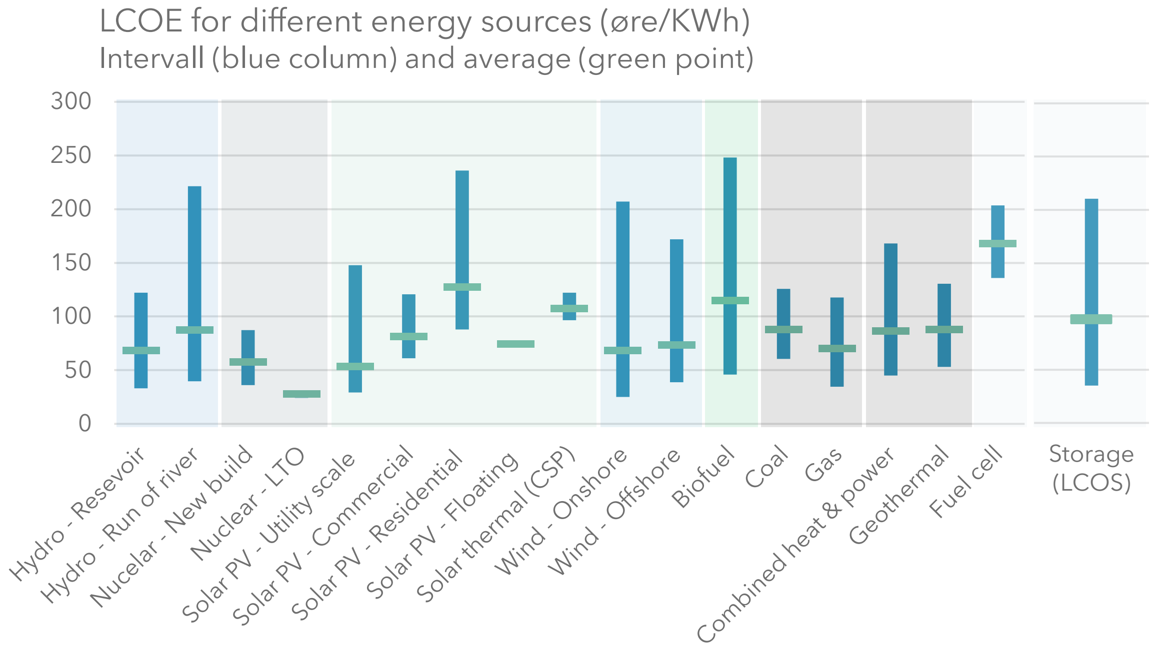


Figure 7.3: International LCOE estimates on different energy sources. Based on (IEA, 2020; Norges Bank, n.d.-c)

To further understand the cost of different sources and technologies we have gathered data from IEA, which is illustrated in *Figure 7.3.* We should note that these estimates are from 2020 based on different assumptions and data collected from different sources. Additionally, the data for nuclear LCOE is for large (around 1.000MW) traditional power plants, which although comparable, will likely differ somewhat from future SMR projects. Again, we stress that these numbers should not be interpreted as actual cost levels for future projects, but rather as a high-level comparative insight into the general cost levels.

As we can observe from the graph the relative cost levels between the energy sources are quite similar to the estimates from NVE, with the average LCOE for nuclear power being slightly lower relative to the average LCOE for wind and solar. Overall, this strengthens our argument that nuclear energy is a cost-competitive source compared to VRE. We can also notice very low LCOE for nuclear long-term operations (LTO), which are lifetime expansions of existing plants. Although not currently relevant for Norway without any commercial nuclear power plants, we still argue it illustrates the potential of nuclear power plants providing cheap energy over its lifetime, which with extension (LTO) can reach up to 70-80 years.

The LCOE estimates from *Figure 7.3* are from a variety of countries from all over the world, and we must realize that producing energy will be dependent on the geographical location and the levels of resources available at the location at hand. Determining to which degree Norwegian nuclear power is suitable and competitive compared to other countries is too complex for us to answer, as it could be academic research on its own. However, we still think it is important to point at some material aspects and make comments on the energy sources and technologies where we have data points from Norway.

Norway has had four small-scale nuclear reactors for research purposes but does not have direct experience in commercial nuclear power production (Nærings- og fiskeridepartementet, 2022). Thus, a commercial nuclear energy project would be a first-of-a-kind (FOAK) in Norway. This typically implies higher cost levels, which are then typically followed by cost reductions in nth-of-a-kind (NOAK) projects (IEA, 2020, p. 29). Therefore, for the first commercial nuclear projects, the cost level would be in the higher part of the interval illustrated in *Figure 7.3*. However, Norway still has research on nuclear power and has had for decades, building valuable knowledge and experience, in addition to a strong network with academic and professional environments (Bye & Johannesen, 2023). Additionally, the Norwegian government have recently assigned 200 million NOK to nuclear research and have established 40 new places in higher education in nuclear subjects, both being valuable addition to Norway’s knowledge and experience within the subject of nuclear (Kunnskapsdepartementet, 2023). We argue that missing commercial experience is not a reason in itself for not considering nuclear energy as a possibility in Norway. The world bank (n.d.-a) ranks Norway as the 9th best country to do business in, displaying the country’s highly functioning regulatory environment and access to resources. We could draw parallels to sectors such as aquaculture and petroleum among others, illustrating the feasibility of building large, profitable, and well-functioning industries from limited experience and knowledge.

Again, we want to stress the importance of seeing possible energy sources against and in relation to the relevant alternatives. Although Norway may not have the best base for building nuclear power, we should see it in relation to which degree Norway is efficient in building other sustainable energy sources. As we have mentioned in earlier sections, Norway has valuable water resources that give high amounts of cheap and dispatchable energy, however, there is limited potential in increasing today's capacity. The underlying data from IEA also confirms this, with the data points from Norway displaying a 50% lower LCOE for both reservoir and run of river in Norway compared to the data points from other countries. The same goes for onshore wind with the data point from Norway showing around 50% lower LCOE than the average. Nevertheless, as discussed in previous sections the potential of increased capacity for onshore wind is limited. We don’t have any data points on offshore wind for Norway. However, in an analysis done by NVE, they show that Norwegian offshore wind is generally more expensive than average European projects because of deep water and challenging seabed and estimates LCOE around 90-130 for “sørlige Nordsjø II” and “Sandskallen-Sørøya Nord” (Østenby, 2019). For solar power, there is one data point for commercial plants from Norway from IEA, which is around 35% higher than the average for the other data points, suggesting higher costs for solar in Norway. It is natural to assume that a key driver of this is the lower efficiency of solar power in Norway because of limited sun hours during the year, which we will show in the following section.

7.2.2 Fundamental differences

As mentioned at the start of this section, LCOE has important limitation since it only captures isolated costs of production, and do not capture variability in production or added costs of storage and adaptation to the grid. Therefore, comparing the LCOE of different sources gives limited insight into complete cost levels. Thus, LCOE should not be used as a comprehensive decision foundation – for that, we need to look at the complete picture.

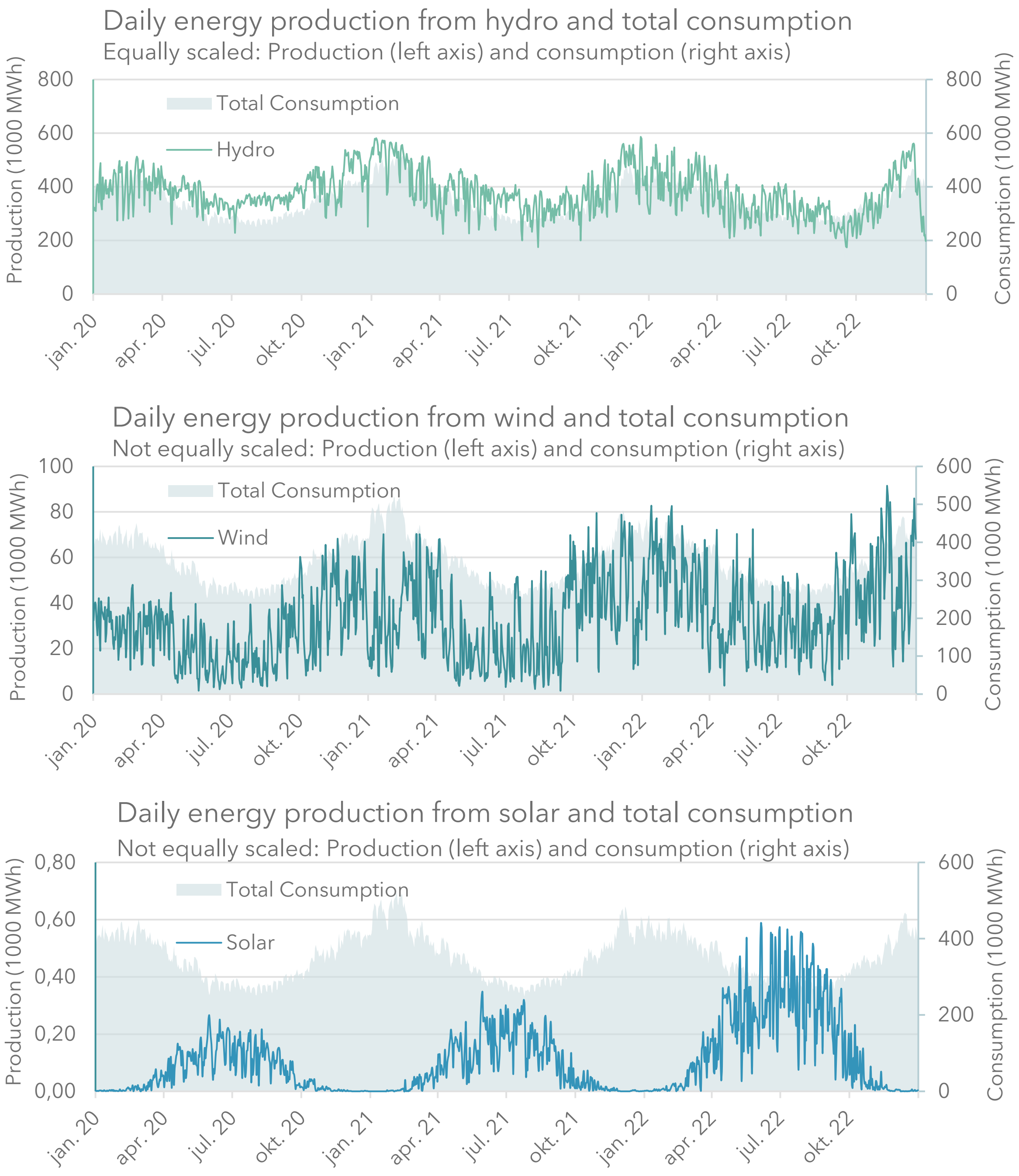


Figure 7.4: Daily production by source and consumption, in Norway. Based on (Elhub, n.d.)

There are several fundamental differences between the relevant energy sources, in particular we highlight two key aspects: firstly, their variation in production as illustrated in *Figure 7.4*, secondly, it's limitations in where they can be located and how they are constructed. The fundamental differences have significant different implications for the total portfolio of sources that makes up the energy mix and the energy grid in which they operate. It is especially important to see this in the light of current and future challenges and opportunities of the energy market and grid, as we have highlighted in previous sections.

As previously explained, both solar and wind are VRE, and the production levels are determined by the levels of sun and wind respectively. As we can observe, wind variates extremely from day to day, but has similar trends to the demand, while solar also variates largely from day to day and has a negative seasonal correlation with demand, producing most energy in the summer when energy demand is low. Thus, they offer very limited reliable instantaneous power production, which we know is a growing problem for managing the grid, as described in previous chapters. With dispatchable energy, shown with Norwegian hydropower in this case, the production levels are adjusted to meet demand, resulting in supply closely following demand. Nuclear energy is traditionally used as baseload, providing high amounts of energy, produced at steady levels over time. Additionally, often, with the ability to adjust production levels and, thereby being used to balance energy grids in countries such as France (Rosvold & Hofstad, 2023). Additionally, a material benefit of SMR is the added flexibility and ability to be used to balance the power grid (IFE, n.d.).

Furthermore, in difference from conventional nuclear power plants, SMRs are smaller, modular, and scalable in addition to being safer with passive safety systems (IFE, n.d.). Therefore, SMRs are much easier to locate where there is energy demand and can be spread across areas of high demand in the energy grid. The same applies for solar power on commercial and residential scales, producing energy typically on roofs of buildings and houses where there is demand. In contrast, hydro, utility-scale solar, and wind are highly dependent on climate and weather aspects of the geographical location in which to place the production plants. Naturally, creating a situation where supply is placed further away from demand, increasing complexity, which in turn adds costs for the grid.

7.2.3 External costs

As discussed in previous sections, a key problem arises with an increased proportion of VRE, with the associated increase in variation of produced energy, which needs to be balanced to meet demand. One solution is to store overproduction from VRE directly in electrical batteries or with pumped storage by pumping water into the reservoirs, both of which can then later be used. Additionally, it is possible to use excess energy to use in electrolysis to produce hydrogen which later can produce electricity with fuel cells. As shown in *Figure 7.3*, storage is expensive, with an average levelized cost of storage (LCOS) of around 100 øre/KWh for both batteries and hydro pumps. This assumes access to energy for storage comes at no costs, implying that to simply cover the investment costs for storage, over time, the stored energy would need to be sold at around 100 NOK øre/KWh. For storage with hydrogen, assuming a cost of hydrogen at around 100 NOK øre/KWh, on average, the LCOE of fuel cells is approximately 160 øre/KWh. The equivalent number for the one data point we have from Norway amounts to an LCOE for fuel cells at around 135 øre/KWh. Additionally, storage methods also include a large loss of energy, which implies inefficient use of resources. This is problematic in a situation where it is material to optimize the use of resources. We will go more in-depth on this and EROI later in this chapter.

For dispatchable energy sources, there is no need for added storage. On the contrary, increased dispatchable energy is an alternative or coexisting solution to batteries in balancing the large variations in VRE production. As mentioned earlier, Nuclear is not as flexible or dispatchable to the same degree as hydro but has some degree of flexibility, and there is a large potential for increased flexibility with SMR technology. Even if we ignore the balancing ability of Nuclear in itself, nuclear power in Norway could release the large hydro capacity to be used more specifically in balancing the grid both in Norway and in connected countries (Nøland & Hjelmeland, 2023). This would be a safe, cheap, and reliable part of the solution in balancing the energy grid and market, without excluding efficient possibilities of batteries and storage.

In addition to producing, balancing, and storing, we also need to consider the cost of operating the energy grid by connecting, distributing, and transforming energy, the total of these is what we call system costs. In an analysis on system costs with different energy mixes from NEA (n.d.), they find that increased levels of VRE and decreased levels of nuclear increases system costs. This is because of added grid costs imposed by the increased need for flexibility and stability, to compensate for increased variability and intermittency, in addition to added connection costs. The system costs in the scenario with 30% VRE are less than half compared to the scenario with 75% VRE (NEA, n.d.). To put this into perspective, ENTSOe estimates that Europe needs to invest six billion EUR each year to 2040, in the energy grid, to be able to handle the energy transition (ENTSOe, 2022, 2:30). This only covers system costs, and we are not suggesting that we should only have nuclear and not VRE – the point is that system cost is an important aspect to consider, and that diversifying the future energy mix with nuclear certainly has the potential of reducing total system costs.

7.3 Environmental and societal effects

When comparing various energy sources, it is essential to consider their varying social and environmental effects. Even though energy is essential for virtually every significant challenge and opportunity the world encounters today (UN, n.d.), each source of energy has both positive and negative consequences. In this segment, we will compare the various energy sources on key aspects in terms of their environmental and social impact.

7.3.1 Extreme risk and emissions

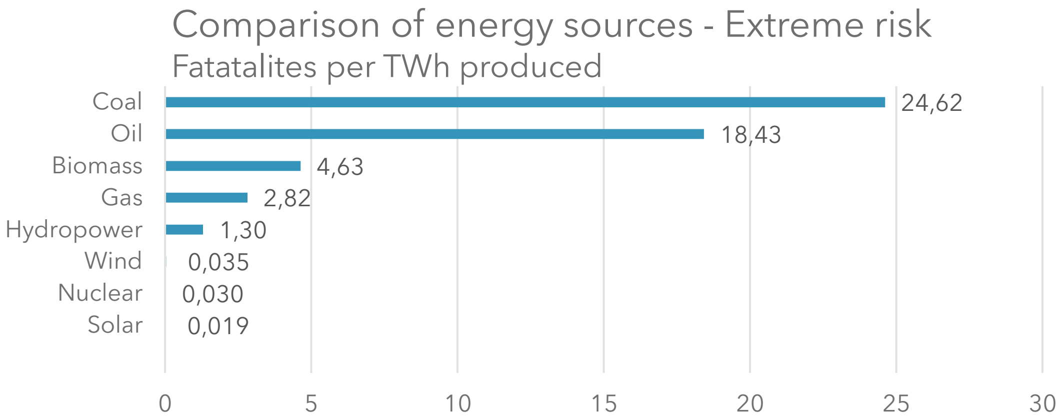


Figure 7.5: Energy source comparison - Extreme risk.
Based on (Ritchie, 2020, Our World in Data)

In the debate over nuclear power, many opponents cite past nuclear disasters, such as Fukushima and Chernobyl, and the number of fatalities as justification for their opposition to nuclear power. However, as shown in *Figure 7.5*, only solar is a safer source of electricity production when comparing the number of fatalities to the amount of electricity produced. Moreover, oil and hydropower, two of Norway's main energy sources, are responsible for a much larger number of fatalities. Whereas the high number for hydropower results from a dam failure disaster in China that claimed the lives of more than 170.000 people. It could be argued that the misinformation regarding nuclear power plants is primarily attributable to media coverage of these two catastrophes, which reported thousands of fatalities (Gaure, 2015). The data in *Figure 7.5* assumes 433 deaths at Chernobyl and 2.314 deaths at Fukushima. It is difficult to determine the precise number of individuals who died as a direct result of radiation from the Chernobyl accident, but according to a UN report, the number is approximately 50 (Øygard, 2016). As a result of radiation, there have been no fatalities due to the Fukushima accident (Gaure, 2015). Overall, we can see that all emission-free electricity sources are considerably safer than hydrocarbons. Nonetheless, if the actual figures are used as the premise for this graph, nuclear power will likely emerge as the safest source of electricity.

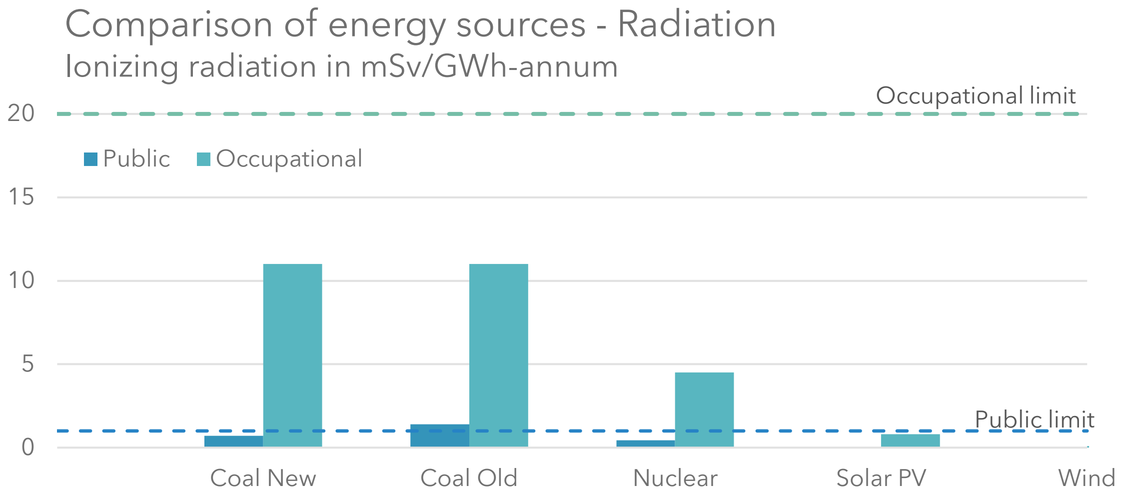


Figure 7.6: Energy source comparison - Radiation
Based on (UNECE, 2022, figure 40)

The fear of radiation, or more specifically ionizing radiation, which is caused to humans by exposure to radioactivity, is an additional argument against nuclear energy. It refers to all forms of radiation with enough energy to detach electrons from molecules where high doses increase the risk of cancer and other adverse health effects (UNECE, 2022, p. 55). Nevertheless, the human environment has always been radioactive, with approximately 85% of the human annual radiation dose coming from natural sources and the remaining 15% almost entirely caused by medical sources, resulting in an average human dose of 2,4 mSv per year (UNECE, 2022, p. 55). To put this into perspective, a CT scan of the abdomen would expose the patient to 10 mSv (Abousahl et al., 2021, p. 168). Due to a lack of statistical evidence, it is difficult to determine a limit for exposure to ionizing radiation; nevertheless, a maximum exposure limit of 1 mSv for the general public and 20 mSv for nuclear workers has been recommended as a precaution (UNECE, 2022, p. 55). As shown in *Figure 7.6*, nuclear power plants are well below both limits, whereas old coal-fired power plants emit more ionizing radiation to the public than is recommended and significantly more than nuclear power plants. This is a result of the coal combustion process and coal ash deposits (UNECE, 2022, p. 56). It is important to note that Solar PV is also a minor source of radiation due to the mining of minerals (UNECE, 2022, p. 55). As stated, ionizing radiation in high doses is dangerous; however, as we have seen, the doses caused by a nuclear power plant are below both the public and occupational limits and are also lower than those caused by coal, which has been a widely accepted source of electricity for the past couple of centuries.

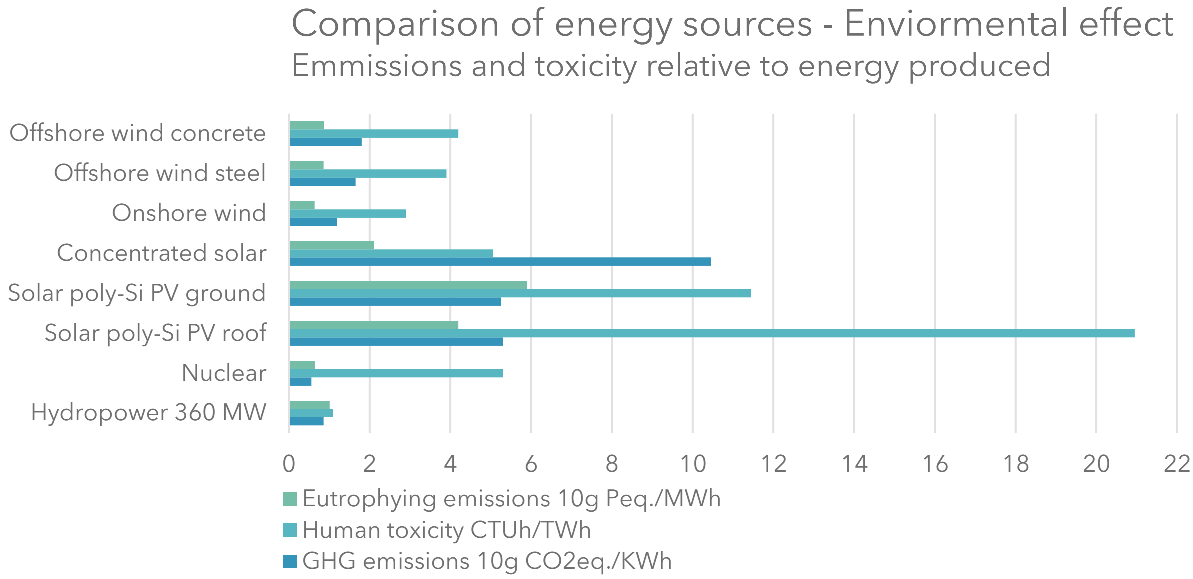


Figure 7.7: Energy source comparison - Environmental effect.
Based on (UNECE, 2022, figure 37, 38, 39 & 41)

In *Figure 7.7*, hydrocarbon-based sources are omitted, such as coal, which produces over 10 times more greenhouse gas emissions than nuclear. Therefore, if we examine *Figure 7.7*, which illustrates the lifecycle emissions of GHG per KWh, human toxicity in CTUh/TWh, and eutrophying emissions per MWh, we can see that all sources are relatively environmentally friendly when compared to hydrocarbons. As these figures represent a life cycle, they include, among other things, the effects of construction, transportation, and extraction. In the case of nuclear energy, the majority of GHG emissions result from uranium extraction and fuel production. In addition, the UNECE estimates that nuclear power emissions can be reduced by 25% by 2050, while rooftop PV, which has the second-best potential among these sources, can reduce emissions by 18% (UNECE, 2022, p. 50). Not only is nuclear power the least GHG-emitting energy source, but it also has the greatest potential for future improvement.

Furthermore, if we examine the human toxicity score and the eutrophying emissions for these sources, we find that they are primarily the result of their arsenic and phosphorus compound emissions to surface and groundwater, respectively, with Solar PV having the greatest impact on both due to its high copper input, which results in high arsenic emissions during the recycling process and emission of phosphorus compounds during metal extraction (UNECE, 2022, pp. 50-53). These figures are all subject to substantial regional variation. However, compared to coal, even with carbon capture, which emits approximately 150 g CO2eq/KWh, 139 CTUh/TWh, and 204 Peq/MWh in the lowest observation (UNECE, 2022, p. 53), these energy sources are vastly superior to hydrocarbons.

7.3.2 Usage and availability of resources

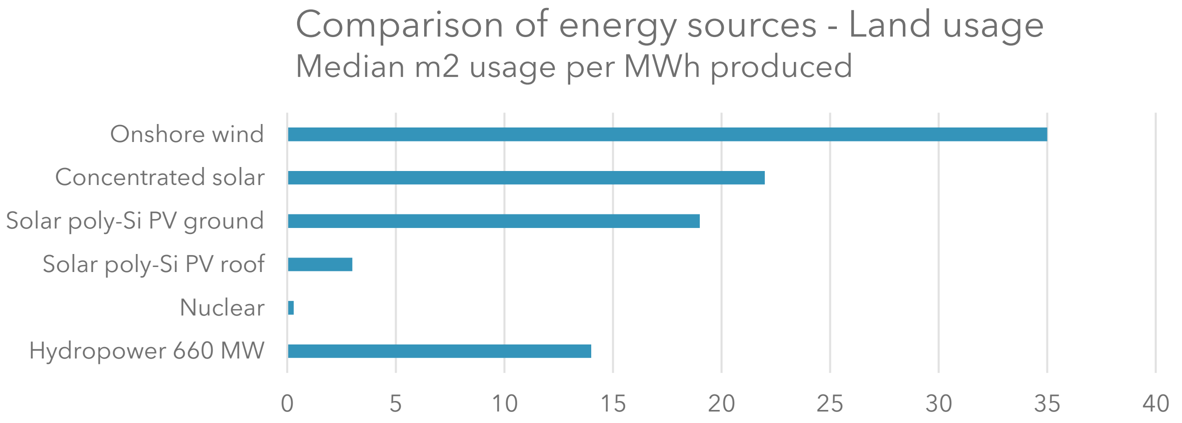


Figure 7.8: Energy source comparison - Land usage. Based on (Ritchie, n.d., Our World in Data; NVE, n.d.-a).

If we look at *Figure 7.8*, which depicts the land occupation by various energy sources per MWh, we can see that nuclear energy is far superior to all other sources. Even roof-mounted solar photovoltaic panels, the next-best source, require 10 times as much land as nuclear power to produce the same amount of energy, with 116 being the equivalent number for wind energy. This advantage is due to the energy density of uranium, which enables nuclear power plants to occupy 99% less land area than wind turbines producing the same amount of energy. This means that the entire world's energy demand could be met by nuclear power from an area the size of half of Viken County, whereas the current energy plan for 2050 would require the land area of the European Union (Nøland, 2023a). The use of land is problematic due to, among other things, the large CO2 stores in nature that could be released as a result of the construction and its prevention of future CO2 absorption in the area, with the destruction of marshes constituting a particular issue (NVE, 2023). Furthermore, given the enormous future energy demand, an energy plan that incorporates nuclear power to a greater extent would allow land to be used for other purposes, such as food production, and would likely result in less opposition from environmentalists.

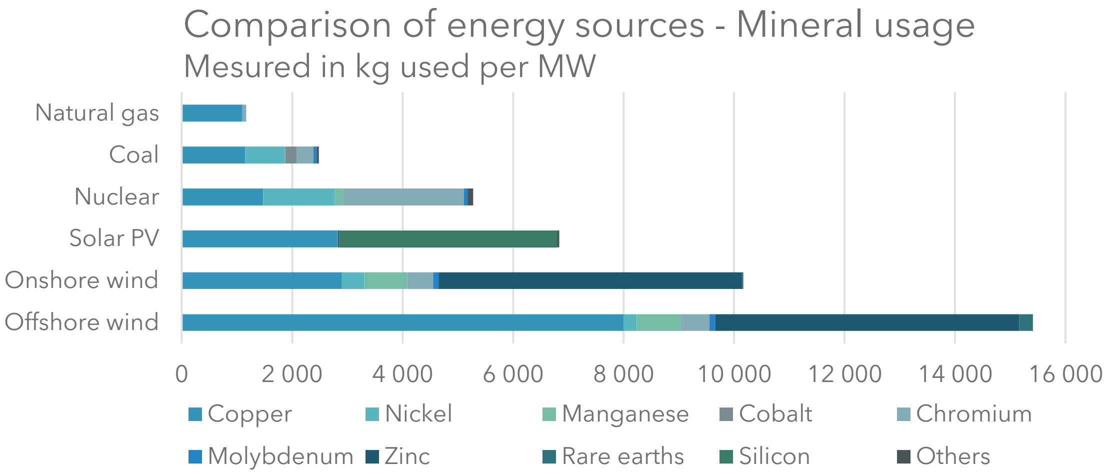


Figure 7.9: Energy source comparison - Mineral usage. Based on (IEA, 2021)

Although not included in *Figure 7.9*, the material intensity including, concrete, cement, iron, steel, aluminum, and glass, is far lower for nuclear than for coal and gas, and especially for wind and solar, with hydro being slightly lower than nuclear (WNA, 2020). Moreover, *Figure 7.9* depicts the mineral consumption of various energy sources relative to their energy production. Coal and natural gas require far fewer minerals than other, clean, energy sources. Given the green transition away from hydrocarbons, which will result in a massive demand for new energy, the future will necessitate huge quantities of minerals. Compared to a conventional automobile, an EV requires approximately six times as many kilograms of minerals per vehicle (IEA, 2021). The resource efficiency of the various sources is thus an important factor; in this regard, nuclear power is far superior to other clean sources, whereas offshore wind would require around three times the amount of minerals.

In the IEA's sustainable development scenario (SDS), depicted above, the demand for minerals is projected to quadruple by 2040, with lithium demand increasing by 40%, cobalt by 20%, and graphite by 23% compared to 2020 levels. The issue with this growth is not a result of potential reserves, as estimated reserves are significantly larger than estimated demand; rather, the issue is the production capacity of mines producing these minerals. Lithium, cobalt, and graphite require average annual growth rates of 21%, 17%, and 17%, respectively, to meet the SDS demand, whereas their annual growth rates between 2011 and 2021 were -1,2%, 0,4%, and 12,2%, respectively (BP, 2023). A significant increase in these growth rates is required.

Because the average mine takes 16 years from discovery to first production (IEA, 2021a), the viability of such growth rates is questionable. Moreover, cobalt is known to be extracted using child labor (Amnesty, 2016), which, given the intensifying scrutiny of social performance, is likely to restrict growth in the future.

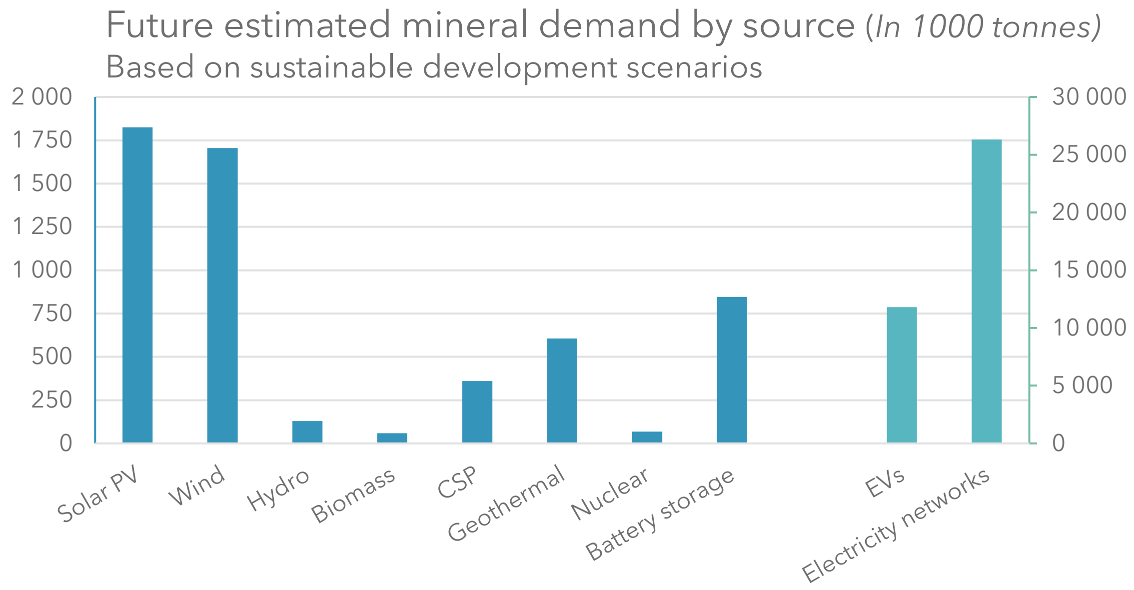


Figure 7.10: Future estimated mineral demand by source. Based on (IEA, 2021)

Figure 7.10 depicts what the use of materials in 2040 could look like if the sustainable development scenario (SDS) is implemented. EVs and the electricity network are depicted on the secondary graph (right) in this figure. The first thing that should be noted is the low usage of minerals in the nuclear sector, which is a result of many countries' plans to phase out nuclear power in favor of solar and wind energy. It is also important to note that, apart from hydro and nuclear, these figures represent a demand that has more than doubled since 2020, with CSP, battery storage, and electric vehicles seeing increases of 8.000, 3.200, and 2.800 percent, respectively. There is no way around a significant increase if we are to reduce emissions and expand the grid in accordance with political goals. However, the increase could be mitigated, thereby reducing supply risks, by choosing energy sources that require fewer minerals. Furthermore, by being more flexible with locating production in high-demand areas, grid expansions can be decreased. Both aspects are more easily addressed by nuclear power plants than by less flexible VRE.

With the increased demand for renewable energy technology, learning effects and economies of scale have reduced costs; for instance, the price of lithium-ion batteries has decreased by approximately 90%. However, this has resulted in an increased exposure to the price of raw materials, such that a doubling of either lithium or nickel would increase battery costs by 6%, or a simultaneous doubling would offset all anticipated unit cost reductions associated with doubling battery production capacity. (IEA, 2021, p. 11)

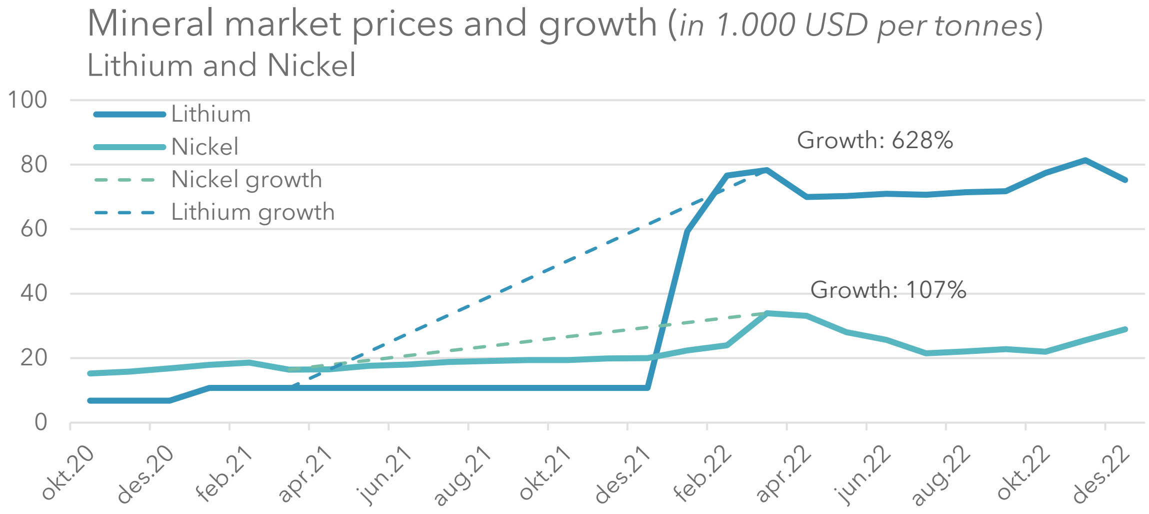


Figure 7.11: Mineral market prices, lithium, and Nickel.
Based on (BP, 2023 & Statista, 2023)

As shown in *Figure 7.11*, the price of both lithium and nickel more than doubled in 2022, and for the first time, EV batteries increased rather than decreased as many had predicted (Edelstein, 2023). According to the IEA's SDS, the expected supply from existing mines and projects is only sufficient to meet half of the projected lithium demand. As a result, this price increase is a problem that will likely become more prevalent in the future. However, current investment and supply plans are designed for a world in which climate change is addressed more gradually and inadequately (IEA, 2021), which would likely reduce the potential pressure on the capacity and price of these minerals.

In addition, the extraction and processing of a substantial portion of these minerals are highly concentrated, with approximately 70% of all cobalt extracted in the Democratic Republic of the Congo and over 60% of cobalt processed in China. China plays the largest role in the processing of the majority of these minerals, accounting for over 80% of the processing of rare earth elements, approximately 50% of lithium processing, etc. (IEA, 2021). This high production concentration heightens the risk of trade restrictions, physical disruptions, and other events that could have a negative effect on the availability and price of these minerals. In addition, the quality of these mineral ores has deteriorated in recent years, increasing energy requirements for extraction, which has led to an increase in price, emissions, and waste (IEA, 2021), which reduces the likelihood of success for the current plan for the green transition due to its reliance on mineral-intensive technologies.

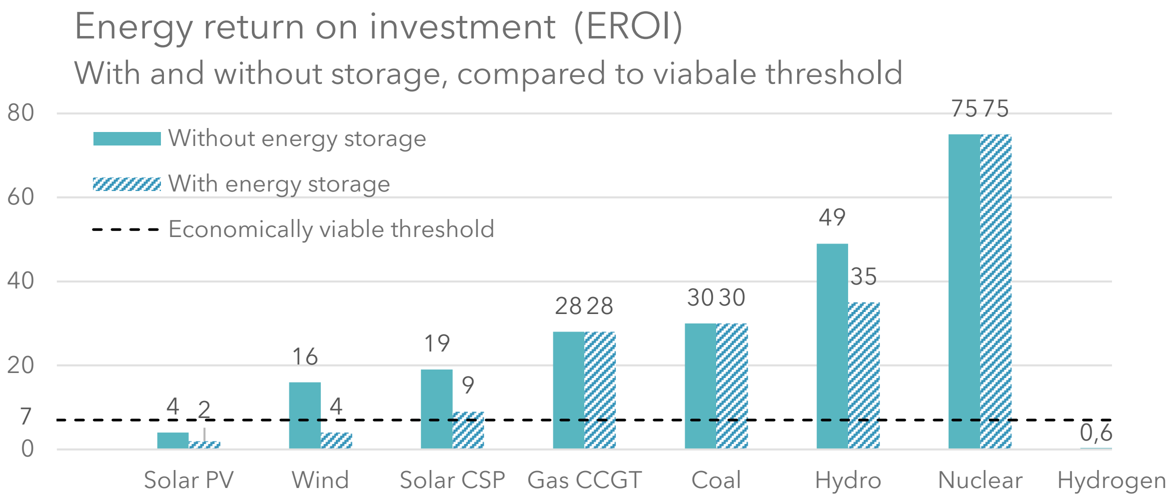


Figure 7.12: EROI of energy sources. Based on (Conca, n.d., Forbes; Horne & Hole, 2019)

When discussing resource utilization, EROI becomes applicable. This measurement's limitations and potential pitfalls have already been discussed. Nonetheless, it provides insight into the effectiveness of various energy sources. *Figure 7.12* demonstrates that nuclear is by far the energy source with the highest return, returning approximately 75 energy units per input, whereas solar and wind return 4 and 16 energy units without storage and 2 and 4 with storage. In this figure, we present an absolute value for a measurement that varies significantly depending on the underlying assumptions. In addition, these values are derived from a 2013 research report, and technological progress may have modified them. Nonetheless, we gain an understanding of the return and the impact of energy storage on EROI.

The storage option chosen in the aforementioned study is pumped hydro, which retains approximately 85% of the energy on a production-only basis (Belsnes, 2022). As shown in *Figure 7.12*, this decreases the EROI by half for solar and more than half for wind. However, if we chose batteries and hydrogen instead, this value would likely be much lower, given that electrolysis of hydrogen requires almost twice as much energy to produce the same amount of energy (Horne & Hole 2019). Consequently, storing energy by producing hydrogen with electricity in order to produce electricity later appears to be a highly inefficient alternative. In addition, as mentioned previously, the deterioration of ore quality, which increases the energy required for extraction could potentially reduce an already low EROI. With the enormous energy demand of the future, energy density and the ability of sources to return more energy than was required to create said energy, are undeniably important for continued economic growth alongside the green transition.

8. Investment case and profitability analysis

8.1 Input analysis

To analyze and model a potential investment in an SMR project, we need to analyze all elements that go into the models. In the following part of the analysis, all input used in the DCF and LCOE models will be analyzed and discussed. Before that, we should note that a possible investment in SMR is not possible today, and there still needs years of regulatory work, planning, design, technical development, etc. before it is even possible for such an investment in Norway. Therefore, our analysis is highly simplified and generalized, based on the limited data and information available currently. We stress the fact that our analysis will have obvious flaws and are not meant to represent an actual investment decision, but rather to give a high-level insight into the financial and economic feasibility of such an investment. Our analysis is of a fictional potential project several years into the future. We stress that our analysis with connected output and discussion should be viewed as such.

8.1.1 Production levels

Production volume is a deciding factor for several of the variable inputs in this analysis, including revenue, fuel costs, and variable O&M costs. Therefore, this is an important aspect of a potential SMR investment project. Based on different scenarios the production volume can differ significantly. We can start by categorizing the different determining factors in two; Firstly, it is a question of when we can start to produce and for how long. Secondly, it is a question of which efficiency and actual volume the plant is able to produce, which again depends on technical aspects and market conditions.

The time in which operations could start depends on the construction time, and here there is risk as to how many years the construction will take, which in turn will affect when production can start. We will cover CAPEX and construction time later in this section. Although, a couple of years does not necessarily seem like a lot in the scheme of things considering an operational lifetime of around 60 years, the first years account for the most value because of the discount effect. Additionally, when considering liquidity and managing the plant, it is evident that income and generation of cash are desired as soon as possible. There is also a question of how long an SMR plant can be in operation, which could significantly affect the total production level, but the current value of operations, 60-70 years down the line are somewhat insignificant. In our model, assuming 60 years of operational lifetime, the question is how far in the future the production will come, which again decides how much we will need to discount cash flow from operations.

When the plant is up and running, the production volume depends on both technical aspects and operational efficiency, in addition to market limitations regarding how much energy it is possible to sell over its lifetime. We capture the uncertainty and risk in technical specification and operational efficiency with modeling capacity factor and excess thermal energy capacity as variable input with different scenarios. Depending on the assumed scenarios for capacity factor and excess thermal energy capacity, the yearly amount of energy produced will differ significantly, as illustrated in *Table 8.1*. We should note however that the two assumptions are necessarily not correlated, meaning that high-capacity factor does not imply high excess thermal energy capacity, or vice versa. This implies that we could realistically have all combinations of the two assumed variables assumptions.

Scenario	Electric energy	District heat	*Underlying assumption*
High case	3.911GWh	782GWh	- *High capacity factor* - *High excess thermal energy capacity*
Base case	3.705GWh	371GWh	- *Base capacity factor* - *Base excess thermal energy capacity*
Low case	3.500GWh	0GWh	- *Low capacity factor* - *Low excess thermal energy capacity*

Table 8.1: Input scenarios – Production levels. Given base case for all other variables.

Overall, we assume quite a moderate efficiency. On the one hand, considering that Norway has no prior experience running a commercial nuclear power plant, especially relevant for the first reactor and the first years of operations. There will probably be some learning effects and increased efficiency over time as experience is gained over the number of reactors and years of operations. On the other hand, however, one of the key aspects of SMR is that they are standardized, which allows for efficient operations with solid management, planning, and training, while also reducing technological risks. Therefore, we argue that our assumptions and the following output are reasonable as average numbers over time.

Lastly, we should note that we assume that there are no market limitations and that the competition in the market allows for the power plant to sell at full production. As we have shown in the market analysis, it is evident that there is a large demand for electricity and district heat, in both the day-ahead and PPA markets. Additionally, nuclear power plants have a low marginal cost and can produce energy at an almost constant level, allowing them to be competitive in the day-ahead market and PPA market. Therefore, with a strategic location of power plants, allowing for large proportions of PPAs, we argue that this is a fair assumption, but realize that there is a risk of overstating the production volume.

8.1.2 Revenue

The revenue is directly correlated to the production volume and the only deciding factor left is the price at which the energy is sold. There are possibilities of differentiating between markets, either wholesale or fixed contracts which can have differences in price levels and volatility. Additionally, we should differentiate between electric energy sold in the electricity markets and thermal energy sold in district heat markets. However, we have simplified this significantly by implicitly assuming an average price for all energy produced.

We have established possible outcomes of production level in the previous section, which then leaves us to establish possible energy price outcomes. Estimating exact prices decades into the future is beyond the scope of this thesis, and thus we simplify the prices by using fixed average prices, based on external price estimates. Although we have collected price estimates for all Norwegian price zones, we base our scenarios on average estimated prices in southern price zones. The reasoning being, as highlighted in the market analysis, the southern zones have the largest demand for added energy production. We argue that external estimates are better than any independent analyzes we have the capacity to perform. As we have shown in the market analysis, estimates and prognoses point to a decreasing energy price in the years to come, which at some point and some level will stabilize. The question is then at what price levels the prices stabilize, at the time of possible investment in an SMR project.

From the estimates based on collected future price prognoses, we find it reasonable to assume energy prices within the interval of 50-80 øre/KWh, with a base case of 70 øre/KWh. As illustrated below, in *Table 8.2*, the electricity price naturally has a significant impact on revenue. If we look at an SMR project in isolation, this again will have a significant effect on profitability. We should note however that the dependency on energy prices is universal for all alternative energy sources, which somewhat offsets the exposure to price risks. We stress the concept of alternative costs and argue that although low prices may result in low returns for an SMR project, it could still be a better alternative than investments in other energy sources which potentially could offer even lower returns. Additionally, although we do not specifically model it, we should note that the risk of price fluctuations could be hedged with PPAs and other financial energy market contracts.

Scenario (Revenue)	Electric energy	District heat	*Underlying assumption*
High case	2.964M NOK	296M NOK	- *Base production volume* - *High price estimates (80 NOK Øre/KWh)*
Base case	2.594M NOK	259M NOK	- *Base production volume* - *Base price estimates (70 NOK Øre/KWh)*
Low case	1.853M NOK	185M NOK	- *Base production volume* - *Low price estimates (50 NOK Øre/KWh)*

Table 8.2: Input scenarios – Revenue. Given base case for all other variables.

8.1.3 Fuel costs

As described in the data and methodology chapter, fuel costs in this case refers to the costs associated with the front-end fuel cycles, as the back-end fuel cycle costs are captured in the O&M costs. The fuel costs are split into two parts, firstly it's the first fueling of the reactor, and secondly, it is running fuel usage in operational years. The fuel costs are dependent on the fuel cycle costs for each unit of fuel and the amount of fuel. The former is assumed to be fixed throughout the project's lifetime and accounts for the cost of uranium, conversion, enrichment, and fuel fabrication. The latter is dependent on reactor fuel capacity for the first fueling, and production level for running fuel usage. All these factors are highly dependent on technical aspects and market conditions. Risk and uncertainty in fuel usage factor and fuel-cycle costs per unit of fuel are captured by modeling them as variables with different scenarios.

With an assumed fuel capacity of 35.250 kilograms of uranium in the reactor, we get quite large variations with the assumed fuel cycle cost scenarios. As illustrated below in *Table 8.3*, the interval goes from almost 1 billion NOK to around 700 million NOK, with the base case being around 880 M NOK. Note that this is only a one-time effect, in the last year of the construction period, and will therefore have a limited effect on the overall profitability.

Scenario	First fuelling	*Underlying assumption*
High case	1 058M NOK	- *High fuel cycle costs (30.000 NOK/KgU)*
Base case	881M NOK	- *Base fuel cycle costs (25.000 NOK/KgU)*
Low case	705M NOK	- *Low fuel cycle costs (20.000 NOK/KgU)*

Table 8.3: Input scenarios – Fuel costs of first fueling.
Given base case for all other variables.

For the running fuel usage costs, besides fuel costs per unit of fuel, we also need to consider fuel usage per produced unit of energy. With our assumed scenarios, and a base case production level, the yearly fuel costs will vary significantly, as illustrated below in *Table 8.4*. This accounts for a bigger effect on the overall profitability since the cost occurs every year of operations, however, it is still relatively small compared to the revenue.

Scenario	Fuel cost of usage	*Underlying assumption*
High case	381M NOK	- *High fuel cycle costs (30.000 NOK/KgU)* - *High fuel usage factor (0,030 TU/MWe)*
Base case	286M NOK	- *Base fuel cycle costs (25.000 NOK/KgU)* - *Base fuel usage factor (0,027 TU/MWe)*
Low case	212M NOK	- *Low fuel cycle costs (20.000 NOK/KgU)* - *Base fuel usage factor (0,025 TU/MWe)*

Table 8.4: Input scenarios – Fuel costs of usage. Given base case for all other variables.

We have made some independent adjustments to the assumed scenarios for fuel cycle costs, by making the calculated costs based on estimates from WNA the low case. Based on the estimated low case, we have assumed a base and high case, which is also in line with high-level estimates from NKK. Furthermore, the cost levels have been calculated from 2021 levels in USD, to 2023 levels in NOK. This project will happen several years into the future, therefore also having significant risk in both future currencies and price fluctuation in the uranium market. We make this simplification, since there are, to our knowledge, no publicly available estimates and forecasts we could use, and limited data on the market to analyze. We will however highlight the risk and exposure by scenario and sensitivity analysis.

In total, the fuel costs amount to around 8 NOK øre/KWh, which is in line with fuel cost levels in LCOE estimates from both NVE and IEA, as discussed in the comparative analysis. We should note that our analysis does not capture possible deviations in fuel costs for SMR from conventional nuclear power plants, as we estimate the costs by scaling high-level parameters from traditional nuclear power plants. However, from conversations with NKK, we understand this to be a fair assumption as there will be a minimal deviation in fuel costs from SMRs compared to conventional plants.

8.1.4 Operation and Maintenance

In our data, front-end fuel costs have been omitted, but costs associated with decommissioning and back-end fuel have been included. This indicates that the presented O&M costs include everything from day-to-day operations, such as payroll expenses and insurance premiums, to the handling of used fuel, the shutdown of the nuclear plant, and the disposal of nuclear waste in a landfill. Due to the small proportion of O&M costs in total LCOE, this aspect of SMR economic analysis has received less attention in existing literature. Nonetheless, it represents a sizeable proportion of the total costs and must be factored into the analysis.

According to NKK, the O&M costs of a first-of-a-kind SMR project should fall within the range of 16 to 20 øre/KWh and between 16 and 18 for NOAK. This is consistent with the average O&M cost of 16,43 NOK øre/KWh for nuclear power plants in the US in 2021(eia, n.d.) and eia estimates of 16,63 øre/KWh for an operational 600 MWe SMR project in 2028 (eia, 2022). Moreover, it is assumed that the O&M costs are comparable to those of conventional nuclear reactors relative to electrical capacity (Vegel & Quinn, 2017, p. 11). This assumption is based on the possibility of modularity enabling greater automation, which lowers costs for a variety of operations. This cost reduction is, however, offset by the lower production volume, which diminishes the value of economies of scale. Furthermore, O&M costs evidently vary considerably between projects. Despite this, when we compare the O&M costs for conventional nuclear power plants to projections for SMR projects, we find that the average value is quite similar, with a difference of approximately 1 øre/KWh in favor of SMRs, which seems quite reasonable given that the standard deviation for conventional reactors is 8,6 NOK øre/KWh.

In addition, the obtained data includes nuclear power plants utilizing various technologies and operating in various nations. These differences are a potential source of error due to the varying operational requirements of various reactor designs and the different wage levels between nations. Nevertheless, according to OECD (2022), Japan has one of the lowest average wage levels among the countries we examined, despite having the highest O&M costs. Inferring that the measure of wage levels may have a minor effect on outcomes, despite some estimates indicating that wages account for approximately 60% of O&M costs. Additionally, the examined reactors all utilize the same coolant, and "studies on the cost correlation between different reactor designs demonstrate that there is high correlation between designs utilizing the same coolant" (Bolden & Sabharwall, 2014, p. 6).

Furthermore, some studies indicate that O&M costs increase with the lifetime of a nuclear power plant because of equipment deterioration; consequently, it is reasonable to assume that O&M costs for an SMR would increase over time. However, this increase is very modest and is not anticipated to occur before 10 years of operation. In addition, this increase would be partially offset by a decrease in spent fuel costs due to the maturation of the decommissioning fund and reversed by any refurbishment (S&L, 2018). In addition, SMRs are created with a more standardized design, resulting in a more cost-effective and streamlined maintenance and upgrade process that potentially reduces downtime. Based on this information, it is likely to assume that an eventual increase in costs due to aging equipment will be less than for conventional nuclear power plants. Consequently, as illustrated in *Table 8.5*, we utilize 17,1 øre/KWh throughout the entire operational lifetime of the project. Which, due to differences in potential production capacity and actual production, as well as fixed and variable costs, we achieve an O&M cost of approximately 18,6 øre/KWh in our base case of 90% production capacity, which decreases if production increases.

Scenario (O&M)	Fixed O&M cost	Variable O&M cost	*Underlying assumption*
High case	182M NOK	732M NOK	- *High O&M estimates (34,9 øre/KWh) (75th percentile of conventional NPP)*
Base case	137M NOK	552M NOK	- *Base O&M estimates (17,1 NOK øre/KWh) (Median of conventional NPP)*
Low case	104M NOK	420M NOK	- *Low O&M estimates (13,01 øre/KWh) (25th percentile of conventional NPP)*

Table 8.5: Input scenarios – O&M costs. Given base case for all other variables.

8.1.5 CAPEX

As was previously explained, CAPEX consists of two components: project planning and construction. Rolls Royce will deliver and assemble the entire power plant due to the modular nature of this reactor. Therefore, our estimated costs are based on Rolls Royce and NKK projections. Even though an SMR requires a somewhat lower initial investment than a conventional nuclear power plant, it is still a significant amount that will have a substantial impact on the NPV. Several nuclear power plant projects in the past experienced cost overruns and construction delays (Chandler, 2020), so it is important to account for this. Naturally, cost overruns have a direct impact on profitability, but construction delays also delay production and, consequently, revenue. Naturally, with construction delays the construction cost will likely also increase, therefore, they may have a significant negative impact on a project's profitability. As this is an SMR project, the reactor is standardized and modular, with large parts of the reactor being manufactured in a factory, before it is shipped and constructed on-site, largely done by the supplier. Additionally, the supplier, which in this case is Rolls Royce SMR, will have carried out multiple projects in the UK before a potential project in Norway is carried out. Both these factors significantly mitigate the risk of construction overruns in time and cost levels.

Furthermore, the acquired values are in GBP, and the NKK's project is not expected to be operational until at least 2030, making any cost estimates susceptible to fluctuations in exchange rates and inflation, with inflation having a particularly negative impact on current estimates for existing SMR projects. However, we are disregarding these aspects of the analysis since they are macroeconomic factors that affect the entire market, and because inflation is likely to increase revenues, partially offsetting the negative effects rising costs have on NPV.

Moreover, due to the magnitude of the initial investment and the impact of discounting on the present value of expenses, variations in the down payment structure may have a substantial impact on the overall profitability of the project. As this is a completely unexplored topic, no structure can be viewed as more probable than any other; however, we have a base case of 2,25 billion NOK in project preparation costs that are due before construction commences, regardless of the down payment structure agreed upon with the vendor. And equal down payments of 5,9 billion NOK for the initial four years.

Cash flow from different down payment structures of construction costs *(in million NOK)*	0	1	2	3	4
Equally distributed	2.250	5.908	5.908	5.908	5.908
All upfront	25.882	-	-	-	-
All after construction	2.250	-	-	-	23.632

Table 8.6: Input scenarios – Payment structure of CAPEX.
Given base case for all other variables.

8.1.6 Financing and Cost of Capital

Financing a nuclear power plant can be a difficult process due to the large initial investment required. According to our estimates, NKK will need to raise approximately 23,6 billion NOK in financing. We believe that obtaining a business loan through a bank would be challenging given the size of this financing requirement. As a result, the most realistic financing options are either equity with the issuance of new shares or the bond markets. Or as is far more likely, a combination of the two. In our base case, we finance with 50% debt and 50% equity. This means that NKK will incur approximately 11,8 billion NOK in both debt and equity.

To begin with, equity financing will be accomplished through stock issuance, which will, of course, include some form of remuneration for whoever facilitates this process. This, however, is disregarded in our analysis. Furthermore, as previously stated, we believe the project will be financed through a combination of equity and debt. This is because we believe it is unlikely that this project could be funded entirely by equity. For example, suppose we were to issue shares in the company to obtain the 23,6 billion NOK while the current owners retained a combined 10% ownership. NKK would be implicitly valued at 26,25 billion NOK. Given the market value of the most valuable companies listed on the Oslo Stock Exchange, retrieved from DnInvestor (n.d.), this would imply that NKK would be the 27th most valuable company on the Oslo stock exchange before construction of the power plant begins, which would be at least 4 years before any revenue is generated from the project. This is, of course, a simplified view, but it explains why a combination of debt and equity is more realistic and why we are operating with a 50% equity share of the financing in our base case.

We presented a theoretical method for estimating the cost of capital in the chapter on theory. However, this cost estimate can vary significantly based on the underlying assumptions. During the course of our research for this thesis, we came across articles employing a WACC between 3% and 12%. Additionally, the cost of capital has a substantial effect on the overall profitability of a capital-intensive project with long cash flows, such as a nuclear power plant. Therefore, it is necessary to use discretion when evaluating the estimates. The selected comparable companies, for instance, have multiple production sources, including wind, solar, and hydrocarbons. This may suggest that they do not reflect a representative beta for NKK, a company that generates all its electricity from nuclear power. This disparity could have been balanced by the proportion of revenue generated from nuclear power generation. However, such an adjustment would omit costs directly associated with nuclear operations, which could introduce bias due to disparities in the share of revenue and percentage contribution to net income among the various sources. Therefore, we employ an "unadjusted" beta. According to our findings, NKK's unlevered industry-peer beta is 0,37, which, when combined with our target capital structure of 50% debt and 50% equity, yields an equity beta of 0,43. In addition, this results in an approximate 5% equity cost of capital.

As was previously stated, we distinguish between systemic and idiosyncratic risks. The most prominent idiosyncratic risk factors for a nuclear power plant are construction risk and political risk. Due to the long construction period and inability to generate electricity during construction, any delays or cost overruns pose a significant risk. In addition, there is political opposition to nuclear power plants in Norway, making it difficult to obtain a license to construct one. These factors are not accounted for by the CAPM, but we argue that they are better accounted for by scenario analysis, where, for example, any form of revenue would imply the elimination of political risk. This chapter will therefore concentrate primarily on the systemic risk reflected by the beta.

The beta is intended to reflect how NKK's project's future returns will develop relative to the market as a whole. Where a low beta implies less market risk, a desirable characteristic, and thus a lower expected return than the market. The question then becomes, how the profitability of this project will evolve in the future. Carbon quote prices are likely to increase because of the extensive work toward a zero-emissions economy. This means that as long as a portion of electricity is generated from hydrocarbons, they will determine future prices, which will increase. An isolated increase in energy prices is damaging to economic growth (Gúnette & Khadan), but for a nuclear power plant, it is directly related to an increase in revenue. In this regard, one could argue that a low-emission energy source, such as nuclear power, could exhibit a negative correlation with the market, thereby attaining a negative beta.

Moreover, as shown in *Table 8.7*, all price zones in Norway have a weakly negative correlation with the market. A negative price correlation would indicate that NKK's project's revenue is negatively correlated with the market, supporting the argument for a negative beta. And, as we know from economic theory, a negative beta would function as an insurance policy against bad times, implying that an investor is willing to forego returns in exchange for this market hedge. In addition, electricity is an essential commodity, which reduces its exposure to market volatility. Nevertheless, there is a correlation, and decreased market activity will reduce the electricity demand. Nonetheless, several consumers are unable to completely stop consuming electricity, indicating a correlation with the market that is weaker than average, i.e., a beta value at least below 1.

Day-ahead market	NO1	NO2	NO3	NO4	NO5
Correlation with: MSCI world index	-0,0429	-0,0106	-0,2338	-0,2534	-0,0526

Table 8.7: Correlation matrix – Electricity spot market and global stock index.
Based on (Nordpool, n.d.; Yahoo Finance, n.d.)

Debt financing of a nuclear power plant is somewhat challenging because the loan would require a grace period during the construction period due to the lack of revenue. Where accruing interests could potentially become a significant expense, detrimental to the financial viability of the project. Thus, it is critical to obtain reasonable loan terms. To get an estimate of the cost of debt we need to recall *Figure 4.1*, which we can utilize to approximate what a realistic credit rating could be, using some assumptions. First, at the time of securing financing, this project is at least four years away from generating any sort of revenue, which places NKK in a poor liquidity situation, which alone will result in a poor credit rating. However, once the power plant begins production, its income will likely be relatively stable from year to year. In addition, as discussed in the section on equity beta, a low-emitting energy production project would be a great diversification opportunity, particularly during the transition to a net-zero economy, and a debt holder could realistically be willing to forego, or at least reduce the expected return. In any case, when we examine comparable businesses such as Fortum and EDF, we observe that they have BBB ratings (FitchRatings, 2023; Fortum n.d.). We will assume that BBB is the upper limit for a credit rating, with CCC serving as a possible lower limit, because these companies are well-established and have much better liquidity than NKK would achieve in its first years. However, with added projects and increased cash flow from operations, it is natural to assume that the credit rating would improve over time.

Considering the assumption of a credit rating somewhere between BBB and CCC, we can assume a debt beta between 0,1 and 0,31 (Berk & DeMarzo, p. 413). Through CAPM we then achieve a cost of debt between 3,7% and 4,7%. Comparing this to existing corporate bonds with the same rating, we see that the rates range from 5% for a BBB-rated bond up to 14% for CCC (FRED, n.d). Both are far above for example Fortum´s outstanding bonds range from 1,6% to 3,5% (Fortum, 2023). Most likely due to the lower interest rates when these were issued. Nevertheless, we see it as unlikely that any interest rates for NKK´s debt would lie anywhere near 14%. And thus, operate with a base case with a capital cost of debt of approximately 4% obtained with CAPM.

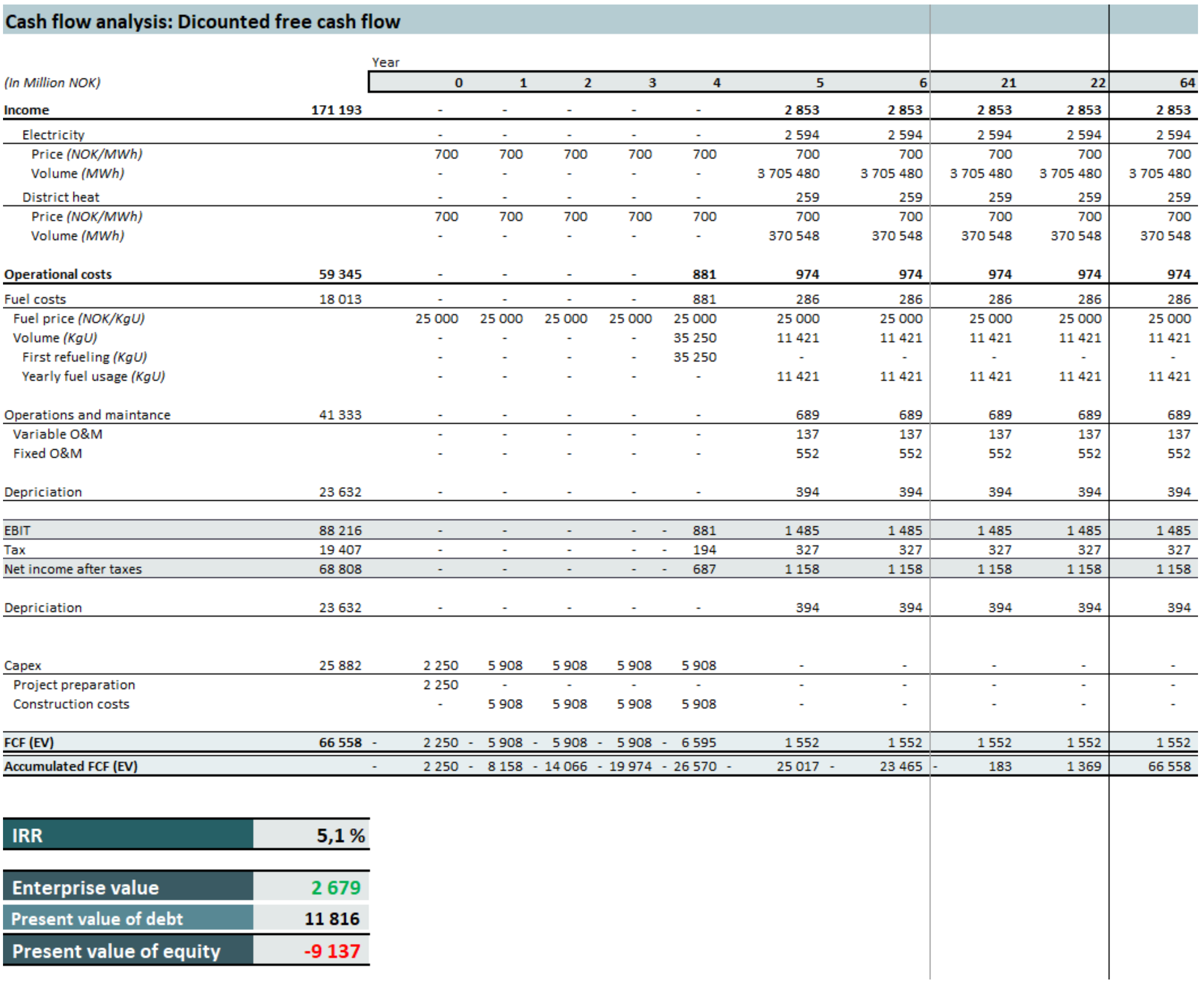
With these estimates, we achieve a WACC of approximately 4,5%, which considering the aforementioned arguments, appears to be reasonable. On the one hand, this is a new project in a country that has no commercial experience with nuclear power plants and a relatively high debt-to-equity ratio. In isolation, this would indicate a higher risk than the market average. On the other hand, a negative beta would indicate that, on average, investors are willing to accept a return below the risk-free rate because diversification provides value. This, however, would require a negative long-term correlation, which seems unlikely if we assume a zero-emissions economy by 2050. Nevertheless, if one considers the importance of energy and Damodaran's estimation that the average industry peer beta for power producers is approximately 0,7 (Damodaran, 2023), our estimated capital costs appear to be quite probable.

8.2 Investment and cost analysis

Before we present our estimated models, we want to stress the intention and purpose of our analysis. As mentioned initially in this chapter, we are essentially modeling a fictional potential project several years into the future. Consequentially, with limited available information and specification in combination with high uncertainty to both technical, political, and economic development, we argue that it is impossible to give precise and conclusive results. However, we are still able to provide quite comprehensive high-level insight into the economic and financial aspects of an SMR project in Norway. Therefore, we stress the importance of interpreting the results in accordance with the intended purpose of the analysis.

8.2.1 Investment analysis - DCF

To evaluate the profitability of a potential SMR project, we have modeled an after-tax enterprise value discounted cash-flow model. The model will be presented with base case assumption on its own followed by key insight into profitability with estimated present value, internal rate of return, payback time, and other key figures. Furthermore, key insights from our analysis will be discussed in this section.



Cash flow analysis: Dicounted free cash flow

(In Million NOK)		Year 0	1	2	3	4	5	6	21	22	64
Income	**171 193**	-	-	-	-	-	**2 853**	**2 853**	**2 853**	**2 853**	**2 853**
Electricity		-	-	-	-	-	2 594	2 594	2 594	2 594	2 594
Price *(NOK/MWh)*		700	700	700	700	700	700	700	700	700	700
Volume *(MWh)*		-	-	-	-	-	3 705 480	3 705 480	3 705 480	3 705 480	3 705 480
District heat		-	-	-	-	-	259	259	259	259	259
Price *(NOK/MWh)*		700	700	700	700	700	700	700	700	700	700
Volume *(MWh)*		-	-	-	-	-	370 548	370 548	370 548	370 548	370 548
Operational costs	**59 345**	-	-	-	-	**881**	**974**	**974**	**974**	**974**	**974**
Fuel costs	18 013	-	-	-	-	881	286	286	286	286	286
Fuel price *(NOK/KgU)*		25 000	25 000	25 000	25 000	25 000	25 000	25 000	25 000	25 000	25 000
Volume *(KgU)*		-	-	-	-	35 250	11 421	11 421	11 421	11 421	11 421
First refueling *(KgU)*		-	-	-	-	35 250	-	-	-	-	-
Yearly fuel usage *(KgU)*		-	-	-	-	-	11 421	11 421	11 421	11 421	11 421
Operations and maintance	41 333	-	-	-	-	-	689	689	689	689	689
Variable O&M		-	-	-	-	-	137	137	137	137	137
Fixed O&M		-	-	-	-	-	552	552	552	552	552
Depriciation	23 632	-	-	-	-	-	394	394	394	394	394
EBIT	88 216	-	-	-	-	- 881	1 485	1 485	1 485	1 485	1 485
Tax	19 407	-	-	-	-	- 194	327	327	327	327	327
Net income after taxes	68 808	-	-	-	-	- 687	1 158	1 158	1 158	1 158	1 158
Depriciation	23 632	-	-	-	-	-	394	394	394	394	394
Capex	25 882	2 250	5 908	5 908	5 908	5 908	-	-	-	-	-
Project preparation		2 250	-	-	-	-	-	-	-	-	-
Construction costs		-	5 908	5 908	5 908	5 908	-	-	-	-	-
FCF (EV)	**66 558**	- 2 250	- 5 908	- 5 908	- 5 908	- 6 595	1 552	1 552	1 552	1 552	1 552
Accumulated FCF (EV)		- 2 250	- 8 158	- 14 066	- 19 974	- 26 570	- 25 017	- 23 465	- 183	1 369	66 558

IRR	**5,1 %**
Enterprise value	**2 679**
Present value of debt	**11 816**
Present value of equity	**-9 137**

Figure 8.1: Base case DCF model with output.

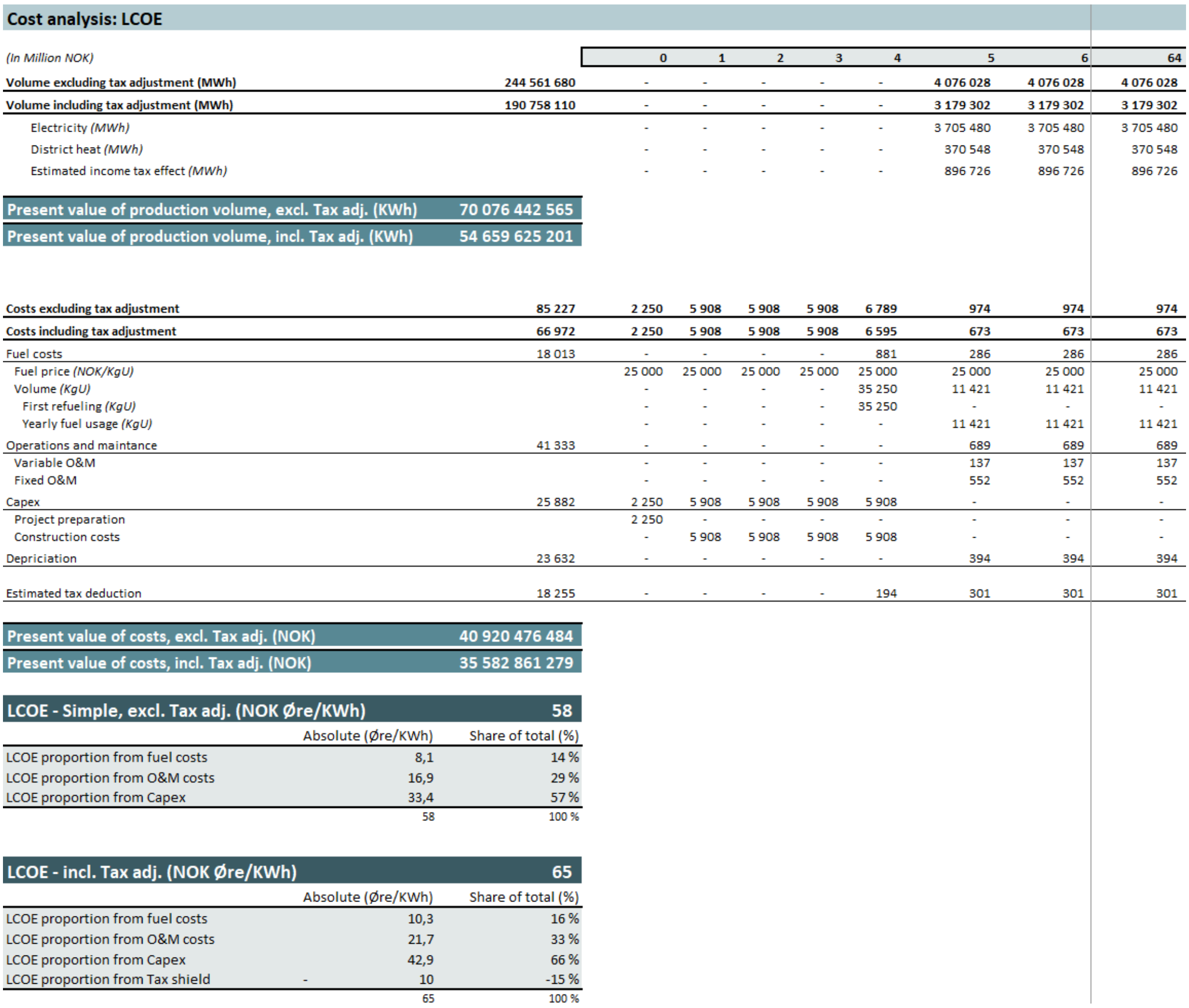
With the assumed base cases for all variables, as illustrated in *Figure 8.1,* we estimate that an SMR potentially can achieve an internal rate of return of 5-6% and an enterprise value of around 2-3 billion NOK. Therefore, if we look at the project, excluding financing, it is evident that there is potential for profitable investments. However, these are large investments amounting to tens of billions of NOK, which also creates the need for large debt financing with associated finance costs, which in turn creates a negative present value for the potential shareholders. This does not necessarily imply that it's impossible to create shareholder value, it just illustrated the need for, and importance of getting affordable and appropriate financing solutions. As we will highlight later in this analysis, there are also large variations in the output of the model, depending on the applied scenarios.

The project will be able to accumulate a large positive net cash flow of around 60-70 billion NOK at the end of its lifetime, with a payback time of around 20 years. The payback time may seem quite high, though it should be seen in the context of a long lifetime of 60+ years. The longevity of the project is an important aspect to keep in mind since it is a material factor for the profitability. To put it into perspective, in the 60 years of operations, a project like this could generate around 100 billion NOK while also supplying energy to thousands of households and several businesses, with an investment of around 25 billion NOK, implying a net present enterprise value of around 75 billion NOK if we ignore the cost of capital. We are not suggesting that we should ignore the costs of capital, the point is to highlight that since a lot of the cash generation comes a long time in the future, combined with a high upfront investment, the effect of discounting the cash flow is highly significant.

As we can see from the cash flow in the operational years, the operation in itself is highly profitable. In our assumed base case, the gross profit margin is around 85%, because of the low level of variable costs. Implicitly, within certain production volume intervals, the marginal costs are also low. Since they only need to cover around 7 and 3 øre/KWh for fuel and variable O&M respectively, such SMR projects to sell power at low prices down toward 10 øre/KWh. Thus, considering microeconomics and the energy market, such power plants are in a strong competitive position, which allows for high usage of capacity. This is important, considering that fixed costs make up around 70% of all operating expenses. However, the total cost level is overall moderate, allowing for an EBIT margin of around 50-60%. Additionally, revenue is translated to free cash flow in the rate of around the same rate of 50-60%. The operational period alone is strongly profitable with limited uncertainty and risk.

8.2.2 Cost analysis – LCOE

To give a more comparative picture of the cost levels, we have also created an LCOE model. We should note that we have included tax and accrual effects of depreciation, to match the LCOE with our DCF model. Additionally, the LCOE uses the same input as the DCF, meaning that the key aspects of cost distribution are similar, as discussed in the previous section. Instead of repeating ourselves, this section will focus on LCOE as a relative number and will especially be discussed considering findings on general LCOE levels from the comparative analysis. By using LCOE as a comparative number, we also remind the reader that the different alternative energy sources are fundamentally different and that LCOE has its fallacies by not capturing them.



Cost analysis: LCOE

(In Million NOK)		0	1	2	3	4	5	6	64
Volume excluding tax adjustment (MWh)	**244 561 680**	-	-	-	-	-	**4 076 028**	**4 076 028**	**4 076 028**
Volume including tax adjustment (MWh)	**190 758 110**	-	-	-	-	-	**3 179 302**	**3 179 302**	**3 179 302**
Electricity *(MWh)*		-	-	-	-	-	3 705 480	3 705 480	3 705 480
District heat *(MWh)*		-	-	-	-	-	370 548	370 548	370 548
Estimated income tax effect *(MWh)*		-	-	-	-	-	896 726	896 726	896 726

Present value of production volume, excl. Tax adj. (KWh)	**70 076 442 565**
Present value of production volume, incl. Tax adj. (KWh)	**54 659 625 201**

		0	1	2	3	4	5	6	64
Costs excluding tax adjustment	**85 227**	**2 250**	**5 908**	**5 908**	**5 908**	**6 789**	**974**	**974**	**974**
Costs including tax adjustment	**66 972**	**2 250**	**5 908**	**5 908**	**5 908**	**6 595**	**673**	**673**	**673**
Fuel costs	18 013	-	-	-	-	881	286	286	286
Fuel price *(NOK/KgU)*		25 000	25 000	25 000	25 000	25 000	25 000	25 000	25 000
Volume *(KgU)*		-	-	-	-	35 250	11 421	11 421	11 421
First refueling *(KgU)*		-	-	-	-	35 250	-	-	-
Yearly fuel usage *(KgU)*		-	-	-	-	-	11 421	11 421	11 421
Operations and maintance	41 333	-	-	-	-	-	689	689	689
Variable O&M		-	-	-	-	-	137	137	137
Fixed O&M		-	-	-	-	-	552	552	552
Capex	25 882	2 250	5 908	5 908	5 908	5 908	-	-	-
Project preparation		2 250	-	-	-	-	-	-	-
Construction costs		-	5 908	5 908	5 908	5 908	-	-	-
Depriciation	23 632	-	-	-	-	-	394	394	394
Estimated tax deduction	18 255	-	-	-	-	194	301	301	301

Present value of costs, excl. Tax adj. (NOK)	**40 920 476 484**
Present value of costs, incl. Tax adj. (NOK)	**35 582 861 279**

LCOE - Simple, excl. Tax adj. (NOK Øre/KWh)		**58**
	Absolute (Øre/KWh)	Share of total (%)
LCOE proportion from fuel costs	8,1	14 %
LCOE proportion from O&M costs	16,9	29 %
LCOE proportion from Capex	33,4	57 %
	58	100 %

LCOE - incl. Tax adj. (NOK Øre/KWh)		**65**
	Absolute (Øre/KWh)	Share of total (%)
LCOE proportion from fuel costs	10,3	16 %
LCOE proportion from O&M costs	21,7	33 %
LCOE proportion from Capex	42,9	66 %
LCOE proportion from Tax shield	- 10	-15 %
	65	100 %

Figure 8.2: Base case LCOE-model with output.

To begin with, we have calculated two forms of LCOE. First, we have a simple LCOE, excluding taxes, which is comparable to the LCOE data presented and discussed in the comparative analysis. However, to match the LCOE with the DCF, we also need to include tax effects. We refer to the data and methodology chapter for further explanation. The difference between the two estimates is rather small but still has an effect. Although the simple LCOE is the more comparable, the tax-adjusted LCOE is the actual average price we need for the present enterprise value to equal zero. Therefore, we argue that this LCOE represents a better picture of relative cost levels, and it is the one we will focus on this for the sensitivity analysis. We note, however, that the tax-adjusted LCOE is somewhat higher than the simple LCOE, which implies that it is overstated by a few øre/KWh compared to LCOE estimates from the comparative analysis.

With our base case assumptions, the simple LCOE excluding tax adjustments is around 55-60 øre/KWh, implying that the project in itself is profitable at all average price levels throughout the project lifetime above that level. In relation to the comparative analysis, the LCOE is in line with both estimates from NVE and IEA, with a somewhat lower estimate than the former, and around the average estimate compared to the latter. In the comparative analysis, we argued that nuclear energy, and in particular, SMRs represent a cost-competitive alternative in Norway. Our independent LCOE estimates certainly strengthen our argument, although it is not conclusive because of the high uncertainty within our estimate and regarding future development.

When we adjust for taxes and calculate the actual LCOE for the fictional SMR project, we get an LCOE between 50-60 øre/KWh. At today’s price levels, which according to the market analysis from NVE is around 100-150 øre/KWh in the southern zones in 2023, the project is certainly profitable with significant margins. However, a potential SMR project is not relevant before several years into the future and has a longevity of multiple decades, also having exposure to the market prices several decades into the future. As highlighted in our analysis, market prices generally are expected to decrease and stabilize at a significantly lower level. Therefore, there is high uncertainty as to whether future price levels allow for potential SMR projects to be profitable.

Then again, this is the case for all alternative energy sources. From a comparative perspective, lower LCOE from nuclear power and particularly SMRs, implies a better ability to endure lower price levels, compared to other alternatives with high LCOE. This is especially relevant for VREs such as wind and solar in combination with storage, which generally have a relatively high LCOE and LCOS, as highlighted in the comparative analysis. To put it into perspective, although an SMR project seen in isolation might be unprofitable at price levels below 50-60 øre/KWh, it should still be seen as the best alternative compared to another energy project with higher LCOE. Additionally, when also considering external costs and implications, the argument is likely strengthened for SMRs.

8.3 Sensitivity and scenario analysis

8.3.1 Sensitivity analysis

To gain a better understanding of the potential profitability of a small modular reactor project in Norway, we have employed a DCF model. However, a DCF model is only as good as its input, which can be highly variable, resulting in vast differences in profitability based on the significance of said input. To account for this and to highlight the most significant input variables, we will present a sensitivity analysis of how various economic measures vary in response to input changes. As shown in the figures below, some inputs are considerably more significant than others, but excluding these variables, the changes in our economic indicators are minor overall. Inferring that only a few variables have a substantial effect on the profitability of this project.

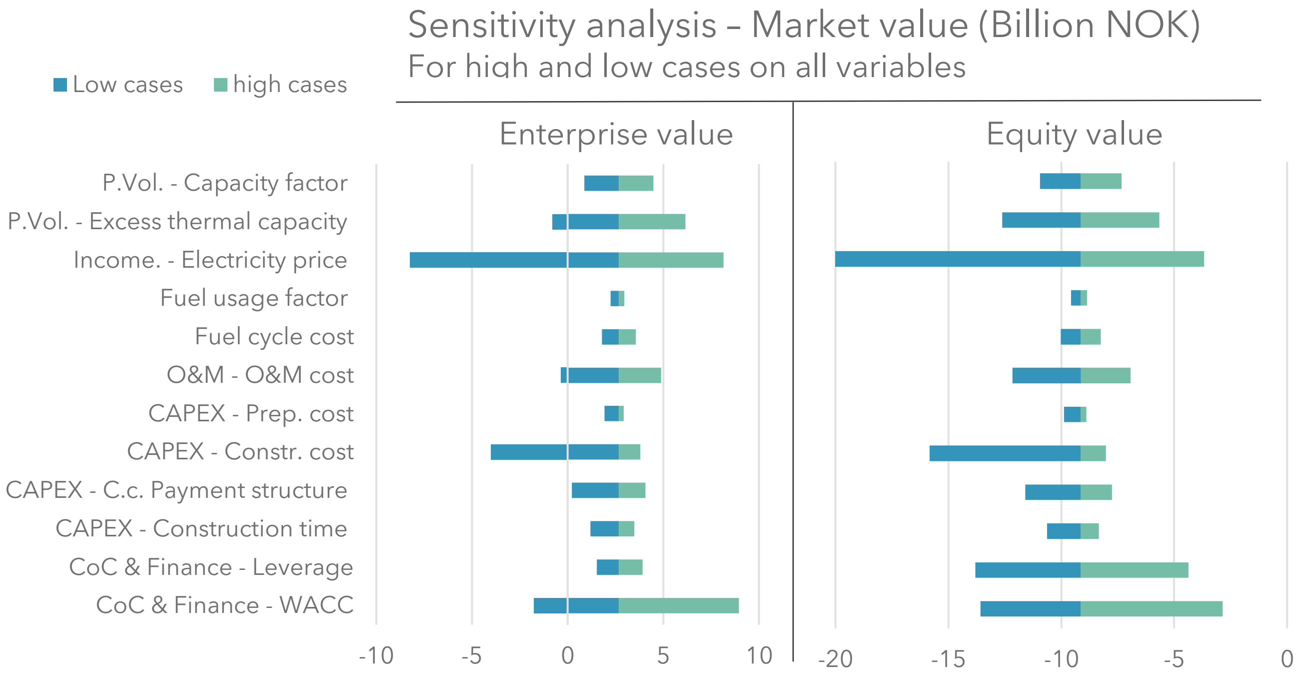


Figure 8.3: Sensitivity analysis - Enterprise value and equity value.

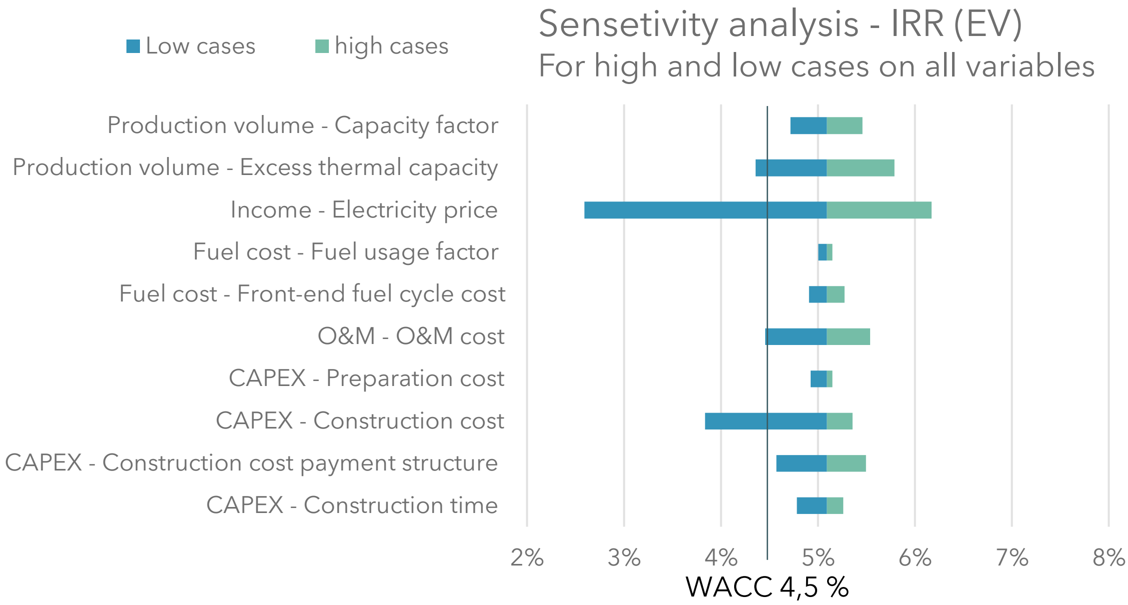


Figure 8.4: Sensitivity analysis - Internal rate of return (IRR) to enterprise.

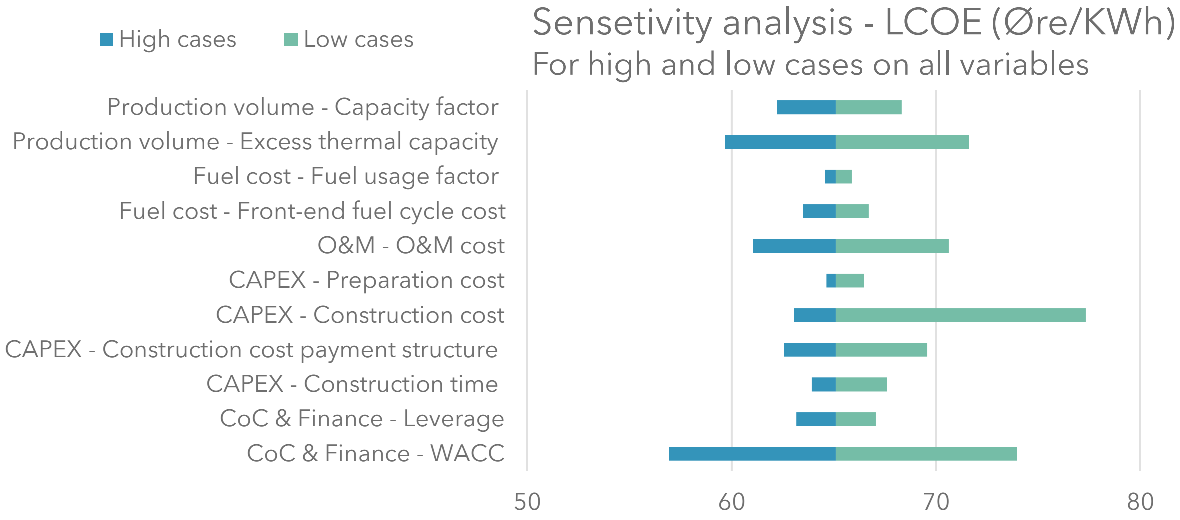


Figure 8.5: Sensitivity analysis - Levelized cost of energy (LCOE)

Revenue, Production volume & price

This project's revenue consists of two components, the quantity produced and the selling price of this quantity. Independently, we can see that their effects on the various economic measures are distinct; for example, the power price does not affect the LCOE because it is a cost measure. Moreover, price by itself, although highly significant, is not particularly interesting because, all other factors being equal, a higher price results in greater profitability, and vice versa. Any price above the LCOE will yield a positive enterprise value, and any price above 86 will yield a positive equity value. Furthermore, when we examine the sensitivity of volume, it appears to be one of the most significant variables, particularly when viewed as a whole, incorporating excess heat and capacity factor. For example, a five-percentage point increase from 90% capacity factor to 95% capacity factor increases enterprise value by 68%. Examining the low-case scenario for excess heat reveals that removing the ability to export the excess heat would result in a negative enterprise value. In addition, the difference between low capacity and high capacity for excess thermal capacity is nearly 12 øre/KWh. Demonstrating the potential risk reduction impact of generating revenue by utilizing excess heat.

Fuel Costs

A power producer's variable costs are a crucial metric, as they should reflect the price at which it can sell power. However, as stated previously, the variable costs of a nuclear power plant represent a negligible portion of total costs. And as can be seen from the preceding figures, fuel costs, and usage factors are two of the less significant variables in determining profitability, having little effect on the LCOE, with a 50% increase in variable fuel costs only increasing the LCOE by 5%. However, from an overall cost perspective, all contributions will be beneficial, and any increases in fuel efficiency or decreases in fuel costs, such as the ability to recycle fuel waste, could increase the profitability of the project.

Operation and maintenance costs

We have previously stated that the O&M costs represent a relatively small portion of the LCOE of a nuclear power plant due to discounting effects. Consequently, variations in O&M should have minimal effects on the LCOE. Based on the preceding figures, this appears not to be the case. However, the variation in our input variable is quite extreme with a 75% increase from low to high, making the O&M costs appear to be more significant than they actually are. And despite this substantial increase, the LCOE only rises by 15%. Nonetheless, O&M is a significant portion of the annual costs, and as *Figure 8.5* illustrates, obtaining a reasonable O&M cost could be the difference between a profitable and unprofitable project. This graph illustrates that a 25% reduction in O&M costs per kilowatt-hour, from 22,7 to 17,1 Øre, results in an increase in enterprise value from -350 million NOK to +2,7 billion NOK. Moreover, the enterprise value of this project would be approximately 1 billion NOK, with an LCOE of 68 Øre/KWh, even if NKK's worst estimate of 20 øre/KWh is accurate. Which is roughly 22 øre less than the latest offshore wind subsidy estimates of 90 øre/KWh (Holter & Melgård, 2023).

CAPEX

We have previously demonstrated that, due to discounting effects, the large initial investment represented by CAPEX is the single most significant cost variable in terms of the profitability of this project. This is also reflected in the preceding numbers, where the enterprise value decreases from approximately +2,7 billion NOK to -4 billion NOK in our low-case scenario, which reflects a high construction cost. The high construction cost is based on the base case for construction duration and evenly distributed down payment structure. Nonetheless, if we accounted for the possibility of an increase in construction time, this reduction would be even greater. As can be seen from the figures, which do not account for the correlation between construction delays and cost overruns, thereby reducing the effect of CAPEX with an increase in discounting effect, the enterprise value continues to decrease due to revenue loss with increased construction time. Moreover, the various down payment structures allow us to clearly observe the effect of discounting. Where, for example, the ability to pay equally over four years results in an approximately 11-fold increase in enterprise value compared to paying in full prior to construction. A difference that grows exponentially as the WACC increases. Clearly illustrating the potential impact of the down payment structure and initial investment size on the NPV of the project. Additionally, it highlights the potential of largely increased profitability, especially to the shareholders, with favorable short-term financing of the construction costs.

Financing and cost of capital

With a large initial investment and a stable cash flow over the long term, it comes as no surprise that the cost of capital is the most significant variable affecting the profitability of this project. For instance, a reduction of one percentage point in the WACC results in a two- to threefold increase in enterprise value. In addition, our estimated LCOE with a 3,5% WACC is approximately 57, which is comparable to hydropower from reservoirs. Demonstrating the significance of reasonable financing to a nuclear power plant's profitability. This is further demonstrated by the various debt amounts, where for all values, which alter the value of debt and simultaneously the WACC, the enterprise value remains positive while the equity value remains negative.

8.3.2 Scenario analysis – Profitability trends of multiple projects

We have simplified the thesis by only modeling one project. However, In the case that SMR technology becomes feasible and politically mature in Norway, it will not consist of one project, but several reactors spread across the county. A key part of any new technology, which is highly relevant for all potential energy sources, is technological advancements, learning effects, and operational improvements. All factors contribute to reducing the cost over time.

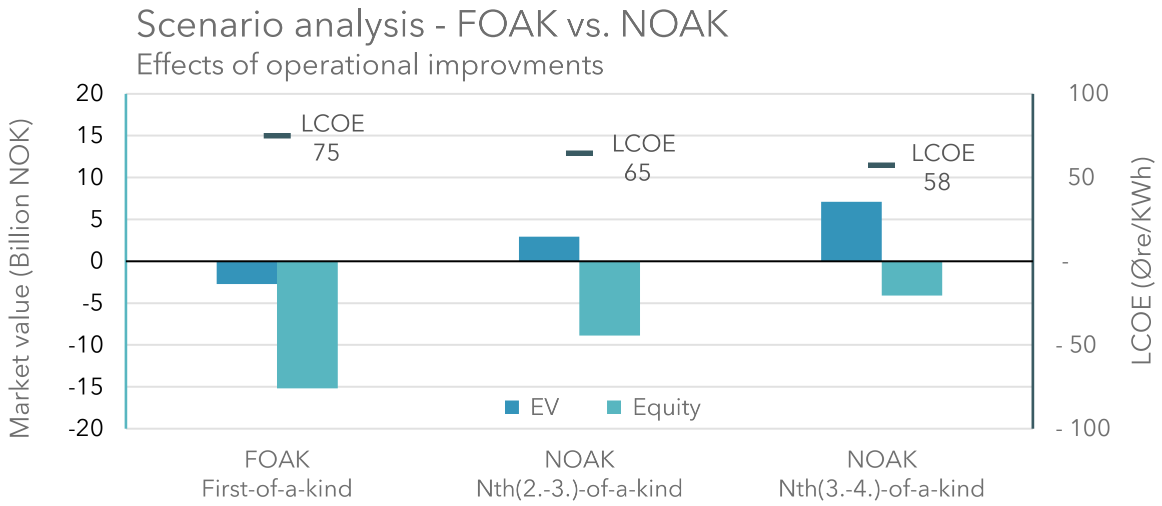


Figure 8.6: Scenario analysis - FOAK vs. NOAK, operational improvements.

Figure 8.6 illustrates operational improvements, which are done by using low, base, and high cases for the variable input on O&M costs, CAPEX costs for preparation and construction, and construction time. For in-depth information about the underlying assumptions and scenarios, we refer to previous sections in this chapter, in addition to the data and methodology chapter. Again, we stress that SMR is a new technology still under development, and Norway has no experience in operating commercial nuclear power plants. Naturally, building a power plant FOAK will likely come with challenges in planning, constructing, and operating the plant. This is associated with higher cost levels and lower profitability for the first project. Especially connected to preparing and constructing the plant, both in terms of investment size and the time it takes to construct it. Both revenue and fuel costs are highly dependent on price levels and are not significantly affected by experience.

With gained experience from the first project in combination with technological improvements and adjustments, it is very likely that 2.-3. projects can be planned, prepared, constructed, and operated more efficiently. This naturally represents cost reduction and improved profitability, from the reduction in O&M costs, in addition to reduced investment costs and construction time of the power plant. This is the same as our base case presented previously in this chapter. We argue that the effects from learning and improvements in technology and operations will continue to the 3.-4. These projects will have significantly reduced cost levels and improved profitability. Additionally, if it happens, by the time we start building in Norway, the supplier of the SMR will already have built reactors in other countries. Additionally, the key argument for SMRs is the modularity and standardization, which we could argue offsets some, but not all FOAK effects. We could potentially see the first project being closer to the cost level of the 2.-3. of its kind, as illustrated in *Figure 8.6*.

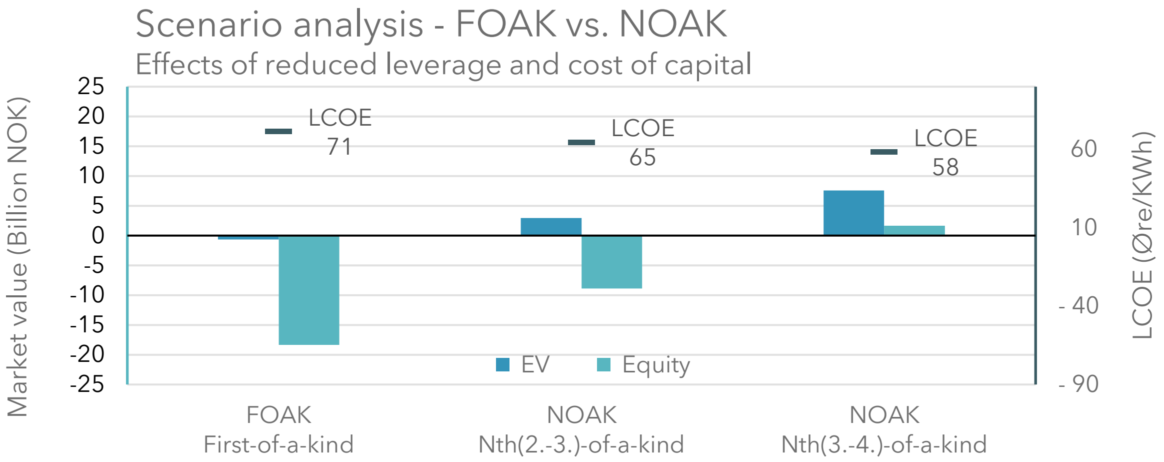


Figure 8.7: Scenario analysis - FOAK vs. NOAK, reduced debt and cost of capital.

Figure 8.7 illustrates a reduction in leverage and cost of capital, which is done by using low, base, and high cases for the variable input on capital structure and the weighted average cost of capital (WACC). Again, for in-depth information about the underlying scenarios, we refer to previous sections in this chapter, in addition to the data and methodology chapter. As highlighted previously in this chapter, both capital structure and cost of capital is important drivers of profitability to a potential SMR investment. One of the key challenges with this type of project is high up-front investments and relatively long payback times, thus also making it challenging to finance. For the first project, financing is challenging as there is uncertainty with a project which has not been done in Norway before. Ultimately there are no proof of the ability to generate cash from the project, making it harder to get investors on board and driving the cost of capital up.

Gradually as more projects are initiated and they start generating cash, the feasibility of the technology and operations is proved, and cash-flow will be generated. These aspects have material implications for the financing and cost of capital. Firstly, generating cash from the initial project allows for internal financing and reduces the need for external debt. Consequentially, the leverage of each project will gradually decrease. Secondly, when proving the feasibility of the projects and the ability to generate cash, the uncertainty and risks are significantly decreased. With decreased uncertainty, the required return from investors, both debt- and shareholder, would naturally decrease, decreasing the cost of capital. Furthermore. These effects increase with time, and as illustrated in *Figure 8.8,* both leverage and cost of capital reduce with each project, which increases the profitability and cost competitiveness of the later projects.

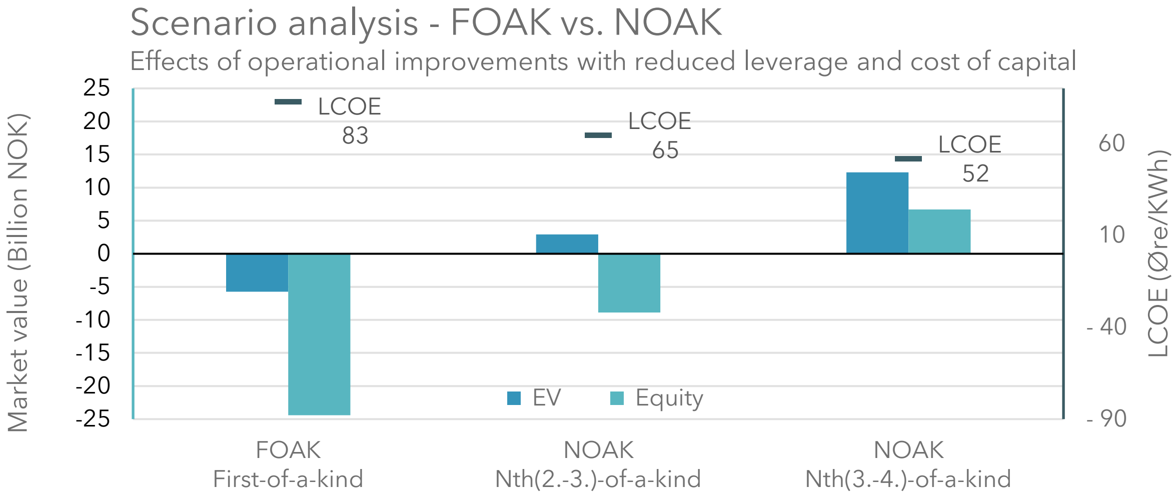


Figure 8.8: Scenario analysis - FOAK vs. NOAK, economic and financial effects.

Now, we can add all the effects together. *Figure 8.9* illustrates the potential profitability and cost levels of different projects over time, with increasing operational improvement and decreasing leverage and cost of capital. All factors are explained previously in this section. Although possibly exaggerated, we can observe that the first project is likely to be unprofitable, with both the net present value of the project itself and the equity of the project being negative. Additionally, an LCOE of over 80 is not cost-competitive in the long run. However, with the following projects experiencing positive impacts from technological advancements, learning effects, and operational improvements, in combination with increased ease of financing and reduced cost of capital, the situation improves significantly with time and amount of projects. The 3.-4. projects and any other project beyond that, we have estimated to be profitable and largely valuable at multiple billions of NOK for both the project itself and the equity of the project. Additionally, we estimate an LCOE of around 50 øre/KWh, which is highly likely to be cost-competitive. Note also that this LCOE is including taxes and is somewhat higher than simple LCOEs, as explained previously. If it were calculated as simple LCOE, the amount would be closer to 45 øre/KWh.

Again, we stress that these are estimates from models with high uncertainty and several underlying assumptions and prerequisites. However, from the analysis above, we highlight there is a large potential value-creation from learning, gaining experience, and technological improvements by investing in nuclear power plants, and SMRs. Additionally, by taking advantage of the modularity, standardization, and experience of the supplier, there is a possibility of reducing the unprofitability of FOAK projects. Moreover, this analysis highlights the importance of financing, and that there is room for improvement by accessing cheap financing to start with. Both these factors combined, we could see projects being more profitable and cost-competitive than the numbers we have presented.

9. Discussion

This master's thesis is a contribution to the energy debate and consists of three parts: the first is a market analysis which investigate the future need for added energy supply, in addition to whether nuclear energy has a place in the Norwegian energy mix, and how it fits with the current supply and relevant alternatives. The second section is a comparative analysis that compares nuclear energy to Norway's anticipated future energy sources on various economic and societal metrics. Finally, we conducted a profitability analysis to determine whether a potential SMR project could be profitable. The purpose of these three sections is to provide a comprehensive and nuanced overview of the potential benefits and challenges of adding nuclear energy to Norway's energy mix. In this chapter, we will integrate the most significant topics from the preceding three sections into a comprehensive discussion considering the most prevalent arguments from both sides regarding the inclusion of nuclear energy in Norway's energy mix.

Future challenges and supply scarcity of power

As we have demonstrated, there will be an enormous demand for energy in the future, which we argue could be met in part by SMRs. Historically, nuclear power has been utilized as baseload, or as a stable foundation in a larger energy portfolio. Hydropower has fulfilled this role in the Norwegian energy mix. Therefore, many will argue that this aspect of energy-generating technology is an unnecessary addition to the Norwegian energy mix. However, due to the projected large increase in VRE, hydropower will be required to serve as both a baseload and a backup producer when weather-dependent sources are unable to produce enough, for which its momentary producing capacity is inadequate. In addition, because there is a correlation between wind and rainfall, years with low inflow into the reservoirs frequently coincide with years with low wind power production (Koestler et al., 2020). Meaning we could potentially experience periods with minimum reservoir capacity and insufficient wind production. This represents a problem that could partially be resolved by incorporating SMRs as baseload, freeing up hydropower capacity to function more as a dispatchable power producer, capable of meeting demand in Norway and other grid-connected countries. In any case, since SMR is a new generation of nuclear technology, the notion that nuclear power plants are only suitable for baseload is overly restrictive. Nuclear power has dispatchable capabilities, SMRs have a more flexible production capability, allowing them to function as part of a larger energy portfolio, potentially also as a dispatchable source filling in the gaps when VREs are unable to produce.

Nuclear power compared to relevant alternatives

There are numerous distinctions in the nature of the various energy sources that are frequently overlooked in the debate. Two common arguments against nuclear power are that it is costly and time-consuming to build, with frequent cost overruns and construction delays. However, the time-consuming nature of the construction of alternative power-generating sources is not taken into account. Øyfjellet wind farm, for example, submitted its license application in 2014 and completed construction of all wind turbines eight years later, in 2022, where construction began in 2019 (Øyfjellet, n.d.). In addition, Equinor recently postponed indefinitely one of their offshore wind projects due to rising costs (Hovland & Jordheim, 2023). Considering the different operational lifetimes of the different sources, which range from 20 to 30 years for wind and 60 to 80 years for nuclear, any construction time estimate must be at least doubled to be comparable to that of a nuclear power plant. Additionally, as previously presented, if we also consider the need for energy storage for VRE with the connected costs increase, nuclear appears to be economically competitive to other alternatives. Additionally, offshore wind is currently estimated to be more expensive than a nuclear power plant. Bearing this in mind, the expected four-year construction period and the substantial initial investment of an SMR appears reasonable.

Furthermore, resource utilization is rarely truly considered. For instance, because of the rising costs that rendered Equinor's project unfeasible, nuclear power's low material intensity relative to alternative energy production becomes a greater advantage. And because China controls a significant portion of the value chain, the addition of nuclear power makes the green transition less susceptible to political tension, such as the trade war between China and the United States. Additionally, if we were to place a value on land area, where the moose hunt alone is estimated to be worth 1,1 billion NOK in Norway (Skillingstad, 2020), thus preventing energy sources from being discounted for their impact on nature, wind and solar power would fare much worse than nuclear due to uranium´s energy density.

Moreover, because of previous nuclear power plant accidents, there is a widespread belief that nuclear energy negatively impacts the environment and could be dangerous. As we have demonstrated, however, this is largely based on misleading media coverage rather than facts.

Whereas Fukushima was more of a crisis due to one of the strongest earthquakes in recorded history and a subsequent tsunami than from the nuclear power plants, “the Chernobyl accident was the result of a flawed reactor design and poorly trained personnel” (WNA, 2022). Both accidents were terrible, but they are unlikely to occur again, therefore, we find the argument to lack nuance and comprehension. Both the EU and the United Nations have concluded in their respective reports that nuclear power is the safest energy source with the least negative impact on society. With a well-documented and secure procedure for managing nuclear waste (Abousahl et al., 2021 & UNECE, 2022).

Financial and economic feasibility of nuclear power and SMRs

Our calculations indicate that an SMR project in Norway could be profitable. To create shareholder value, however, it must be financed affordably, as shown by our sensitivity analysis, which demonstrates that an increase in WACC exponentially increases LCOE and exponentially decreases enterprise and equity value. Moreover, the substantial initial investment, relatively long construction period, and long operational lifetime with stable free cash flow would require investors with a long-term perspective. Possibilities include pension funds and energy-intensive industries that require stable, reliable, and affordable energy. In addition, the economic viability of several industries may be jeopardized if electricity prices remain volatile and high for an extended period of time. In such a scenario, it is not implausible for a bank to provide very affordable financing for a nuclear power plant in order to maintain the portfolio's value.

The green transition is important, but it cannot ignore sustainability, which also involves economic viability. It is therefore paradoxical that Statnett ignores the possibility of nuclear power in the energy mix, in their long-term market analysis, due to it not being economically viable, while at the same time stating the need for subsidies in the seemingly relevant alternatives, offshore wind, batteries, and electrolysis. In addition, as suggested by our own and externally estimated LCOE, an SMR project would be able to compete with offshore wind, where the estimated LCOE and last projection for price subsidy exceed our estimates. Moreover, if we examine NVE's estimated LCOE for various energy sources, it includes learning effects for offshore wind but not for nuclear, even though such effects are well-documented for nuclear power plants and the modularity of an SMR is likely to make it highly susceptible to such a learning effect. In addition, any learning effects are contingent on exploration, meaning there will be no such effects in nuclear if Norway never includes nuclear as an option. Therefore, the two sources are not compared on an equal basis, creating a bias against nuclear energy. Furthermore, such subsidies should not be used to finance the green transition at any cost, rather, they should be allocated to the most economically viable options.

From an investment portfolio perspective, it is shortsighted to base our future energy mix on a small number of sources. For instance, as we have explained, because of the extensive plans for wind in the North Sea, it is likely that all grid-connected countries will simultaneously experience a deficit in their energy balance during periods with little wind, making imports unlikely. This a dangerous situation if it occurs during a cold winter, especially if reservoir levels are low. However, we are not arguing for the addition of only nuclear power to our energy mix. As we saw in France, where a significant portion of their reactors had to be shut down for maintenance at the same time (Wheeldon, 2023), illustrating the risk of having too high exposure to nuclear power. We argue that nuclear power should be permitted as part of a larger and more diverse portfolio of energy sources in order to reduce the risk of energy deficits.

10. Conclusion

> “*Can nuclear small modular reactors (SMR) be economically and financially feasible alternatives to the long-term energy challenges, and represent a positive societal contribution to the Norwegian energy mix?*”

In this thesis, we have taken a three-pronged approach to the issue at hand. Initially, we examined the need for added power supply, in addition to whether nuclear energy has room in the Norwegian energy mix. Subsequently, we conducted a comparative analysis to determine how nuclear energy compares to hydro, wind, and solar in terms of various economic and societal metrics. Furthermore, we have conducted a profitability analysis to determine the potential economic value of an SMR-based project. From our analyzes, we have determined that the future energy demand is nearly undefined. In addition, we find that nuclear energy is the least resource-intensive and has the least negative environmental and societal impact. Lastly, we acknowledge that our profitability analysis is based on several assumptions whose validity is difficult to ascertain. Nevertheless, according to our estimates, nuclear power, with its unique characteristics of a large initial investment and a long and stable cash flow, could achieve profitability with the right investors. Consequently, based on our findings, nuclear energy deserves and should be acknowledged as a viable option for the Norwegian energy mix on par with the relevant alternatives, such as wind and solar.

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