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# Preface

This is my master's thesis for the University of Stavanger's master's programme in Industrial Economics. I would like to thank my fantastic cohabitant, family, friends, and colleagues for their encouragement and support throughout my studies. I would like to thank my supervisor, Knut Erik Bang, and everyone who has consulted with me and helped me identify relevant challenges for the thesis. The work on this thesis has given me a good understanding of how the petroleum industry interacts with politics, which will be valuable in my future work life. Studying such a relevant and rewarding topic has been a privilege.

André Mellemstrand Jarstø

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# Abstract

This thesis aims to answer whether Norway should continue the development of the Norwegian Continental Shelf with power from shore, based on analysis and comprehensive literature study. The world is undergoing a transformation driven by global warming, and the emphasis on sustainable development has never been more prominent. Norway's total reduction in $CO_2$ emissions from 1990 levels was 4,2% in 2020, implying that rapid and significant emission reductions across all sectors are necessary to reach the target. The petroleum industry is Norway's most polluting industry but also the most essential in terms of value creation, government revenues, investments, and export value. Electrification with power from shore is an emission-reducing measure that is critical for Norway to achieve emission reduction targets.

Power from shore to the Norwegian continental shelf will increase energy consumption. Norway is at a crossroads regarding the distribution of surplus zero-emission electricity. The results show that political legislation is the most powerful driver and barrier to electrifying the Norwegian continental shelf with power from shore. The environmental impact analysis shows that electrification will lower Norway's upstream and domestic emissions while increasing downstream emissions that are not included in Norway's national climate targets. The EU Emissions Trading System (EU ETS) implies that electrification has no net environmental impact on $CO_2$ emissions in the 30 member countries if the released gas is used for quota-controlled activities. The net environmental impact outside of Europe depends on several uncertain factors.

The political and economic framework facilitates good conditions for oil and gas companies to electrify the Norwegian continental shelf. The economic sensitivity analysis implies that gas turbine efficiency has the greatest impact on the Norwegian government's decision on whether power from shore should be implemented or not. Oil fields have a limited lifetime, and power from shore reduces the power surplus in Norway, net energy exports to Europe, and increases the electricity prices in Norway.

Based on the findings and results of the three analyses, the thesis concludes that Norway should not continue the development of the Norwegian Continental Shelf with power from shore.

## Abbreviations

PESTL - Political, Economic, Social, Technological, Legal

HVDC – High Voltage Direct Current

AC – Alternating Current

DC – Direct Current

TWh – Terra Watt-hours

LNG – Liquid Natural Gas

NCS – Norwegian Continental Shelf

OECD – Organization for Economic Cooperation and Development

Sm$^3$ o.e. - Standard Cubic meters of oil equivalents

b.o.e. – Barrel of oil equivalents

Mtoe – Million Tonnes of Oil Equivalents

EEA - The European Economic Area

EU ETS – European Union Emission Trading System

EU - The European Union

UK – The United Kingdom

MPE – Ministry of Petroleum and Energy

MCE - Ministry of Climate and Environment

NPD - Norwegian Petroleum Directorate

NVE - The Norwegian Water Resources and Energy Directorate

PSA - Petroleum Safety Authority Norway

CHP – Combined Heat and Power Plant

FPSO - Floating, production, storage, and offloading vessel

IPPC - Intergovernmental Panel on Climate Change

UNFCCC - United Nations Framework Convention on Climate Change

CAPEX - Capital expenditures

OPEX – Operating Expense

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# 1 Introduction

The world is undergoing a transformation driven by global warming, and the emphasis on sustainable development has never been more prominent (IPCC, 2022a). According to the Intergovernmental Panel on Climate Change (IPCC), global warming has increased by 1.0 °C beyond 1990's preindustrial levels and is expected to reach 1.5 °C between 2030 and 2050 if current pollution trends continue (IPCC, 2018). The impacts of global warming can already be witnessed in the deepest parts of the ocean and on the highest mountains. The time is about to run out if we are to save the world as we know it (IPCC, 2022). The planet will likely undergo irreversible climate effects if global warming exceeds 2 °C (IPCC, 2018). Therefore, the world came together in 2015 to try and change the negative trend.

The Paris Agreement was adopted by 193 Parties to prevent irreversible effects through a legally binding international agreement establishing long-term goals to guide nations toward limiting the temperature rise below 2 °C (UNFCCC, 2015). Global emissions must peak between 2020 and 2025 for the world to achieve this target (IPCC, 2022b). The Paris Agreement commits Norway and other member nations to set new and more ambitious $CO_2$ emission reduction targets every five years (UNFCCC, 2015). Norway enhanced its commitment in 2020. The new target is to reduce emissions by at least 50% up to 55% by 2030 and net-zero by 2050, relative to 1990 levels (UNFCCC, 2020). Norway's total reduction in emissions from 1990 levels was 4,2% in 2020 (SSB, 2021), implying that rapid and significant emission reductions across all sectors are necessary to reach the target (IPCC, 2022b).

The petroleum industry is Norway's most polluting industry but also the most essential in terms of value creation, government revenues, investments, and export value (Meld. St. 13, 2021; SINTEF, 2019), accounting for approximately 27% of Norway's $CO_2$ emissions in 2020 (SSB, 2021). Oil and gas will play an essential role in the global energy mix for decades to come due to the ever-growing global energy demand. Electrification with power from shore is an emission-reducing measure that is critical for Norway to achieve emission reduction targets (Meld. St. 13, 2021).

Throughout 2021, the conditions for powering the Norwegian continental shelf from the shore changed. Businesses and consumers have been hit hard by all-time high electricity prices due to extraordinary gas prices, precipitation fluctuations, and $CO_2$ pricing (Nord Pool, 2022;

Statnett, 2022). While many countries are working to make their electricity-generating emission-free, Norway already has renewable electricity production. As a result, the demand for green energy rises as more industries want to connect to the grid or expand their existing outlets (Statnett, 2022). Statnett emphasises in its study «Short-term Market Analysis 2021-2026» that Norway's present power surplus will drop to zero by 2026 if the current expansion trend continues (Statnett, 2021). Power from shore to the Norwegian continental shelf will increase energy consumption. Norway is at a crossroads regarding the distribution of surplus zero-emission electricity. The potentials and consequences of powering the Norwegian continental shelf from shore are unclear, which leads to the investigation of the thesis:

*Should Norway continue the development of the Norwegian Continental Shelf with power from shore?*

Three research questions are formulated to answer the investigation of the thesis:

**1.** What is the most critical driver and barrier for electrifying the Norwegian continental shelf with power from shore?

**2.** Does electrification of the Norwegian Continental Shelf reduce $CO_2$ emissions?

**3.** How do political and economic frameworks facilitate power from shore development?

## 1.1 Structure of the thesis

The thesis consists of 8 chapters. Chapter 2 provides theory about the subject before introducing the methods utilised in Chapter 3 to answer the research questions. The analysis is split into three parts:

- PESTL Analysis
- Environmental Impact Analysis
- Economic Sensitivity Analysis

PESTL Analysis is presented in Chapter 3.5, analysed in Chapter 4 and ends with a summary of the PESTL results in Chapter 4.6. PESTL constitutes the theoretical foundation which will be discussed further in Chapter 7. The environmental impact analysis is presented in Chapter 3.6, and the results are presented in Chapter 5.3. Economic Sensitivity Analysis is presented in Chapter 3.7 with results in Chapter 6.1. All findings and results are discussed in Chapter 7, which provides the basis for the conclusion in Chapter 8. The thesis ends with a recommendation for future research that can contribute to developing new topics for future studies.

## 1.2 Constraints

The master's thesis is based on information and data until April 2022. Due to time and resource restrictions, limiting the report's scope to a feasible size was necessary.

# 2 Theory

## 2.1 Electrification

"Electrification with power from shore" implies that you cease obtaining electricity from gas combustion (gas turbines) on platforms and instead extend cables to shore and transmit power from there (Osmundsen, 2012). Today, most platforms are powered by gas turbines that run on natural gas extracted offshore. Electrification with power from shore reduces the $CO_2$ emissions from oil and gas extraction since the Norwegian electricity mix is generated from renewable energy (NPD, 2020; OECD, 2022). Using power from shore reduces the amount of gas combusted offshore, allowing a greater volume of gas to get exported to Europe (Riboldi, Völler, Korpås, & Nord, 2019).

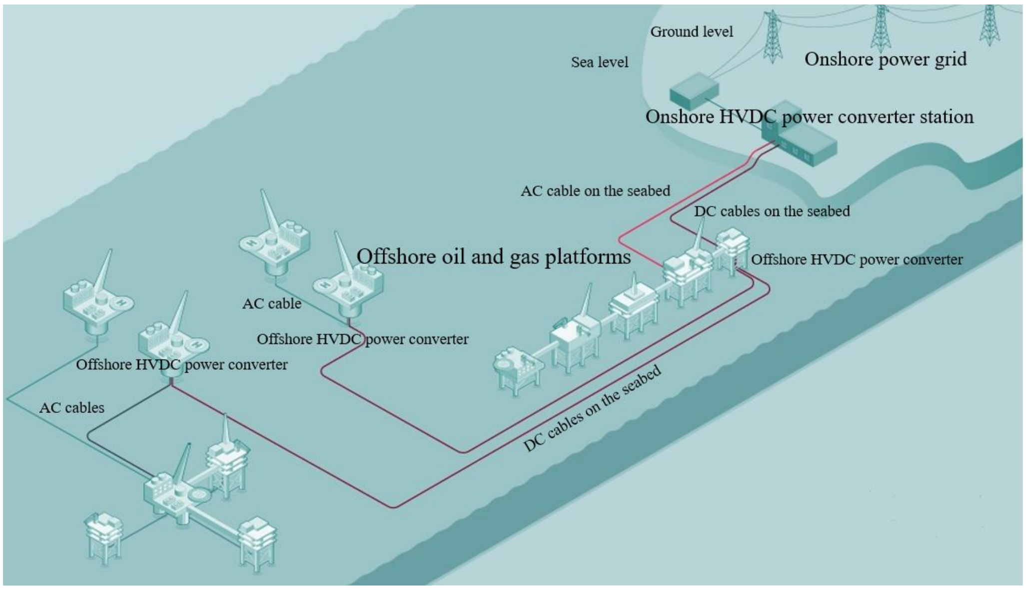


*Figure 1 - Illustration of electrification offshore (Equinor, 2012, 2022a).*

Electrification includes transmitting power from the onshore grid and distributing it to various offshore platforms, as illustrated in Figure 1. Power from shore can be transmitted as either direct current (DC) or alternating current (AC). DC is better suited for transmitting large amounts of power over longer distances because the resistance is lower than in AC cable, resulting in less transmission loss (NPD, 2020). However, if electricity is transmitted from shore as DC, it must be converted on land and offshore since both power systems are based on AC. Electricity conversion results in energy loss (Statnett, 2013). High-Voltage Direct Current (HVDC) converter equipment is typically large, heavy, and expensive, resulting in many offshore installations being better suited to AC cables (NPD, 2020).

Existing offshore installations must reconstruct to have access to shore electricity. These are often more costly and complex projects than designing a new installation with power from shore technology (NPD, 2020). Many power from shore projects is being evaluated for connection to existing facilities, typically costing between four and five billion NOK (NPD, 2020). Conversions and expenses vary depending on the existing facility, size, and the amount of equipment to be changed. The available space and weight capacity, distance from land, and installation style, such as fixed or floating platforms, are critical in determining the scope and expense of power from shore conversion (NPD, 2020).

## 2.2 Norway’s Emission Status

### 2.2.1 Domestic Emissions Status

Norway’s emission level per capita remained below the Organization for Economic Cooperation and Development (OECD) average of 11.3 tonnes $CO_2$ equivalent in 2019, despite its small population size and significant oil and gas production (OECD, 2022). Norway has a good ranking in terms of emission intensity, calculated by dividing $CO_2$ emissions by gross domestic product and has grown to be Europe's largest energy exporter (OECD, 2022; Wood, 2016). Norway is energy self-sufficient on average years and has one of the most decarbonised power sectors globally due to its widespread use of renewable electricity, primarily hydropower (Figure 2). It is giving the country the second-largest share of renewables globally, with 51% of its energy mix and 99% of its electricity output (OECD, 2022).

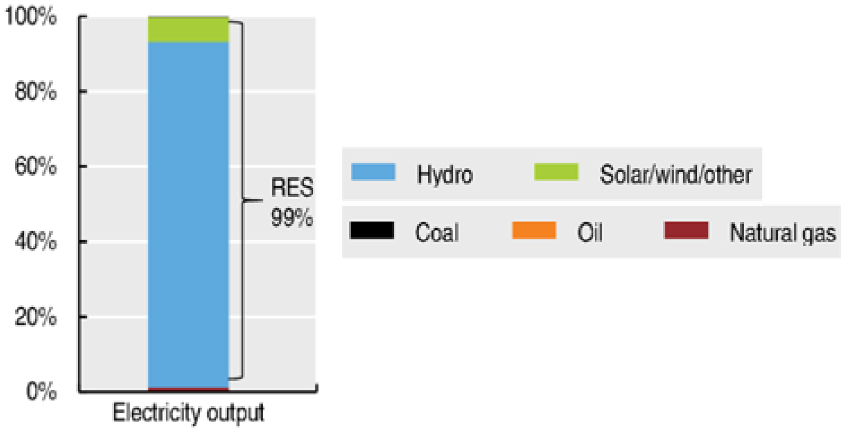


*Figure 2 - Norway’s electricity generation source (OECD, 2022).*

Despite all this, Norway is still far from reaching its enhanced legally binding climate targets through EEA and the Paris Agreement to reduce $CO_2$ emissions by 50% and towards 55% by 2030, compared to 1990 levels. In 2020, they were only 4,2% lower than 1990 levels (SSB, 2021). Norway's low emission reductions result from the country's primary starting point with a renewable electricity mix in 1990, leaving few quick and easy reductions. Figure 3 below illustrates that Norway had a clean electricity output in 1990 and 2018, resulting in the same $CO_2$ emission intensity of electricity generation.

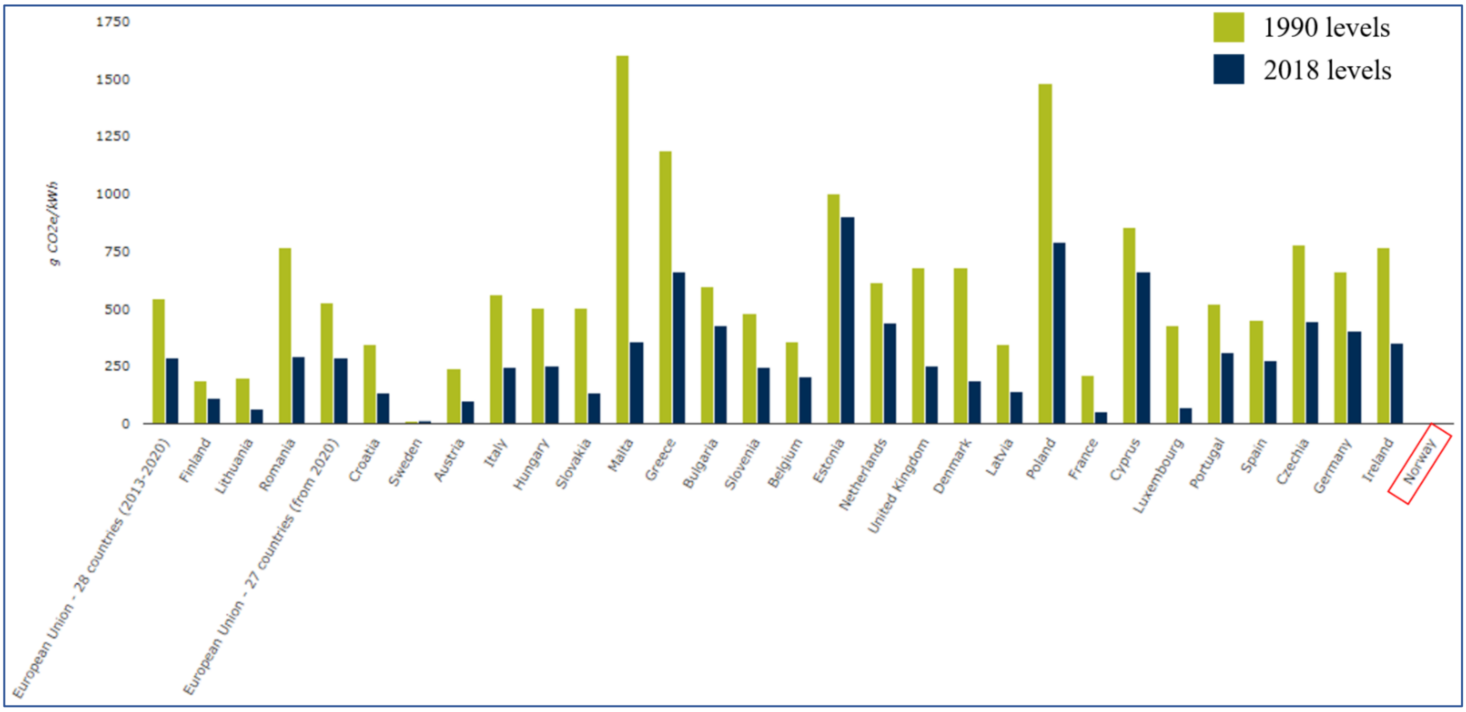


*Figure 3 – $CO_2$ emission intensity of electricity generation by country (EEA, 2020).*

Oil and gas extraction dominates Norway’s emissions, representing approximately 13 out of 49 million tonnes of $CO_2$ equivalents, or 27% of Norway's total $CO_2$ emissions in 2020 (Figure 4). The growth in oil and gas production from 125 to 231 million $Sm^3$ of oil equivalents has contributed to the poor $CO_2$ emission reduction from 1990 to 2020 (NPD, 2022d). Despite adding multiple fields to production, petroleum industry emissions have stayed steady over the last decade (SSB, 2021). $CO_2$ taxes and quota requirements create a financial incentive for oil and gas companies to reduce emissions. The Norwegian petroleum industry has high environmental and climate standards, with one of the world’s lowest carbon footprints for oil and gas extraction (OECD, 2022). Gas turbines account for 82% of $CO_2$ emissions from oil and gas extraction, making electrification of the NCS a very effective emission reduction measure, illustrated in Figure 4 below.

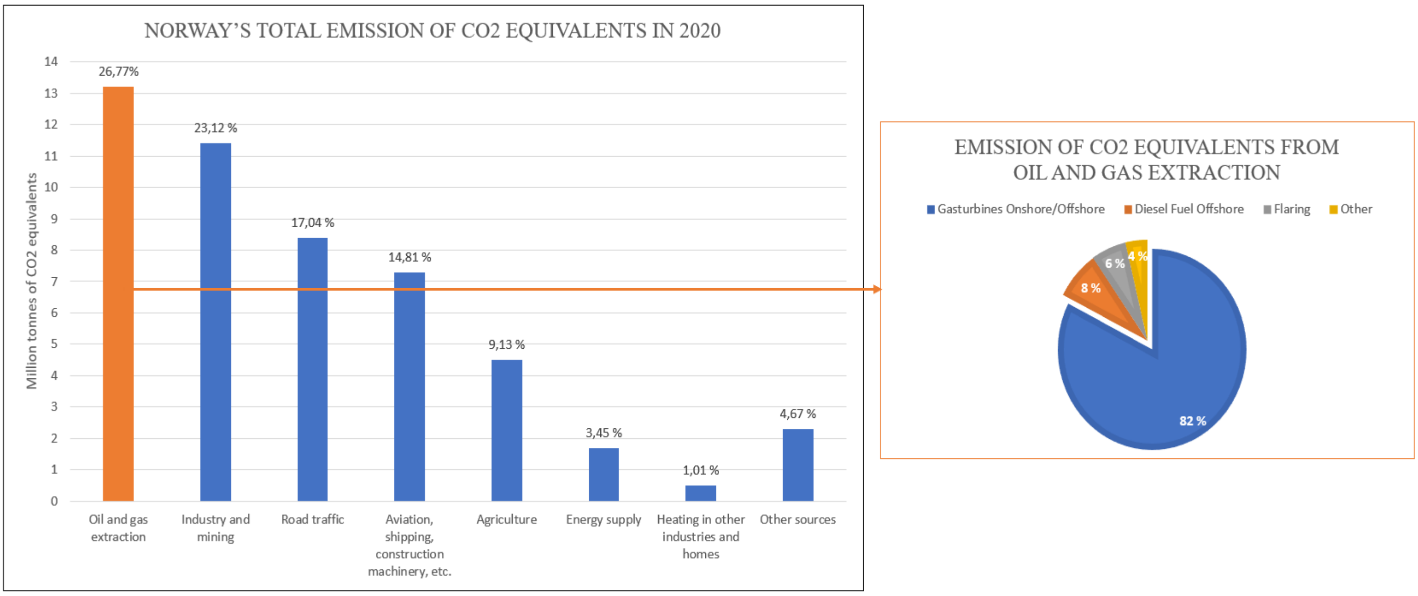


*Figure 4 - Norway's total emission of $CO_2$ equivalents in 2020 with the percentage of total $CO_2$ emission* (SSB, 2021).

As of 2022, 16 oil fields are using or have adopted power from shore to be operational by 2023. Then oil fields powered from shore will account for around 45 % of the Norwegian continental shelf's total oil and gas extraction. The fields will save roughly 3.2 million tonnes of $CO_2$ per year and increase electricity consumption from around 5 TWh in 2020 to around 7.9 TWh in 2024 (NPD, 2020). In addition to the 16 oil fields, six more mature electrification projects have made significant progress in the planning phase. If the projects are authorised, the avoided $CO_2$ emissions from shore power are expected to rise to roughly 4.9 million tonnes of $CO_2$ per year. That corresponds to a third of the total emissions from the petroleum sector in 2020 (NPD, 2020; SSB, 2021). The electrification of the entire Norwegian Continental Shelf will require approximately 15 TWh per year, which is approximately 10% of Norway's total yearly electricity consumption (NPD, 2020; Statnett, 2022).

## Norwegian Forest

Norway has large forest areas that capture $CO_2$ through photosynthesis (Nibio, 2021). Every year between 1955 and 1992, more than 60 million trees were planted each year. In 1990, Norwegian forests captured almost 15 million tonnes of $CO_2$ equivalent, compared to more than 23 million tonnes in 2019 (Figure 5). That corresponds to almost half of Norway's total $CO_2$ emissions in 2020 (Figure 4). The positive environmental contributions of forests are, per April 2022, not included in Norway's commitment to the EU and Paris Agreement (Hermansen, Farstad, Kallbekken, & Voigt, 2021). As illustrated in Figure 5, the impact of large-scale afforestation has begun to fade.

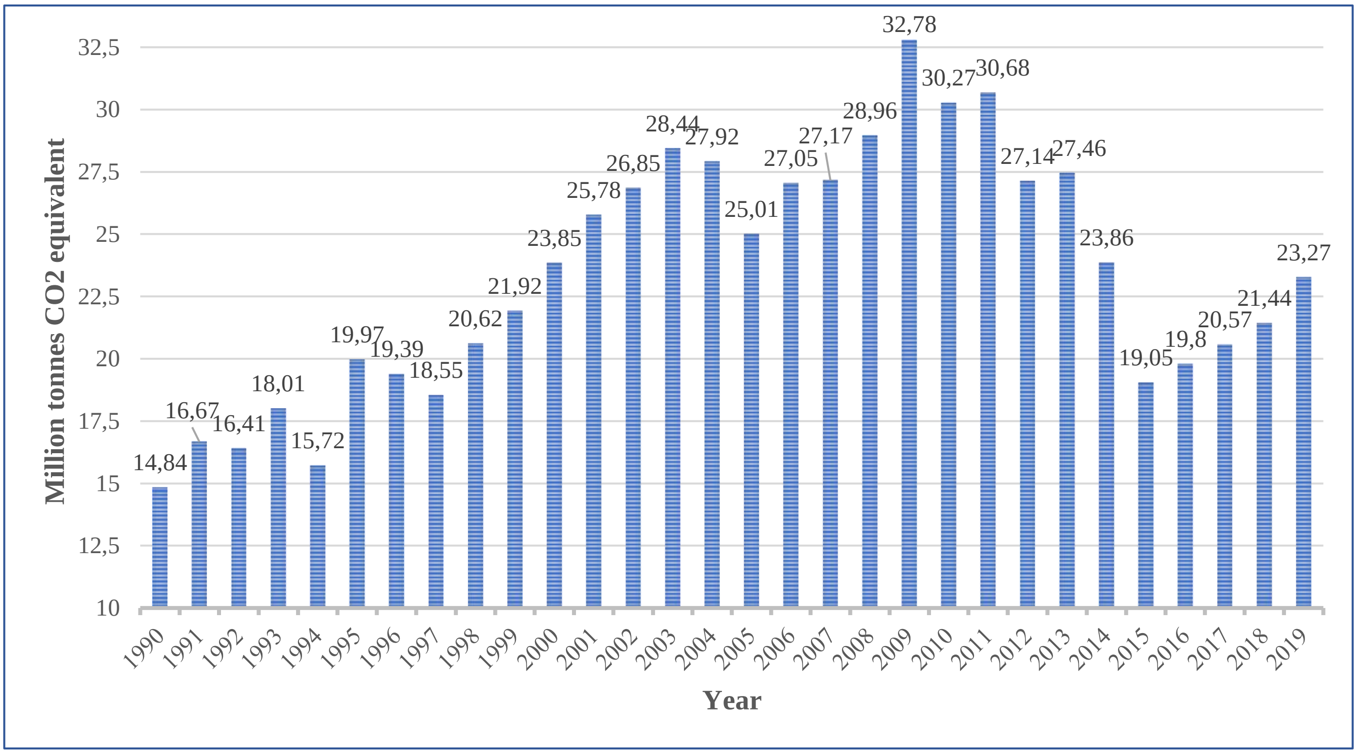


*Figure 5 - Annual $CO_2$ capture by Norwegian forests* (Nibio, 2021).

### 2.2.2 International Emissions

Norway is one of the world's largest downstream emitters since almost all of the oil and gas produced on its continental shelf is exported (McKinnon, Mittitt, & Trout, 2017; NPD, 2021). Norway's downstream emissions, also known as indirect emissions, origins from Norway's oil and gas activities, but the emissions occur at sources controlled by another country. In 2020, Norway exported around 66 million $Sm^3$ of crude oil and over 112 billion $Sm^3$ of natural gas to foreign nations. The gross energy density in Norwegian natural gas sales alone corresponds to approximately nine times the average Norwegian electricity generation (NPD, 2022a; Statnett, 2022).

Norway’s state-owned and biggest energy supplier, Equinor, operates about 70% of all oil and gas production on the Norwegian continental shelf (Equinor, 2021). They recently published their annual “Sustainability Report” (Equinor, 2022c) that provides insight into the significant difference in upstream and downstream emissions. Equinor delivered approximately 1206 TWh to the market in 2021, of which 4 TWh was from renewables (Equinor, 2022c). In 2021, Equinor's downstream emissions were 249 million tonnes of $CO_2$ equivalent, against its upstream emissions of 12.1 million tonnes of $CO_2$ equivalent. That includes all domestic and international activities (Equinor, 2022c). Chapter 3.6 present an analysis of the environmental impact of electrification of the NCS.

## 2.3 Lifecycle of Oil fields

A typical oil field has a production phase that includes a quick build-up to maximum output, followed by a flattening over a few years before production progressively falls (Lake, Johns, Rossen, & Pope, 2014). Future oil and gas production is dependent on investments in current fields, exploration, future discoveries, their size, whether they are permitted to be developed and when they are put into production (NPD, 2022d). Oil output will likely rise in the coming years due to recent shelf development work (NPD, 2022d). In 2021, 231 million barrels of oil equivalents were produced, not far from Norway's peak production of 264.2 million barrels in 2004 (Figure 6). The difference is that we produce significantly more natural gas due to the natural life cycle of a producing field, which includes less oil and lower reservoir pressure (Wei, Jia, Xu, & Fang, 2021).

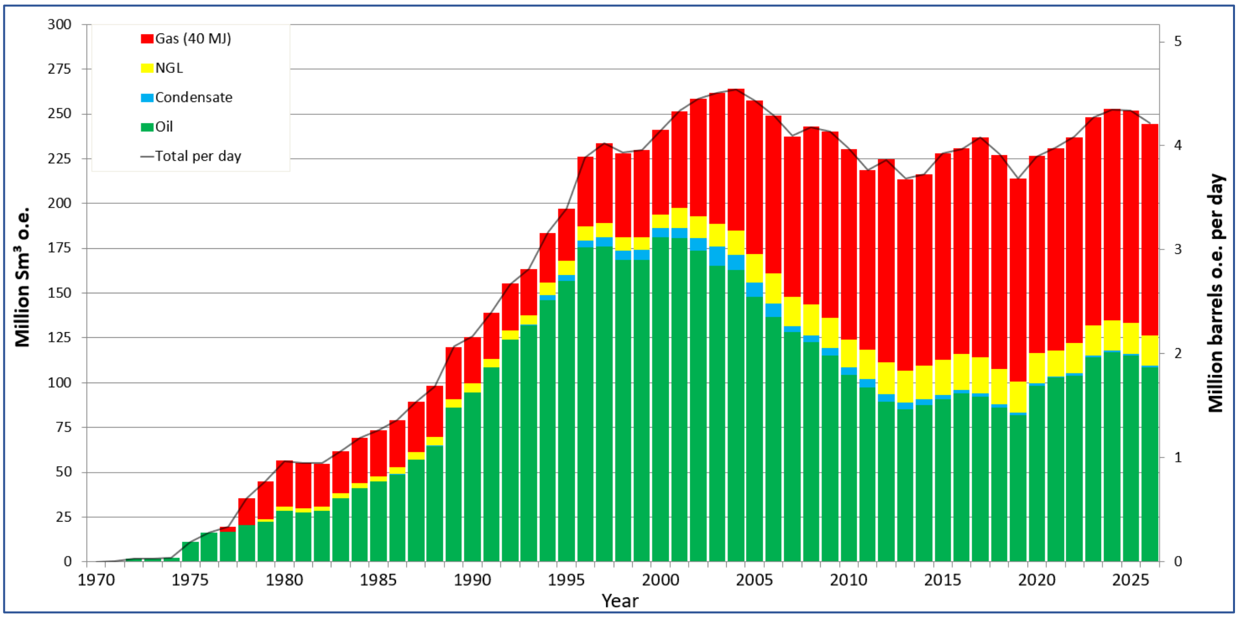


*Figure 6 - Historical and expected oil and gas production in Norway, 1970-2026* (NPD, 2022d).

According to the Norwegian Petroleum Directorate's (NPD) assessments, around two-thirds of Norway's natural gas resources have yet to be extracted (NPD, 2022a). Oil and coal emit significantly more $CO_2$ than natural gas, which is essential in limiting global warming (IEA, 2019). The NPD considers only four fields on the NCS to be inapplicable for electricity from shore since they have less than three years of operation remaining. There is insufficient time to build the electrification facilities before they are out of operation. The remaining fields may receive power from shore in the future (NPD, 2020).

## 2.4 Current Electricity Market

Power rates were at their lowest in recent history during the Covid-19 pandemic in 2020, but by the end of 2021, they had risen to their highest level ever (Nord Pool, 2022). The Norwegian electricity year of 2021 has been defined by significant contrasts, with the highest electrical consumption and generation ever, an hourly imports record, and massive pricing variations across the country (Figure 7 & Figure 8).

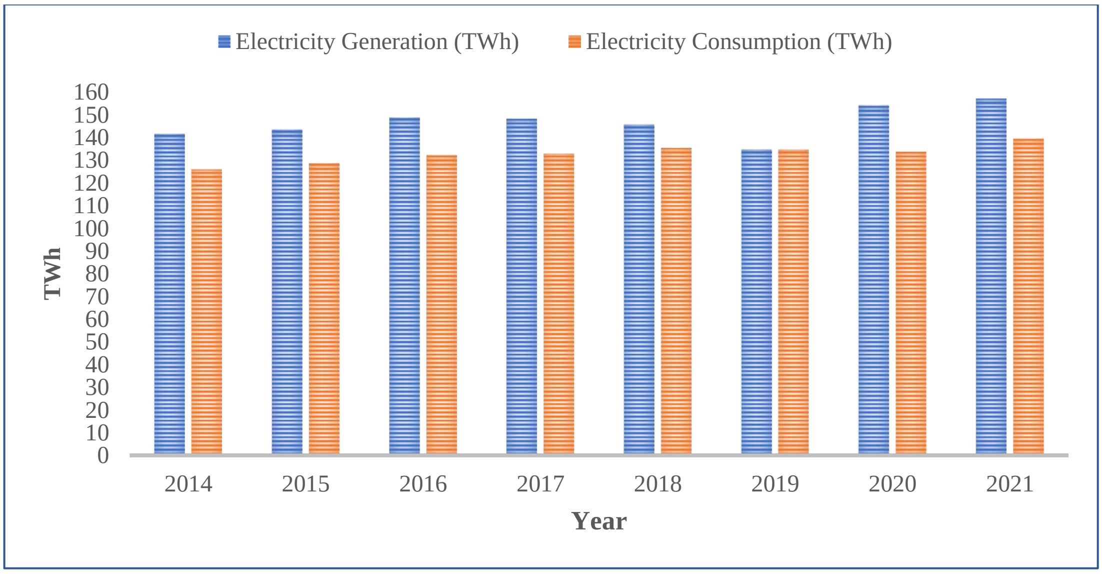


*Figure 7 - Norway's electricity generation and consumption, 2014-2021 (Statnett, 2022).*

Figure 8 below illustrates Norway's average electricity spot price over the last 15 years. Norway's construction of new power lines to Germany and the United Kingdom (UK) has increased its integration with the European power market (OECD, 2022). The integration, lack of wind and precipitation, record-high gas and coal prices, and a doubling of $CO_2$ quota fees contributed to the significant increase in Norwegian electricity prices in 2021 (Rystad Energy, 2022).

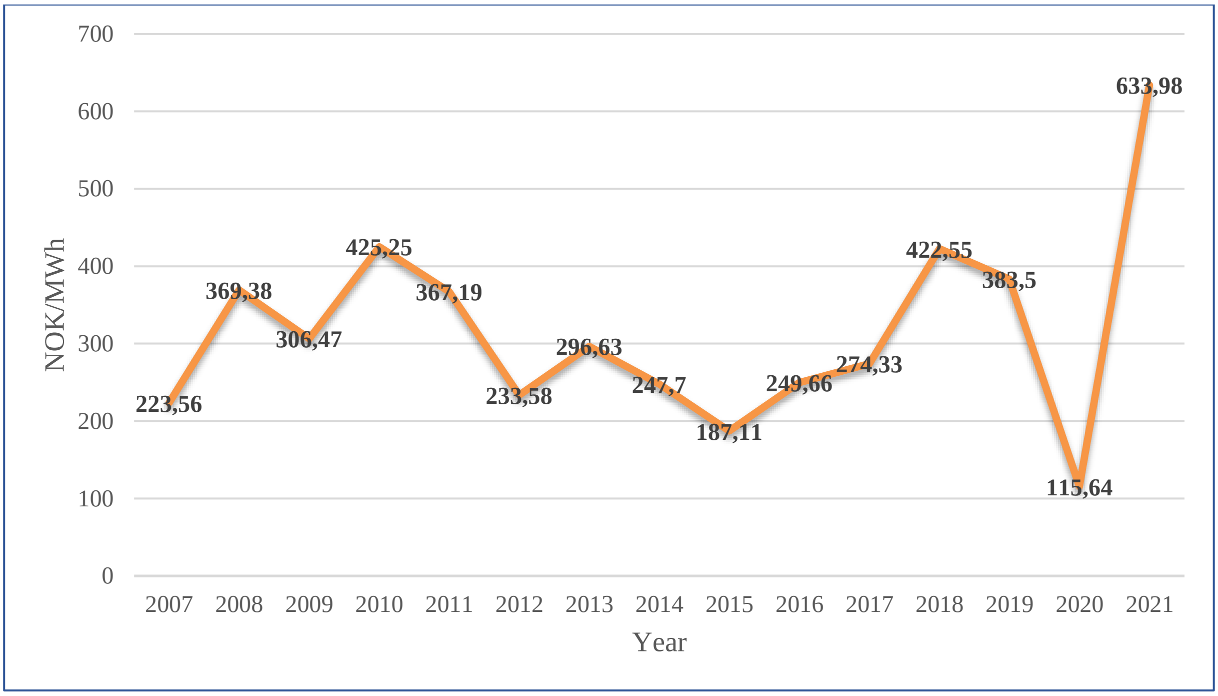


*Figure 8 - Norway's average electricity spot price per year* (Nord Pool, 2022).

# 3 Method

Theoretical research aims to account for empirical results and combine them to provide information (SNL, 2019). This chapter describes the approach to obtaining information and answering the research questions.

## 3.1 Qualitative and Quantitative Method

This thesis contains both qualitative and quantitative research to acquire data and information. The qualitative section aims to provide a solid understanding of the topic by presenting information that statistics alone cannot quantify. The PESTL analysis, which deals with data that presents a broad overview of the thesis's topics, employs qualitative approaches (Sammut-bonnici & Galea, 2015). The qualitative method for determining whether Norway should continue expanding power from shore to the NCS does not quantify the problem-related elements exclusively. The quantitative method has been used to quantify information, such as historical $CO_2$ emissions from oil and gas extraction and future projections of electricity consumption. Historical data make it feasible to give explanations and quantify estimates for potential $CO_2$ emissions and energy prices are included to conclude the research question.

## 3.2 Inductive versus deductive

This thesis required a deductive technique, comprising accumulating theory and evidence to conclude the research question. The inductive technique involves developing new hypotheses responding to an observable problem (Fredagsvik, 2020). The researcher must analyse the acquisition of empirical data before judging whether papers and studies are trustworthy and valid for data collection, which is a drawback of the deductive technique. Since scientists handle research regularly, research may be biased and retain an impression of the researcher's beliefs and opinions. Maintaining objectivity prevents overlooking critical information that challenges one’s ideas and convictions. Validity and dependability are essential for avoiding information and attitude bias (Fredagsvik, 2020; Granstrøm & Brun, 2019).

## 3.3 Reliability and validity

This thesis targets to provide a high level of reliability and validity. Reliability is a measure of the consistency of the research (Samset, 2015). For instance, if the data is consistent across time, the dependability may be determined using a test-retest reliability metric (Fredagsvik, 2020; Granstrøm & Brun, 2019). This is accomplished by repeatedly doing the same study within the same bounds and receiving the same findings. Regardless of who does the study, the research may be considered credible if the data are consistent. Reliable research is objective, and the researcher must maintain objectivity and abstain from personal biases and values when conducting the study. The validity of research is determined by how effectively it explains what it is designed to express (Samset, 2015).

## 3.4 Data collection

The theoretical foundation in the thesis is ideally prepared using primary and secondary data from a wide range of sources to provide different perspectives and opinions. The data collection heavily emphasises trustworthiness and validity based on the chosen authors, content, and publication dates. For factual basis, sources with high reliability and validity from the Norwegian government and large organisations such as the IPCC, IEA, NDP, SINTEF, KonKraft, NVE, Rystad Energy, and SSB were primarily used, with scientific articles and existing research on the relevant topics. These organisations are seen as objective and transparent, having dependable and unbiased viewpoints, while other sources, such as articles, may have more influenced perspectives. Various viewpoints are conducted regarding the research question and electrification of the NCS. Comparisons from other sources have been performed to ensure data consistency and trustworthiness of the thesis (Fredagsvik, 2020; Granstrøm & Brun, 2019).

The concerns about NCS electrification are changing rapidly. Most of the information and data are based on results in new and recent reports from organisations rather than literary books to assure legitimacy. It has been shown that different studies on the same issue may provide conflicting results because there are numerous opposing viewpoints regarding the electrification of the NCS. There is a greater chance of mixing up data with incorrect, biased, or invalid information from various sources. Obtaining data from reliable organisations and comparing information from several sources have been used to assure consensus and trustworthiness. Information develops from substantial data collection consistent across several reports, forming the foundation for eliminating incorrect material (Fredagsvik, 2020).

## 3.5 PESTL Framework

Extensive knowledge in various areas and critical factors regarding power from shore are required to answer the research questions. PESTL analysis is an effective method for analysing strategic risk and changes affected by the external macro-environment (Granstrøm & Brun, 2019; Sammut-bonnici & Galea, 2015). The PESTL framework examines political, economic, social, technological, and legal factors driving or creating barriers to electrification development.

## 3.6 Environmental Impact Analysis

This analysis will investigate the impact of Norwegian continental shelf electrification on the domestic and international CO2 emissions.

### 3.6.1 The Environmental Impact of Gas Turbines

The first part of the analysis will look at how much impact offshore gas turbines have on net oil and gas emissions, including downstream emissions. The analysis will provide insight into the emission reduction potential for power from shore because it substitutes gas combustion with electricity. The analysis compares Norway's total oil and gas production, including average emission factors, to total emissions from gas turbines on the NCS. The results were compared with Equinor's annual "Sustainability Report" (Equinor, 2022c) to ensure validity (Appendix 2).

### 3.6.2 The Environmental Impact of the Electricity Mix

The analysis method is inspired by the Cicero report, "Do electrification of platforms on the Norwegian Continental shelf reduce $CO_2$ emission?" (Torvanger & Ericson, 2013). The analyses research the $CO_2$ impact of electrifying a platform on the NCS. This is analysed by comparing the $CO_2$ emissions intensity of shore electricity generation from Norwegian, Nordic, or European electricity mix (El-mix) replacing the offshore gas turbines (BP, 2021; EEA, 2021; KonKraft, 2021). The analysis is split into two parts, domestic- and global environmental impact of electrification. The domestic part includes the environmental impact the electricity generation emissions have on power from shore implementation but excludes combustion of released gas. The global environmental impact includes released gas combustion. The electricity generated by the released gas replaces coal power or the average existing European El-mix. The analysis excludes replacing Norwegian and Nordic electricity mix because the existing El-mix emission intensities are substantially lower than electricity generated by gas combustion, resulting in a significant high net $CO_2$ emission impact. Power grid- and gaspipe transmission loss impacts the $CO_2$ emissions and the emission intensity to transport released gas through pipes (Torvanger & Ericson, 2013). Chapter 5 provides the data used in the analysis. A complete illustration of the method is in Figure 21, and the complete calculation is found in Appendix 2.

## 3.7 Economic Sensitivity Analysis

An economic sensitivity analysis of the $CO_2$ abatement cost was conducted with @Risk in Excel. The cost of CO2 abatement is the cost of an implementation per tonne of CO2 avoided as a result of the implementation. The analysis's objective is to provide insight into the economic factors the Norwegian Petroleum Directorate (NPD) considers when evaluating power from shore projects for development. The analysis is inspired by the method used by the Norwegian Petroleum Directorate in the “Power from shore to the Norwegian Continental Shelf” report published in 2020 (NPD, 2020). The 2020 report assesses the $CO_2$ abatement cost for all fields on the NCS. These calculations range from just under 1,000 NOK to 8,000 NOK per tonne of $CO_2$ prevented (NPD, 2020). An Excel dataset of a fictive power from shore project was made to obtain a $CO_2$ abatement cost base value. The dataset includes investments starting in 2023 and operating costs until 2036. Larger fields have higher capital expenditure (CAPEX) and operating costs (OPEX), preventing emitting greater amounts of $CO_2$ due to electrification. The equation calculates the $CO_2$ abatement cost:

$$\frac{NOK}{Tonne\ reduced\ CO_2\ emissions} = \frac{NPV(CAPEX+OPEX)_{PFS} - NPV(CAPEX+OPEX)_{APS}}{NPV(CO_2 emissions)_{APS} - NPV(CO_2 emissions)_{PFS}} \quad (1)$$

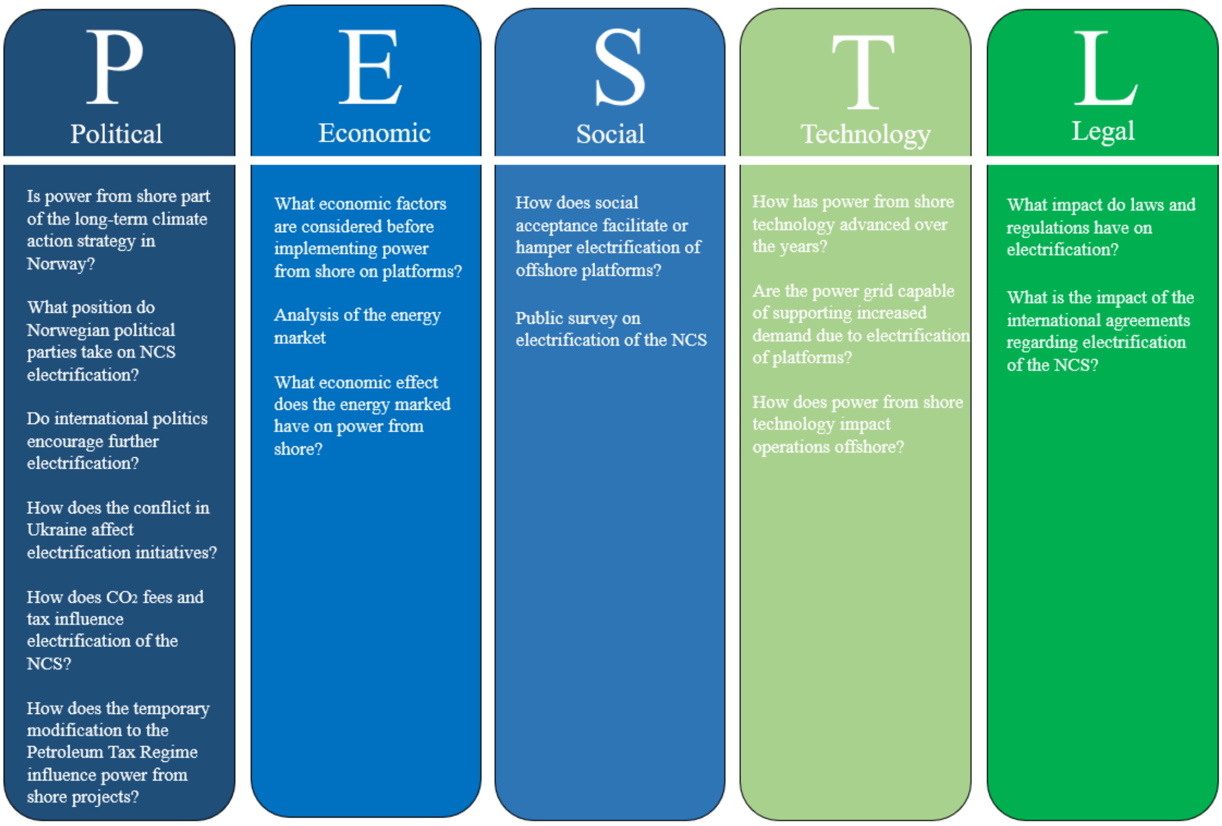
Where: NPV = Net Present Value, PFS = Power from Shore, and APS = Alternative Power Source.

The following parameters are used in the analysis: expected operating years, investment costs (CAPEX), operating costs (OPEX), total lifetime demand for electricity, discount rate, gas turbine efficiency, electricity price, gas price, and $CO_2$ price. The analyses assume that the NOx price is included in the $CO_2$ price. The total amount of $CO_2$ emissions avoided is dependent on the gas released, which is a variable of the fields' total lifetime electricity demand and gas turbine efficiency. All released gas is assumed to be sold on the open market. The released gas is the product of the electricity demand per year and gas turbine efficiency, divided by the theoretical energy density in natural gas, which has an energy density of 11,111 kWh / $Sm^3$ (NPD, 2022b). The total amount of $CO_2$ emissions avoided is the product of the average gas combustion emissions per 1 $Sm^3$ natural gas, 2.34 kg CO2 (SSB, 2017; Torvanger & Ericson, 2013), and the released gas as a result of electrification. The electricity cost per year is the electricity price and electricity demand product. The same method was utilised to calculate $CO_2$ costs and revenue from gas sales. The Excel command “NPV” calculated the net present value (NPV).

The input variables in the sensitivity analysis are economic factors that may change after the implementation is complete to see which variable has the most significant impact on the $CO_2$ abatement cost. The NPD must base implementation decisions on predicted values (NPD, 2020). Sensitivity analysis shows the impact the input variables have on the output number. The $CO_2$ abatement cost is the output number monitored by the "Output" command. The model varies one variable independently and collects the output result. 500 iterations were conducted to ensure convergence of the simulation. To start the sensitivity analysis, press the "simulate" menu and “Advanced Sensitivity analysis”, then choose the input cells to be included in the analysis. The changing input parameters are the discount rate, gas turbine efficiency, electricity price, gas price, and $CO_2$ price. The input has a triangular probability distribution obtained by the command "RiskTriang". @Risk calculates it by changing values from the input variables, one at a time, with a triangular distribution and reporting the output number variation. @Risk then collects the simulation results and how the different parameters affect the abatement cost. Appendix 1 contains the complete Excel model and analysis.

# 4 PESTL Analysis

The elements of the analysis are listed below:



Is power from shore part of the long-term climate action strategy in Norway?

What position do Norwegian political parties take on NCS electrification?

Do international politics encourage further electrification?

How does the conflict in Ukraine affect electrification initiatives?

How does $CO_2$ fees and tax influence electrification of the NCS?

How does the temporary modification to the Petroleum Tax Regime influence power from shore projects?

What economic factors are considered before implementing power from shore on platforms?

Analysis of the energy market

What economic effect does the energy marked have on power from shore?

How does social acceptance facilitate or hamper electrification of offshore platforms?

Public survey on electrification of the NCS

How has power from shore technology advanced over the years?

Are the power grid capable of supporting increased demand due to electrification of platforms?

How does power from shore technology impact operations offshore?

What impact do laws and regulations have on electrification?

What is the impact of the international agreements regarding electrification of the NCS?

*Figure 9 - PESTL Analysis (Granstrøm & Brun, 2019).*

## 4.1 Political

In 2021, the political climate for supplying electricity to the Norwegian continental shelf changed. Businesses and consumers have been hard hit by all-time high power prices and war in Europe, prompting speculation about whether electrification of the NCS is the ideal way to utilise surplus green energy. Political conditions and measures are continuously changing, and investments in powering the NCS with power from shore depend on Norwegian and international politics. Political influences include government activities, tax policy, trade policy, political agreements, and conflicts.

### 4.1.1 Politics in Norway

The Norwegian government announced its “Climate plan for 2021-2030” at the start of 2021 to develop a strategy to meet the commitment to the EU and UN's climate targets (Meld. St. 13, 2021). The EU has revised its 2030 climate target to a net 55% reduction, implying that they include $CO_2$ captured by forests through photosynthesis (Hermansen et al., 2021). Norwegian forests absorbed more than 23 million tonnes of $CO_2$ equivalents in 2019, while $CO_2$ emissions from oil and gas extraction were 13.2 million tonnes of $CO_2$ equivalents in 2020 (Figure 4 and Figure 5). Norway's climate plan excludes forests from the $CO_2$ reduction equation for the 2030 target. The reason is that Norway began preparing the climate plan in October 2019. Meanwhile, Norway and the EU revised and adjusted their climate targets in 2020. Norway must keep delivering on its current climate strategy until it is renegotiated (Hermansen et al., 2021).

The most critical measure for reducing $CO_2$ emissions in the oil and gas sector is to raise the $CO_2$ price to the point where the high emission costs provide an incentive for oil and gas companies to conduct power from shore projects (Meld. St. 13, 2021). As much as 82% of Norwegian oil and gas production emissions come from offshore power generation gas turbines (Figure 4). Therefore, electrification is the only solution to achieve adequate emission reductions to meet the oil and gas industry's climate goals (Meld. St. 36, 2021; Tahir, 2022). Power from shore is expected to save up to 6,5 million tonnes of $CO_2$ equivalents annually, according to KonKraft's status report of The Norwegian government's climate plan in Figure 10 below:

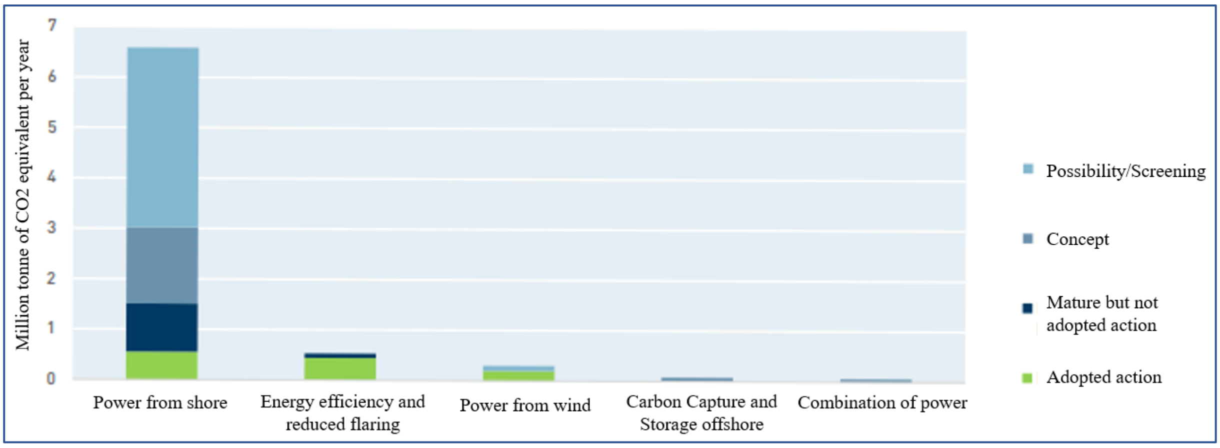


*Figure 10 - Overview of climate measure's maturity with expected impact on the oil and gas industry towards 2030 (KonKraft, 2021).*

Power from shore accounts for 85 % of the measures required to meet the 2030 $CO_2$ reduction target. Zero-emission technologies, such as $CO_2$ capture and storage, hydrogen, and ammonia, are not mature enough to significantly reduce emissions (KonKraft, 2021; Tahir, 2022). The

Figure below shows a forecast for electricity consumption from the NCS, 2020– 2040 (KonKraft, 2021).

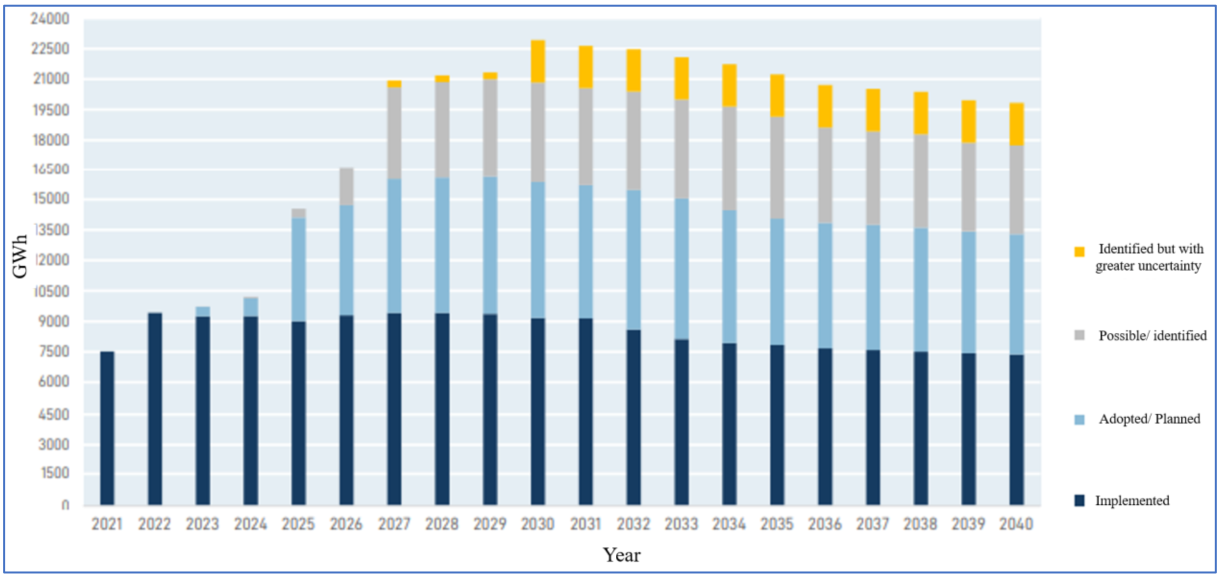


*Figure 11 - Basis forecast for electricity consumption from the NCS, 2020 – 2040 (KonKraft, 2021).*

Electrification plays a significant role in Norway's climate plan. However, debates among Norwegian government parties took place early in 2022 due to extraordinary high electricity prices. The political party Fremskrittspartiet proposed to the government to stop the electrification of the NCS, which was voted on and evaluated in March 2022 (Prop. 60 S, 2022). The votes were evident, as the only political parties voting to stop further NCS electrification development were Rødt and Fremskrittspartiet, as illustrated in Figure 12 below:

*Figure 12 - Positions of Norwegian political parties on NCS electrification (Prop. 60 S, 2022).*

### 4.1.2 International Politics

Norway's engagement and commitment to international climate policy are ambitious and heavily influenced by other countries. The UK has set an ambitious new climate target to reduce emissions by 78% by 2035 (GOV.UK, 2022). The United States' target aims to reduce $CO_2$ emissions by 50-52% by 2030 relative to 2005 levels by 2030, and China adopted a long-term goal of carbon neutrality in 2060 (The White House, 2021; UNFCCC, 2021). The EU decided in the autumn of 2021 to raise its climate target from at least 40% to at least 55% net $CO_2$ reduction by 2030 and make them legally binding through the European Climate Law (European Commission, 2022b). Norway's government aims to be a leader in global climate initiatives, one of which is to make oil and gas extraction less polluting (The Norwegian Environment Agency, 2021). The EU and the UK import around 92% of their natural gas from five countries; Russia, Norway, Algeria, the USA and Qatar (Rystad Energy, 2022). Norway has the lowest $CO_2$ emission intensity in natural gas extraction (Figure 13). The low emissions are primarily due to distance, transportation method, and low $CO_2$ emissions during extraction due to the electrification (Rystad Energy, 2022).

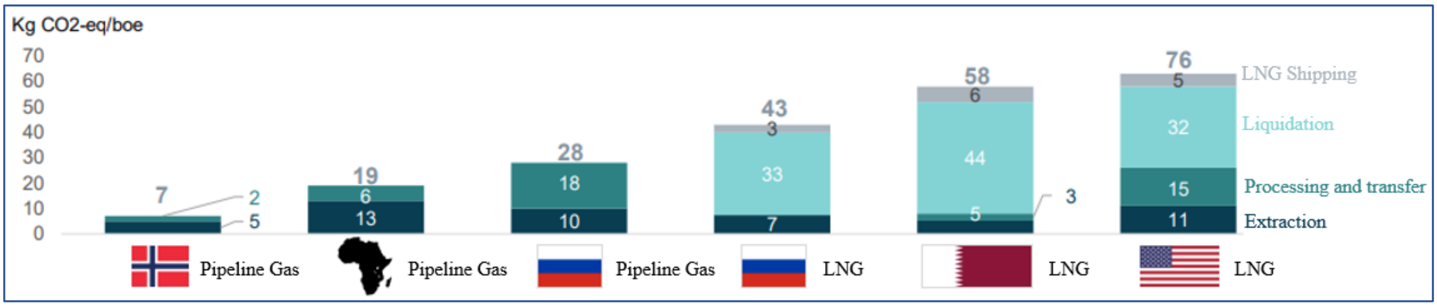


*Figure 13 - Emission intensity of gas imported by EU and UK, 2021 (Rystad Energy, 2022).*

Russia launched an invasion of Ukraine on February 24, 2022. In protest of the invasion, the EU and other Western countries implemented tough economic sanctions on the Russian economy. However, Europe's strong reliance on the Russian energy supply is an issue since new gas pipelines take a long time to build (Aanesen et al., 2022; Rystad Energy, 2022). Russia's oil and gas profits contribute significantly to Russia's state budget, which funds the military (Wezeman, 2020). The EU and UK spent 689 million euros per day on Russian gas during the first week of the war (Zachmann, Sgaravatti, & McWilliams, 2022). The International Energy Agency (IEA) launched a 10-Point Plan to Reduce the European Union's Reliance on Russian Natural Gas on March 3 (IEA, 2022). The strategy will assist Europe in getting independent of Russian fossil fuels before 2030 and may reduce the EU's dependence on Russian gas by two-thirds by the end of the year (McPhie, Parrondo, & Bedini, 2022).

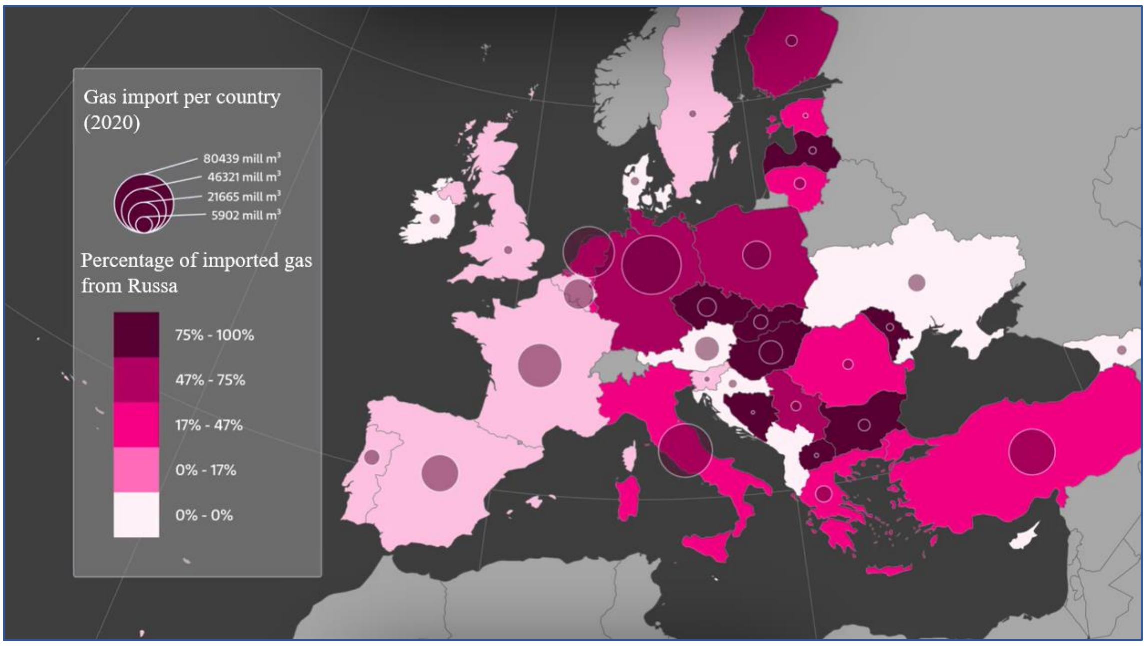


*Figure 14 - Russian gas import per country in 2020 (Aanesen et al., 2022).*

Since Russia invaded Ukraine, Europe's natural gas imports from Russia have decreased significantly, resulting in Norwegian gas having the largest market share in terms of volume (Rystad Energy, 2022a). Norway's output alone is insufficient to meet the expanding import needs of the EU and UK. Even if they receive all Norwegian natural gas, it will require more than twice as much gas from other sources (Rystad Energy, 2022). Europe strongly relies on natural gas to supply basic needs such as cooking and heating, and there are currently few feasible short-term alternatives (Rystad Energy, 2022). Future energy consumption will require new investments and development of natural gas extraction (Rystad Energy, 2022). Electrification of the Norwegian continental shelf enables more significant natural gas export to Europe.

Norway is a member of the European Economic Area (EEA) and is therefore bound to the EU Emission Trading Scheme (EU ETS) quota system. The EU ETS provides an annual carbon budget for its members, who must report quota and non-quota emissions to meet its obligations (European Commission, 2019, 2022a). Quota-restricted emissions accounted for approximately 95% of all $CO_2$ emissions from the petroleum industry in 2019 (NPD, 2020). The EU ETS quota system includes the petroleum sector and all power generation in Europe. If the released gas is used for activities covered by the quota system, electrification of the Norwegian continental shelf will not impact $CO_2$ emissions within EU ETS's 30 member nations. The number of allowed quota emissions is fixed, and companies receive or buy emission allowances, which they can trade as needed (European Comission, 2022). Reduced $CO_2$ emissions will offset a corresponding increase in emissions in another activity (Torvanger & Ericson, 2013).

### 4.1.3 $CO_2$ fees and Petroleum Tax System

The $CO_2$ fee and EU ETS create a financial incentive for oil and gas companies to reduce their emissions and encourage investment in emission-reducing technologies such as electrification. The $CO_2$ cost helps explain why petroleum industry emissions have remained steady over the last decade despite adding multiple fields to production (SSB, 2021). The Norwegian government plan to increase the total emission cost ($CO_2$ tax plus EU ETS quota price) to NOK 2 000 per tonne of $CO_2$ by 2030, measured in fixed 2020 kroner (Meld. St. 13, 2021).

Due to the extraordinary profitability of extracting petroleum resources, oil and gas companies are subject to a special tax. The petroleum tax system is based on the rules of the ordinary corporate tax system but governed by a separate petroleum tax law. The tax rate is 78%, comprised of the standard tax rate of 22% plus a special tax rate of 56% (NPD, 2022c). Only net profits at the company level are taxable rather than in each field. That implies that losses or expenses in a field can be subtracted from the company's overall profits. Oil and gas companies can carry forward deficits and tax-free income to subsequent years with interest compensation. Deductions for all relevant costs include expenditures linked to exploration, research and development, financing, operation, and final disposal of facilities (NPD, 2022c). Even if the projects are costly, it is financially beneficial for oil and gas companies to develop fields with power from shore.

#### 4.1.3.1 Temporary modifications to the Petroleum Tax System

As a result of the Covid-19 epidemic, global oil demand declined dramatically in the first half of 2020. The low oil prices generated temporary liquidity and financial issues and raised concerns about future projects. Therefore, the government authorised a temporary modification to the Petroleum Tax Act in June 2020. The temporary tax modifications were a mitigating action toward investment activity on the Norwegian continental shelf to lower the risk of postponing investment and projects (NPD, 2022c; Rystad Energy, 2021). The modifications include new regulations for depreciation, tax-free income, and economic loss handling. Full depreciation plus 24 % tax-free income is allowed in the special tax base in the investment year, and companies with losses may demand payment of this amount. The investment return is 73% in the first year. The implementation of negative forward tax implies that companies are paid the tax value of the predicted loss during the fiscal year (NPD, 2022c). The temporary modifications to the petroleum tax system apply to all investments made in 2020 - 2021 and plans for development and operation filed before January 1, 2023, and approved before January 1, 2024 (NPD, 2022c). Assuming that full-scale electrification of the NCS will cost 50 billion NOK, the Norwegian government will pay for 45.72 billion NOK, which corresponds to 91,44% of the cost (NPD, 2022c). The temporary modifications to the petroleum tax system make it highly lucrative for oil and gas companies to conduct new power from shore projects, even if the profits are uncertain.

Shortly after the temporary modifications to the petroleum tax system were implemented, energy prices returned to normal before skyrocketing towards the end of 2021 (NPD, 2022d). The price resulted in a record profit after tax for Norwegian oil companies in 2021 (Aker BP, 2022; Equinor, 2022c; Vår Energi, 2022). Short-term investments in existing fields are substantial due to the opportunity to directly deduct all investment expenses in 2020 and 2021 and investments up to the start of production in development plans submitted before January 1, 2023. The temporary tax package has resulted in a record number of investment decisions. Electrification with power from shore is the primary initiative to reduce emissions among the sustainability projects completed in 2020 and 2021 (Rystad Energy, 2021).

## 4.2 Economics

### 4.2.1 $CO_2$ abatement cost

The Norwegian Petroleum Directorate (NPD) conducts a cost-benefit analysis to see whether the project provides socioeconomic benefits before deciding whether it should be executed (NPD, 2020). $CO_2$ abatement cost is the net socioeconomic cost per tonne of $CO_2$ reduced due to implementing power from shore (NPD, 2020). Chapter 3.7 elaborates on how to calculate the $CO_2$ abatement cost, and Figure 14 illustrates the key economic factors:

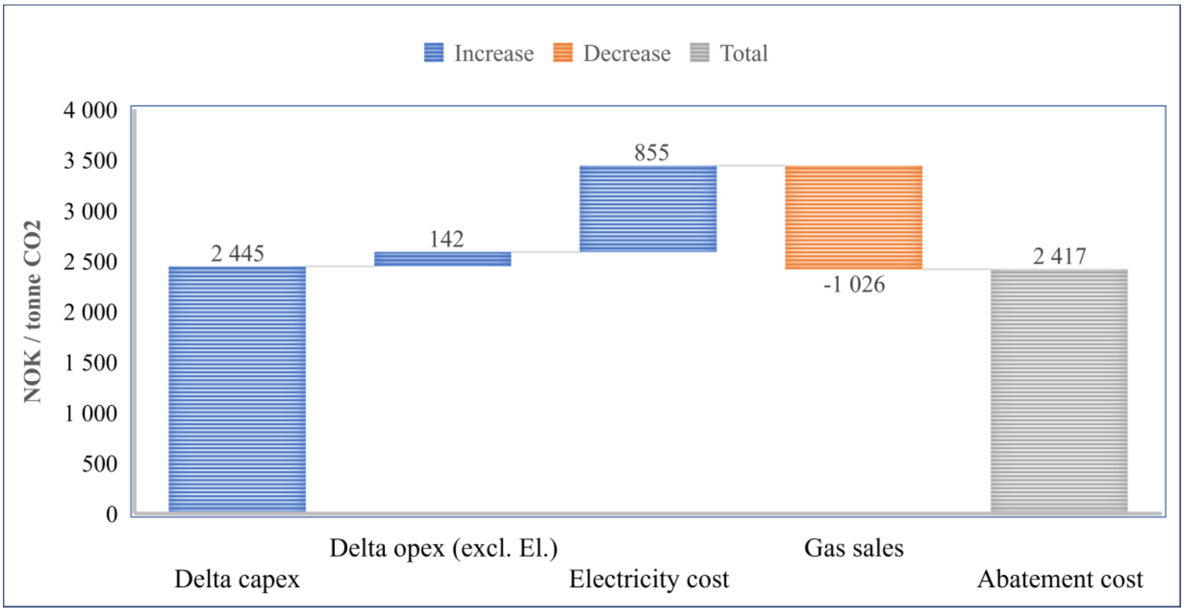
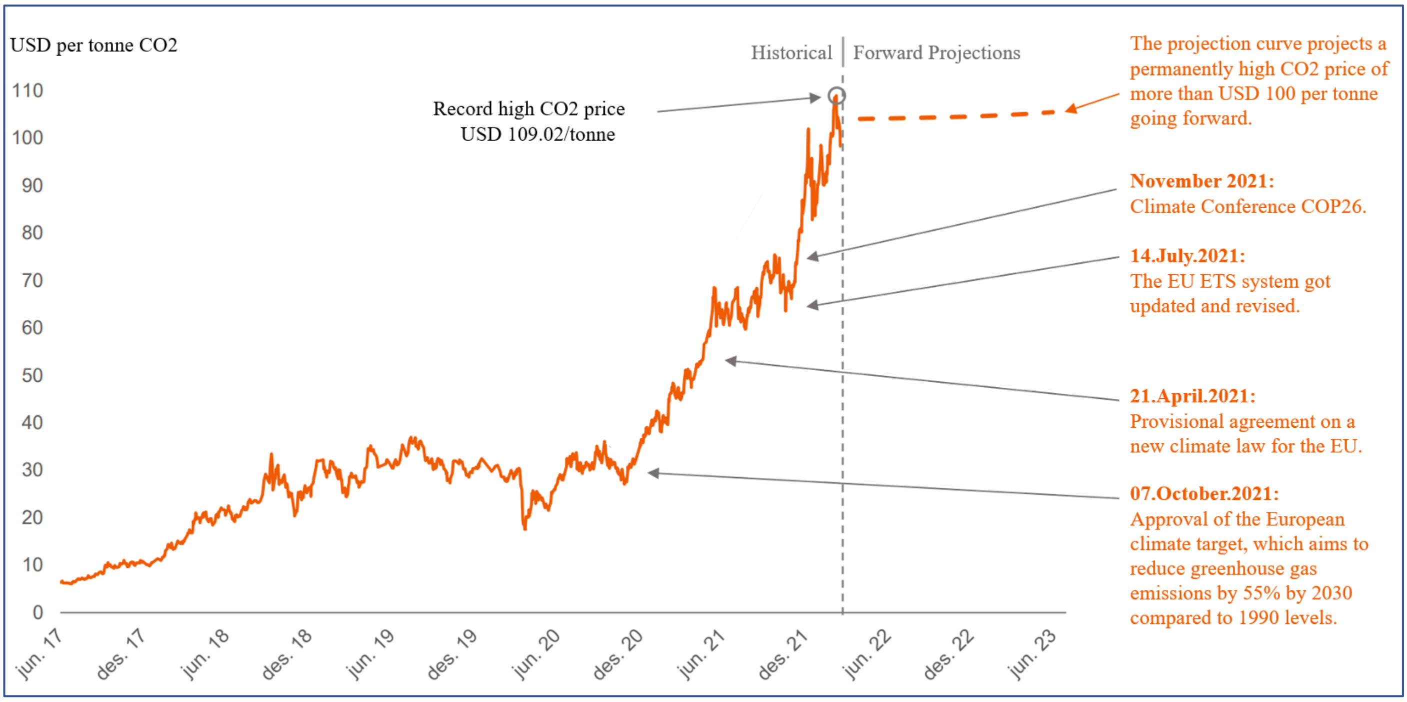


*Figure 15 - Illustration of $CO_2$ abatement cost calculation, including economic factors (Appendix 1).*

The $CO_2$ abatement cost is affected by volatile factors such as the electricity price, gas price, and the amount of $CO_2$ released (Figure 15). It is common to believe that the $CO_2$ pricing level indicates that emission reduction is socioeconomic beneficial. According to the NPD, if the $CO_2$ abatement cost is less than the $CO_2$ price, the implementation is socioeconomically profitable and should be carried out (NPD, 2020). To determine whether Norway should continue electrification development, it is crucial to analyse the energy market to see how $CO_2$ abatement costs will likely develop. Norway and Europe have been affected by extraordinary high electricity prices since 2021. The following chapters will investigate the driving factors, starting with the $CO_2$ price.

#### 4.2.1.1 $CO_2$ Price (EU ETS)

The quota price of one-carbon credit is determined by policy, supply, and demand, resulting in a volatile price (European Commission, 2021b). A market stability reserve was implemented in 2019 to remove excess quotas from the market. When the surplus of allowances surpasses a specific value, the market is reduced by withdrawing available allowances sold and placing them in the market reserve. If the number of allowances in the market reserve exceeds the number of allowances auctioned, the surplus quota is erased permanently in 2023 (European Commission, 2021a). The EU recently amended the market for tradable carbon allowances in 2021. The modifications are conditional on the number of yearly emission permits in segments with a high carbon footprint, such as industry and power generation, being reduced by an annual rate of 4.2% instead of 2.2%, and total abandonment of free quotas. The new EU ETS will also incorporate buildings and transportation under a separate system that will regulate the fuel supplier rather than the consumer (European Commission, 2021b). This caused the price of $CO_2$ to skyrocket, as seen in Figure 16 below:



Record high CO2 price
USD 109.02/tonne

The projection curve projects a permanently high CO2 price of more than USD 100 per tonne going forward.

**November 2021:**
Climate Conference COP26.

**14.July.2021:**
The EU ETS system got updated and revised.

**21.April.2021:**
Provisional agreement on a new climate law for the EU.

**07.October.2021:**
Approval of the European climate target, which aims to reduce greenhouse gas emissions by 55% by 2030 compared to 1990 levels.

*Figure 16 - Historical and projected $CO_2$ prices, 2017-2023 (Rystad Energy, 2022; Appendix 3).*

The $CO_2$ price dropped to USD 18 when the global outbreak of Covid-19 in May 2020. Since then, the price has risen to over USD 100 per tonne of $CO_2$, with projections indicating that this will continue (Rystad Energy, 2022). The total carbon cost that oil and gas companies pay per April 29, 2022, is approximately 1372 NOK per tonne $CO_2$ equivalent. That includes the Norwegian $CO_2$ fee of NOK 543 and the European quota price (EU ETS) of NOK 829 per tonne $CO_2$ equivalent (Ember, 2022; KonKraft, 2021; NPD, 2022c). If the $CO_2$ abatement cost exceeds the $CO_2$ price, the implementation is socioeconomically profitable and should be executed. This high $CO_2$ price increases the $CO_2$ abatement cost limit, making power from shore projects more likely to get approved by the Norwegian Petroleum Directorate. Oil and gas companies are also driven by the high $CO_2$ price to power fields from shore to hedge against future $CO_2$ price increases.

### 4.2.1.2 The natural gas market

The revised EU ETS aims to direct investments toward emissions-cutting technology. Higher $CO_2$ prices have increased gas demand due to low emission intensity (Rystad Energy, 2022). The European power market strongly relies on natural gas to supply basic needs such as cooking and heating, and there are currently few feasible short-term substitutes. As a result, gas demand is more predictable than oil demand, which dropped significantly during the pandemic (Rystad Energy, 2022). Natural gas production in the EU and the UK has declined in recent years while consumption has remained consistent. Resulting in an import requirement of 84% to meet overall demand in 2021 (Rystad Energy, 2022). The extraordinary demand for natural gas made the price increase significantly. High natural gas prices contribute positively to the $CO_2$ abatement cost because the electrification releases gas for sale. The high gas price has led to the re-opening of old coal-fired power plants to cut gas prices and make electricity more affordable. The mitigating action was unsuccessful, as illustrated in Figure 17 below. The gas price will remain high in the coming years due to rising $CO_2$ prices and the conflict in Ukraine, where the EU will phase out Russian energy.

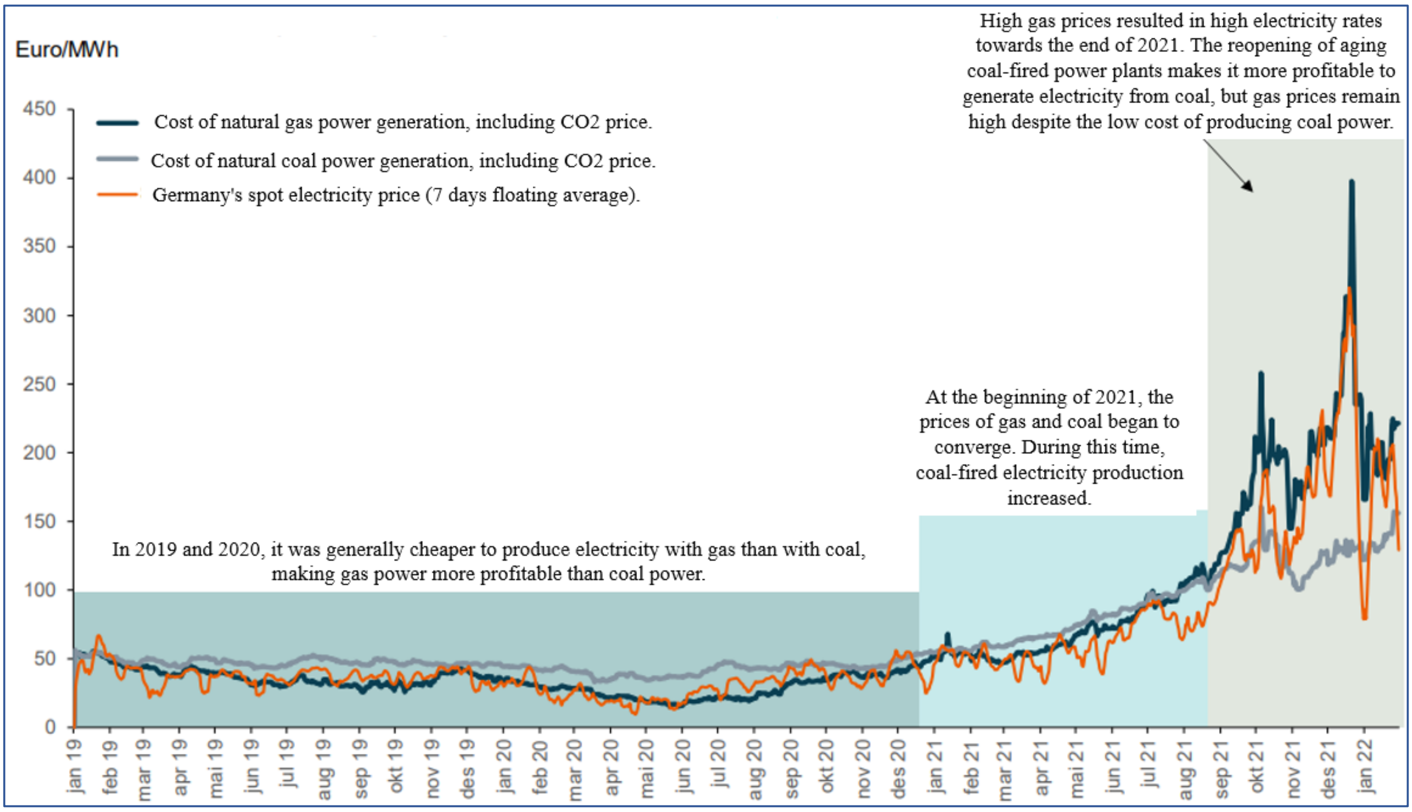


*Figure 17 - Costs of gas and coal power generation in Europe, including EU ETS * (Rystad Energy, 2022)*

#### 4.2.1.3 The electricity market

Since the fall of 2021, Norway has been characterised by very high electricity prices, particularly in southern Norway. The increased prices are primarily a consequence of extreme gas prices (NVE, 2022; Rystad Energy, 2022a). The Nordic and European electricity markets have proven to impact Norwegian prices significantly. The energy market in Norway and Europe is rapidly changing as renewable energy sources are replacing fossil fuels, and demand grows due to societal electrification (European Commission, 2022b). Norway has traditionally been an energy-dimensioned system, being over-dimensioned compared to the rest of Europe (NVE, 2022). Norway's construction of new power lines to Germany and the UK has increased its integration with the European power market, influencing Norwegian electricity prices (OECD, 2022). The integration provides considerable power security in import capacity, reducing the risks associated with dry years.

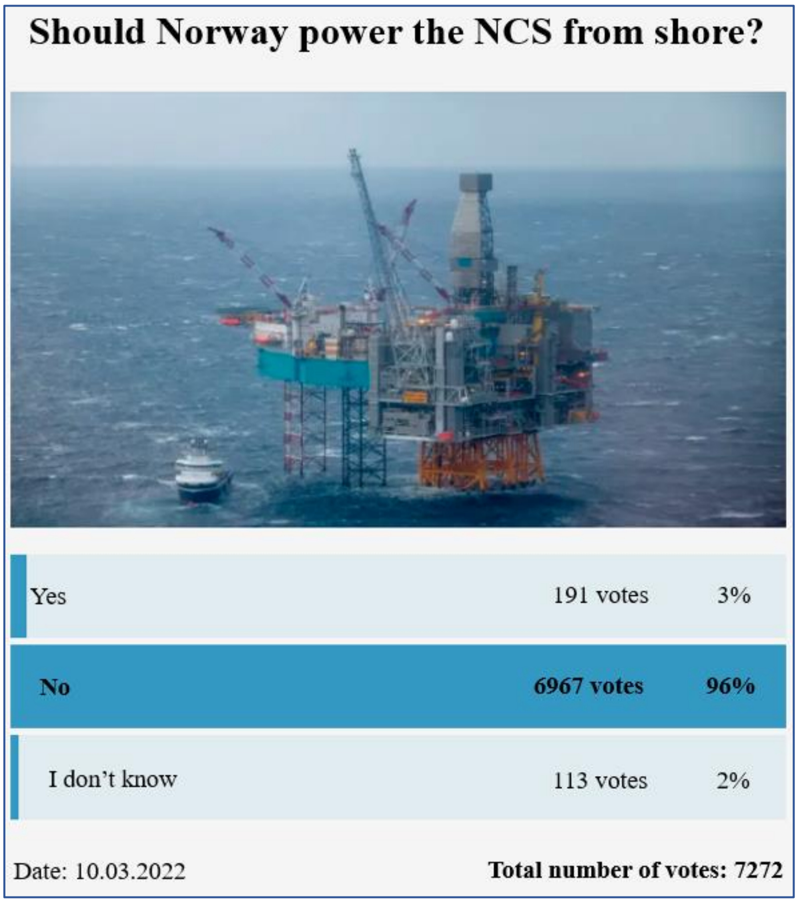
On the other hand, it makes Norway more reliant on electricity imports (NVE, 2022). The Nordic region already has a power shortage, which will worsen by 2030 as they become more weather dependent. The movement of excess electricity from one region to another requires international collaboration. This will likely result in extremely high periodic electricity costs in Norway (NVE, 2022). Further electrification of the NCS will increase power consumption and demand, resulting in a reduced surplus of electricity in Norway and higher electricity prices (NPD, 2020). There are currently no plans for additional electricity generation or energy-saving measures to meet the increased power demand that extensive electrification of the NCS requires (Statnett, 2021).

## 4.3 Social

Social factors such as gender, employment, degree of education, status, age, conventions, values, and other demographic traits all influence how individuals in society view and interpret the world (Baker, 2021). People's concerns about the environment and sustainability have grown in recent years. Population expansion, climate change, and increased awareness have contributed to significant shifts in the public's perception of non-renewable energy sources such as the oil and gas industry. "The Green transition" has developed shifts in societal norms and expectations, particularly among the younger generation. Norwegian universities are forced to close or change the title of petroleum subjects to increase the number of candidates. The number of applications for petroleum courses at the University of Stavanger decreased by 73.5 % between 2015 and 2019 (Søndeland, 2020). Changes in societal standards have led to a significant tightening of laws and regulations, with several Norwegian oil and gas corporations adopting ambitious climate targets to achieve carbon neutrality (Equinor, 2022b; Vår Energi, 2021). Oil and gas companies must continue electrification development to achieve carbon neutrality and remain social competitive (NPD, 2020).

### 4.3.1 Public Survey

Nettavisen launched a public survey on March 10th, 2022, following the Storting voting results with the proposal that no further electrification of oil and gas installations occur (Figure 18). The Figure below presents the result of 7272 random people's responses to the public survey "Should Norway power the NCS from shore?":



**Should Norway power the NCS from shore?**

| | | |
|---|---|---|
| Yes | 191 votes | 3% |
| **No** | **6967 votes** | **96%** |
| I don't know | 113 votes | 2% |

Date: 10.03.2022 **Total number of votes: 7272**

*Figure 18 - Public Survey regarding the electrification of the NCS (Heldahl, 2022).*

The findings show that 95.8% of the voters are against further electrification of the NCS with power shore, while 2.6% vote in favour. 1.6% voted that they are unsure whether Norway should power the NCS from shore or not (Heldahl, 2022).

## 4.4 Technology

Electrification from shore is a well-established technology that has been under development since its debut on the Troll A platform in 1996 (Equinor, 2022a). The primary objective of development is to make equipment smaller, lighter and transport more power over greater distances at a lower cost (NPD, 2020).

### 4.4.1 Power from shore technology

Power from shore technology has significantly improved, as illustrated in Figure 19 below. The offshore wind sector has contributed significantly to accelerating the development even further in recent years (NPD, 2020). In 2016, The Martin Linge platform achieved the record for the longest high-voltage AC cable in the world (Thibaut & Leforgeais, 2016).

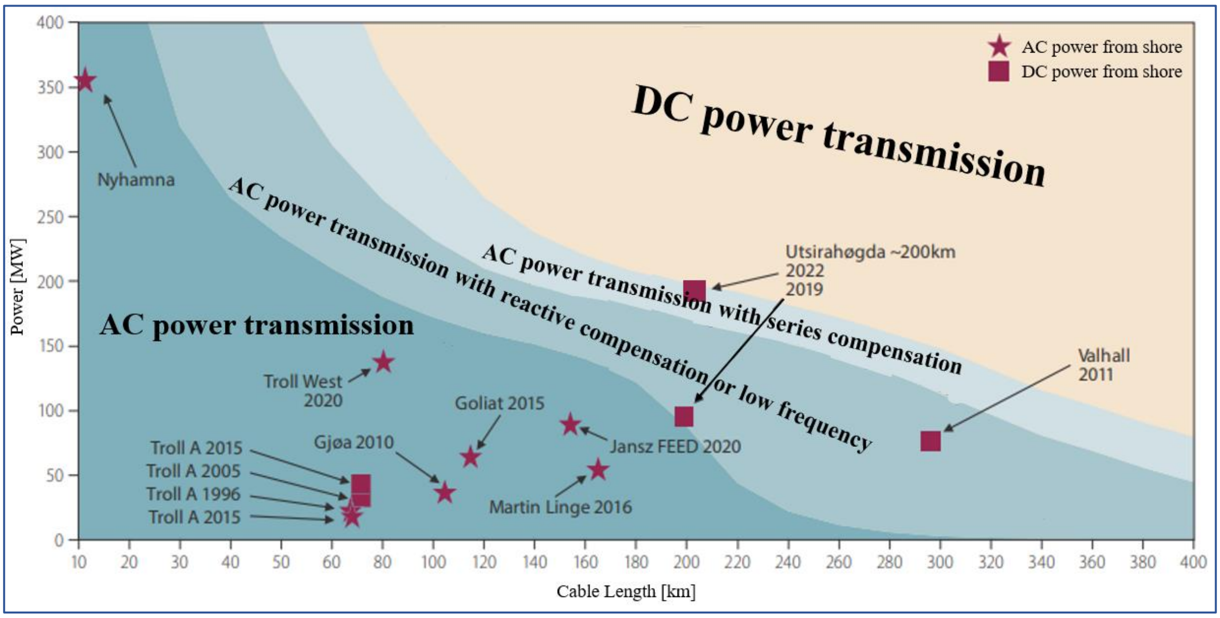


*Figure 19 - Transmission technologies for AC and DC electricity as a function of distance and power* (NPD, 2020).

Valhall and Utsirahøgda were built using DC due to the significant power demand and distance from shore. Technologies such as reactive compensation, low-frequency and series compensation enable AC to be transmitted at similar distances with net corresponding transmission loss (Figure 19). The advancement of power from shore technology has enabled the placement of additional converter equipment on the seabed, saving space and weight on the infrastructure. This technique allows an underwater transformer to power floating, production, storage, and offloading vessels (NPD, 2020).

Although power from shore technology has made advancements, energy loss is expected when converting and transmitting electricity. Reactive power is a crucial issue with AC in general, necessitating the use of coils and capacitors to balance the network. The reactive effect is triggered by frequency and the capacity of the cable. The reactive loss increases as frequency increases (NPD, 2020). Since direct current has no frequency, is there no reactive effect, only active losses due to resistance (Thibaut & Leforgeais, 2016). There are further losses from inverter stations on the ground and inverter stations on the platform. For example, the transmission loss from shore to Johan Sverdrup (Phase 1) is between 11-12 % at maximum output on the transmission, with roughly 5.6 % of the overall loss in the HVDC converter and as transmission loss (Statoil, 2014). Transmission loss varies depending on numerous factors such as heat, distance, technology, and materials. The average loss for the NCS is around 5% transmission loss when transmitting electricity from shore to offshore field via subsea cable (Statnett, 2021; Statoil, 2014; Torvanger & Ericson, 2013). Power consumption on the NCS is expected to be roughly 7.9 TWh in 2024. A 5% transmission loss corresponds to around 0.4 TWh loss, or the yearly consumption of 25 000 average Norwegian homes (SSB, 2018).

### 4.4.2 The Power Grid

The transfer of electricity from land to the NCS will increase power consumption significantly. A critical requirement for expanding power from shore to the NCS is that the Norwegian power grid can manage the growth in demand without affecting the security of supply for current consumers. Production and grid capacity must be sufficient to meet demand in all areas (Statnett, 2021). Such demand increases may need significant grid improvements in places with insufficient grid capacity or manufacturing capability, which might take a long time to implement. Large new consumption, regardless of where it occurs in Norway, may need some strengthening of the transmission network (NPD, 2020). The power from shore projects already in use has a power requirement of 700 MW and total power consumption of up to 5.1 TWh per year. The predicted power demand is most significant around 2025-2030. Field activity is expected to decline by 2040, resulting in reduced power consumption (NPD, 2020). Table 1 shows the considerable modifications to the power grid that are necessary for the future power from shore projects:

*Table 1 - Cost estimates for power grid upgrades required for further electrification of the NCS* (NPD, 2020).

| **Location** | **Fields** | **Total cost [BNOK]** | **Projected year of completion** |
|---|---|---|---|
| Northern Norway | Melkøya | 4,0 - 6,4 | 2030 |
| Central Norway | Halten & Draugen | 1,9 - 2,7 | 2028 |
| Western Norway | Troll B & C,<br>Oseberg Field-center & South,<br>East Sleipner | 1,0 - 3,0 | 2030 |

Northern Norway will have the most significant increase in electricity consumption and the greatest cost impact (Table 1). Hammerfest cannot currently handle the planned electrification projects (NPD, 2020). A new 420 kV cable connecting Skaidi and Hammerfest and new transformer stations at both ends will be required. Furthermore, according to Statnett's report *"The Power System Study for Finnmark (2020–2036)"*, the transmission network to Western Finnmark has a moderate capacity deficit in the energy and power balance in 2030 (Statnett, 2016). Significant power grid investments are necessary for Norway to achieve large-scale shelf electrification.

### 4.4.3 Operation

Power from the shore can impact oil field output positively or negatively. Closure and delayed production during the power from shore installation period might result in lost value generation. However, experience indicates that the working regularity of platforms powered by land is generally more significant than that of plants powered by gas turbines (NPD, 2020). As mentioned in Chapter 2.3, procedures are required to sustain optimum resource usage throughout the life of the fields. More gas compression, injection of water or gas for pressure support, or other techniques to improve recovery are examples. The platform may require more power than its initial design. A power from land project increases the quantity of electricity accessible on the infrastructure. As a result, power from shore projects allows investigation of new power-intensive strategies for enhanced oil recovery (NPD, 2020).

## 4.5 Legal

### 4.5.1 The Petroleum Act

The petroleum sector is Norway's most significant industry in terms of Government revenue, investment, and proportion of overall value creation in Norway (KonKraft, 2021). The petroleum law and license system's objective are to ensure that the value generation from petroleum resources benefits the Norwegian population. It is essential that the corporate structure and separation of duties and responsibilities take all significant social concerns into account (NPD, 2022e). Comprehensive rules maintain government administration and control, with licenses and permissions from the appropriate authorities necessary at all stages of petroleum activity. The Petroleum Act provides a general legal framework for effective resource management, including the licensing system that permits companies to perform petroleum operations. The Petroleum Act specifies that Norway owns the oil and gas on the NCS (NPD, 2022e).

### 4.5.2 The Energy Act

The NPD's role is to contribute to creating the highest potential value for society from the oil and gas sector through competent resource management based on safety, emergency readiness, and the external environment (MPE, 2022). All licenses are given according to The Energy Act, such as power lines needed in electrification projects (KonKraft, 2021). The licensing procedure is time-consuming and might take several years to complete, increasing the developer's risk since the basis may change throughout the process. All offshore platform electrification projects must go through this licensing procedure. Licenses are judged after social and environmental interests have been considered societal beneficial. For example, the electricity price may have changed significantly since the development plans application. Political changes may result in new regulations for granting licenses, or companies may be in a poor financial situation due to extended waiting periods (NPD, 2022e).

The Energy Act governs energy production, transformation, transport, sale, distribution, and consumption while rationally protecting private and public interests. All licenses for technical facilities with capacities ranging from 1000/1500 (AC / DC) kV, including all electrification projects on the NCS, must be given according to the Energy Act (MPE, 1990). Before oil and gas companies can carry out electrification projects, the Ministry of Petroleum and Energy must approve the development plan, including how the licensees will develop and operate the field

(NPD, 2020). The outcome of the electrification project is highly reliant on the $CO_2$ abatement cost, as stated in Chapter 4.2.1.

### 4.5.3 The Paris Agreement

The Paris Agreement was adopted by 193 Parties to prevent irreversible effects through a legally binding international agreement establishing long-term goals to guide nations toward limiting the temperature rise below 2 °C (UNFCCC, 2015). The Paris Agreement is legally binding and relates to the $CO_2$ emissions and removals covered by Norway's first nationally determined contribution (MCE, 2021). It aims to promote the implementation of Norway's climate targets as part of its transformation into a low-emission society by 2050 (MCE, 2021). Norway is committed to reduce emissions by at least 50% up to 55% by 2030 and net-zero by 2050, relative to 1990 levels (UNFCCC, 2020). The Paris Agreement requires each nation to deliver new and enhanced climate targets every five years, referred to as the "progression principle.” The new targets must also reflect the highest possible ambition for the country and are, therefore, a driver for further electrification of the NCS (Hermansen et al., 2021).

### 4.5.4 The European Climate Law

The EEA agreement brings together the EU member states and the three EEA EFTA states, Norway, Iceland, and Liechtenstein, in a market governed by the same rules (UD, 2022). Environmental cooperation is part of the EEA agreement, which means that almost all EU environmental legislation, such as the EU ETS, is implemented in Norwegian law (UD, n.d.). Norway is committed to reducing $CO_2$ emissions by at least 55% by 2030 compared to 1990 levels and ensuring a fair transition to a low-carbon economy (European Commission, 2022c).

## 4.6 PESTL Results

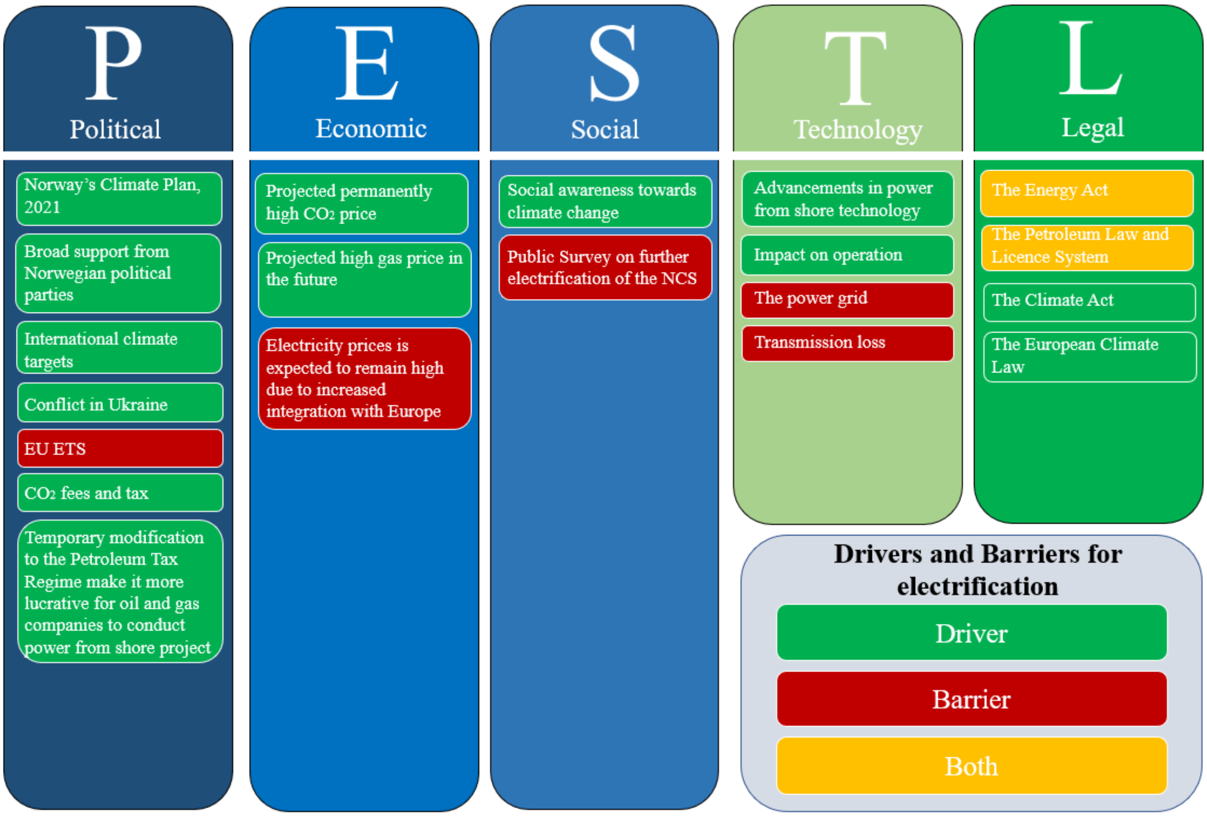


*Figure 20 - PESTL Results*

# 5 Environmental Impact Analysis Data

## 5.1 The Environmental Impact of Gas Turbines

Find the complete calculation and sources in Appendix 2. The method is presented in Chapter 3.6.1.

In 2021, Norway produced 103 million $Sm^3$ o.e. of oil and 113 $Sm^3$ o.e. of gas (Figure 6). The average oil $CO_2$ emissions from combusted oil are 3,57 kg $CO_2$ per kg (Gavenas, Rosendahl, & Skjerpen, 2015; SSB, 2017) and 2,34 kg $CO_2$ per $Sm^3$ combusted natural gas (SSB, 2017; Torvanger & Ericson, 2013). The emissions from oil and gas extraction equalled 13,2 million tonnes of $CO_2$ equivalent in 2021, with gas turbines accounting for 82% of it (Figure 4).

*Table 2 - Parameters used in the environmental impact of gas turbines (Appendix 2).*

| Parameters | # | Unit | Source |
|---|---|---|---|
| 1.0 $Sm^3$ o.e. oil | 1 | $Sm^3$ oil | (NPD,2022b) |
| 1.0 $Sm^3$o.e. natural gas | 1000 | $Sm^3$ natural gas | (NPD,2022b) |
| 1.0 $Sm^3$ o.e. oil | 858 | kg | (NPD,2022b) |
| 1 tonnes $CO_2$ equivalent | 1000 | kg | |
| Average $CO_2$ emissions from 1 $Sm^3$ combusted natural gas | 2,34 | kg $CO_2$ | (Torvanger and Ericson, 2013; SSB, 2017). |
| Average $CO_2$ emissions from 1 kg combusted oil | 3,57 | kg $CO_2$ | (Gavenas et al., 2015; SSB, 2017) |
| Norway's total $CO_2$ emission from gas turbines on the NCS, 2021 | 10,8 | Million tonnes of $CO_2$ equivalent | (SSB, 2021) |
| Norway's total production of oil, 2021 | 103 | Million $Sm^3$ o.e. | (NPD, 2022d) |
| Norway's total production of natural gas, 2021 | 113,10 | Million $Sm^3$ o.e. | (NPD, 2022d) |

## 5.2 The Environmental Impact of the Electricity Mix

Find the complete calculation and sources in Appendix 2. The method is presented in Chapter 3.6.2. Energy loss occurs when transferring electricity and gas. Increased electrification of the NCS reduces net power exports due to transmission losses in cables and gas pipelines (NPD, 2020). The total transmission loss for electricity transmission from Europe to Norway is estimated to be 15%, including losses on transmission from Europe to the Nordic countries, transmission from the Nordic countries to Norway, and transmission through Norway. The estimated transmission loss from Europe to an NCS platform is 20% (Statnett, 2013, 2022; Torvanger & Ericson, 2013). Gas transmission from the NCS to a Nordic country or Europe requires energy that results in an average 5% energy loss of the theoretical energy content of the natural gas (Rystad Energy, 2022; Torvanger & Ericson, 2013). Electrification of the NCS release gas for export, which is the starting point for the amount of energy delivered, as a function of the theoretical energy density in natural gas, which is 11.11 kWh/$Sm^3$ (NPD, 2022b), and power plant efficiency (Eurostat, 2020; IEA, 2020; Torvanger & Ericson, 2013). Utilizing the same methodology, the emission intensity of coal power was determined.

To determine the emission factors, the theoretical energy content of gas, and the average $CO_2$ emissions of gas per standard cubic meter ($Sm^3$) before compensating for gas utilisation efficiency. Europe's demand for natural gas is high compared to the amount of gas released (Rystad Energy, 2022; Torvanger & Ericson, 2013). Natural gas is also an adequate substitute for coal to reduce $CO_2$ emissions. As a result, it is assumed that the released gas is sold on the open market and adds electricity to the existing El-mix or replaces an electricity source such as coal. The gas is assumed to be utilised in a gas power plant, combined heat and power plant (CHP), or buildings as heating (Torvanger & Ericson, 2013). The efficiency of gas turbines on the NCS ranges from 25 to 35 %, depending on the design, age, and operation of the plant, whereas the efficiency of gas power plants in Europe ranges from 50 to 60% (KonKraft, 2021; Rystad Energy, 2022; Torvanger & Ericson, 2013). The average efficiencies have been utilized in this analysis to obtain the average emission intensities from the different sources. Obtaining data from reliable organisations and comparing information from several sources have been used to assure consensus and trustworthiness.

*Table 3 - Parameters used in the environmental impact analysis of the electricity mix (Appendix 2).*

| Parameter | Values | Unit | Sources |
|---|---|---|---|
| Average emission of 1 $Sm^3$ gas | 2,34 | kg $CO_2$ | (Torvanger and Ericson, 2013; SSB, 2017). |
| Average emission 1 kg coal | 2,52 | kg $CO_2$ | (SSB,2017) |
| The conversion factor of 1 $Sm^3$ of Natural gas | 11,111 | kWh | (NPD,2022b) |
| The conversion factor of 1 kg Coal | 6,667 | kWh | (Torvanger and Ericson, 2013) |
| Average emission intensity from turbines on the NCS | 0,702 | kg $CO_2$/kWh | |
| Average emission intensity Norway | 0,026 | kg $CO_2$/kWh | (BP,2021; EEA,2021) |
| Average emission intensity in the Nordic countries | 0,146 | kg $CO_2$/kWh | (BP,2021; EEA,2021) |
| Average emission intensity in Europe | 0,278 | kg $CO_2$/kWh | (BP,2021; EEA,2021) |
| Emission factor, Coal power plant | 0,945 | kg $CO_2$/kWh | |
| Emission factor, Natural gas power plant | 0,383 | kg $CO_2$/kWh | (Verified in Rystad Energy, 2022a) |
| Emission factor, CHP with natural gas | 0,248 | kg $CO_2$/kWh | |
| Efficiency factor, Coal power plant | 0,4 | % | (IEA,2020; Rystad Energy 2022a) |
| Efficiency factor, Natural gas power plant | 0,55 | % | (IEA,2020; Konkraft, 2021) |
| Efficiency factor, CHP with natural gas | 0,85 | % | (IEA,2020; Rystad Energy 2022a) |
| Efficiency factor, Natural gas turbines on the NCS | 0,3 | % | (Torvanger and Ericson, 2013; Konkraft, 2021) |

| | | | |
|---|---|---|---|
| Efficiency factor, Heating in buildings | 0,9 | % | (Konkraft, 2021; Rystad Energy, 2022a) |
| Energy Transmission loss from shore to NCS | 5 | % | (Torvanger and Ericson, 2013; Statnett, 2021) |
| Energy transmission loss in Norway | 5 | % | (Torvanger and Ericson, 2013; Statnett, 2021) |
| Energy transmission loss from the Nordic countries | 5 | % | (Torvanger and Ericson, 2013; Statnett, 2021) |
| Energy transmission loss through Europe | 5 | % | (Torvanger and Ericson, 2013; Statnett, 2021) |
| Energy transmission loss in gas pipeline | 5 | % | (Torvanger and Ericson, 2013; Rystad Energy, 2022a) |

Find a schematic illustration of the data and method in Figure 21 below, and the complete calculation and sources in Appendix 2.

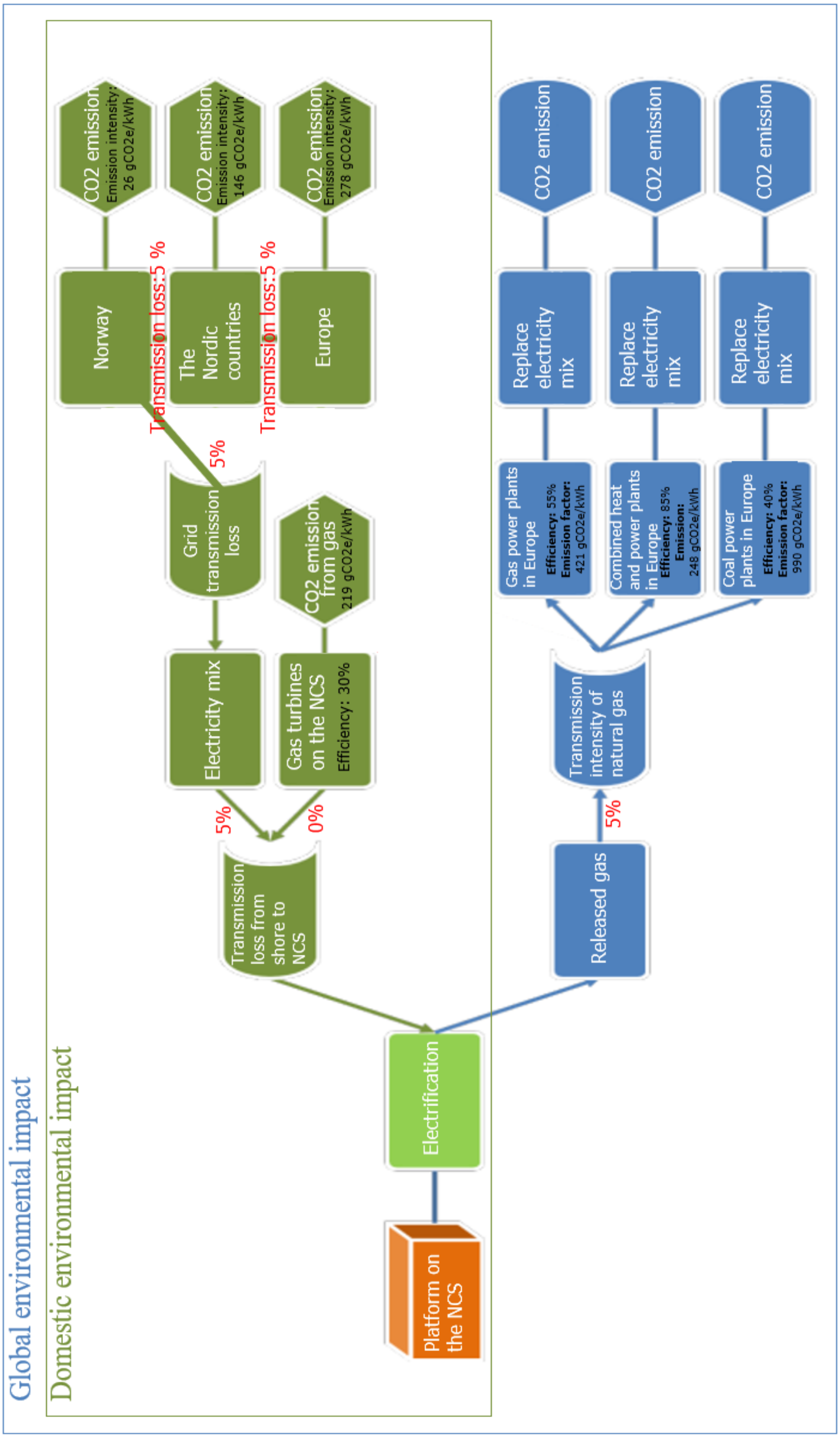


*Figure 21 - Schematic illustration of the environmental impact analysis of electrification of the NCS (Appendix 2).*

## 5.3 Environmental Impact Results

### 5.3.1 The Environmental Impact of Gas Turbines

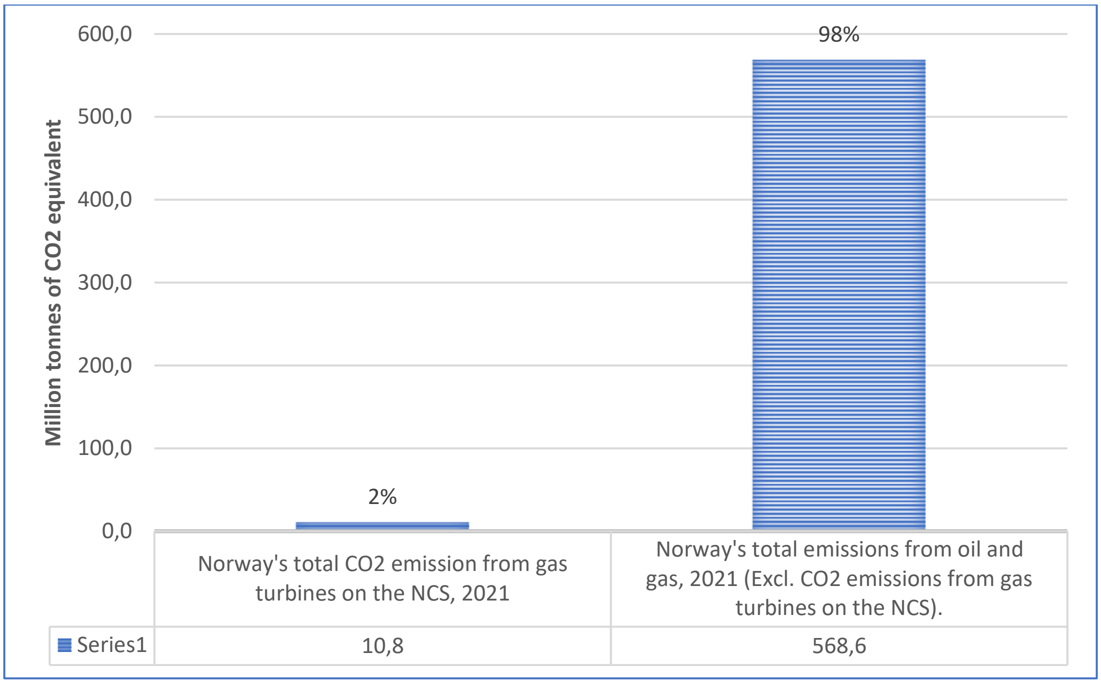


*Figure 22 – Norway's net $CO_2$ emissions from oil and gas, including upstream and downstream emissions, 2021 (Appendix 2).*

Figure 22 illustrates that 98% of Norway's $CO_2$ emissions are not related to electricity generated by gas turbines on the NCS when including upstream and downstream emissions. Gas turbines on the Norwegian continental shelf account for approximately 2% of Norway's net $CO_2$ emissions related to the petroleum industry. Electrification with power from shore replaces natural gas combustion offshore with electricity generated onshore, reducing upstream and domestic $CO_2$ emissions while increasing Norway's downstream emissions.

### 5.3.2 The Environmental Impact of the Electricity Mix

#### Domestic Impact

Figure 23 illustrates the domestic emission impact of different electricity mixes transmitted offshore. The released gas due to the power from shore implementation is not combusted. $CO_2$ emissions from gas turbines on the NCS are normalised to 100 million tonnes of $CO_2$ equivalents. The Norwegian El-mix has the lowest emission intensity and transmission loss due to renewable electricity generation and distance, making it ideal for electrifying the NCS. The best impact is when the power from shore is from the Norwegian El-mix, which results in a 96% reduction in $CO_2$ emissions compared to offshore gas turbine combustion with a 30% efficiency. When the electricity is imported from a Nordic El-mix, the transmission loss to the NCS is around 15%, resulting in 27 million tonnes of $CO_2$ equivalents instead of 100 million tonnes of $CO_2$ equivalents. Europe has the highest emission intensity when generating electricity and the furthest distance from the NCS. When the electricity is imported from Europe with average European El-mix emission intensity, the reduction is 52% of $CO_2$ emissions compared to gas combustion offshore. Electricity delivered from a gas power plant in a Nordic country or Europe reduces emissions by approximately 35% since the gas turbine combustion efficiency is better in gas power plants onshore. The net $CO_2$ emissions increase by at least 56% compared to gas combustion offshore when the electricity is imported from a coal-fired power plant with 40% efficiency. The net $CO_2$ emissions increase from 100 to 163,6 million tonnes of $CO_2$ equivalents when the electricity from shore is imported from a European coal power plant.

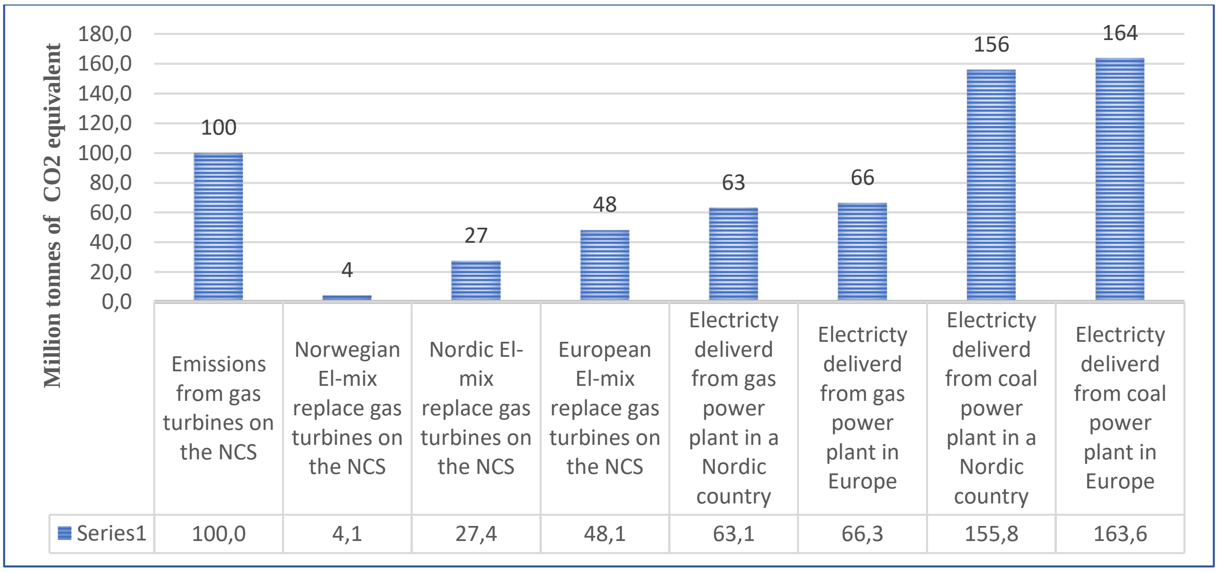
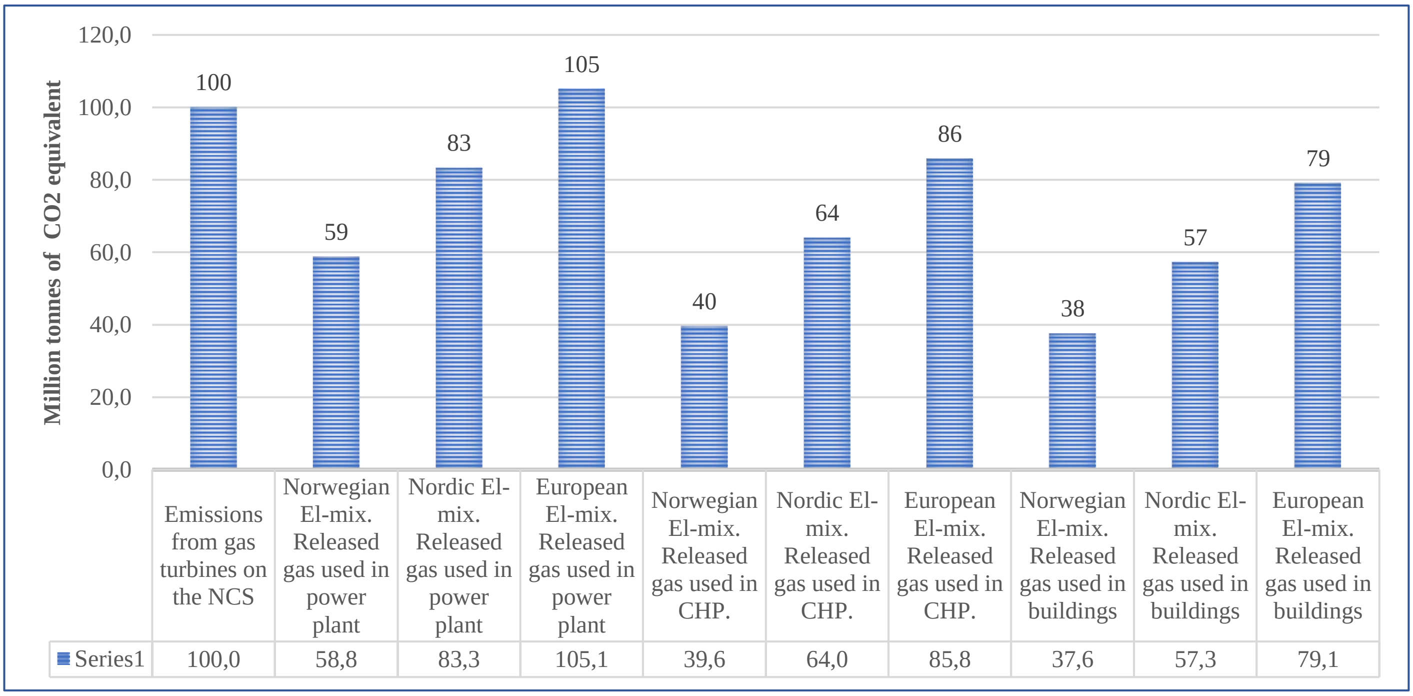


*Figure 23 – Net $CO_2$ emissions from offshore electricity import to the NCS that replaces offshore gas combustion. El-mixes with different $CO_2$ emission intensities compared to offshore gas combustion emissions. The released gas is not combusted (Appendix 2).*

### International Impact

Figure 24 illustrates the $CO_2$ emissions impact of different electricity mixes, and released gas from electrification is transported onshore and combusted. Emissions from gas turbines on the NCS are normalised to 100 million tonnes of $CO_2$ equivalent. Power from the Norwegian El-mix, where the released gas is used in a Combined Heat and Power Plant (CHP), or buildings heating, has the best environmental impact. CHP have 85% energy efficiency, and the gas used in buildings has 90% energy efficiency when combusting gas. When gas released from Norwegian El-mix is used in CHP or buildings, the $CO_2$ reduction is approximately 60% compared to gas turbines on the NCS. The $CO_2$ emissions rise by 5% when the power offshore is delivered from European El-mix, and the released gas is combusted in a 55% efficient gas power plant.



| | Emissions from gas turbines on the NCS | Norwegian El-mix. Released gas used in power plant | Nordic El-mix. Released gas used in power plant | European El-mix. Released gas used in power plant | Norwegian El-mix. Released gas used in CHP. | Nordic El-mix. Released gas used in CHP. | European El-mix. Released gas used in CHP. | Norwegian El-mix. Released gas used in buildings | Nordic El-mix. Released gas used in buildings | European El-mix. Released gas used in buildings |
|---|---|---|---|---|---|---|---|---|---|---|
| ▤ Series1 | 100,0 | 58,8 | 83,3 | 105,1 | 39,6 | 64,0 | 85,8 | 37,6 | 57,3 | 79,1 |

*Figure 24 - $CO_2$ emissions from delivering electricity offshore and released gas are used onshore in a gas power plant, CHP, or building as heat (Appendix 2).*

Figure 25 illustrates the international net $CO_2$ emission impact from importing electricity offshore with different El-mix emission intensities compared to offshore gas turbine emissions. The released gas is used onshore and replaces the existing electricity mix with average emission intensities or electricity generated from coal power. The outcomes are determined by the El-mix delivered offshore, the electricity generating utilisation of the released gas, and the emission intensity of the electricity-generating source the released gas replaces. The best outcome is when Norwegian El-mix releases gas used to generate electricity in CHP, which substitutes electricity from a coal power plant. Gas combustion produces significantly less $CO_2$ than coal combustion. When Norwegian El-mix released gas is combusted in an onshore gas power plant that replaces coal power electricity, the net $CO_2$ emission is reduced by 76 million tonnes of $CO_2$ equivalents. The net $CO_2$ emission is reduced by 71 million tonnes of $CO_2$ equivalents if the El-mix is imported from a Nordic country and released gas is combusted in a CHP that replaces coal electricity. The $CO_2$ emission impact is more significant when generating electricity in CHP since it is more energy-efficient than a gas power plant. If Norwegian El-mix released gas is used in CHP and replaces the average European El-mix emission intensity, the net $CO_2$ emission is unchanged. All other replacements of average electricity mixes result in a net $CO_2$ emission increase. The results show that using the released gas to replace electricity generated by coal power is the most environmentally friendly alternative since the average El-mix emission intensity in Europe is lower than gas combustion.

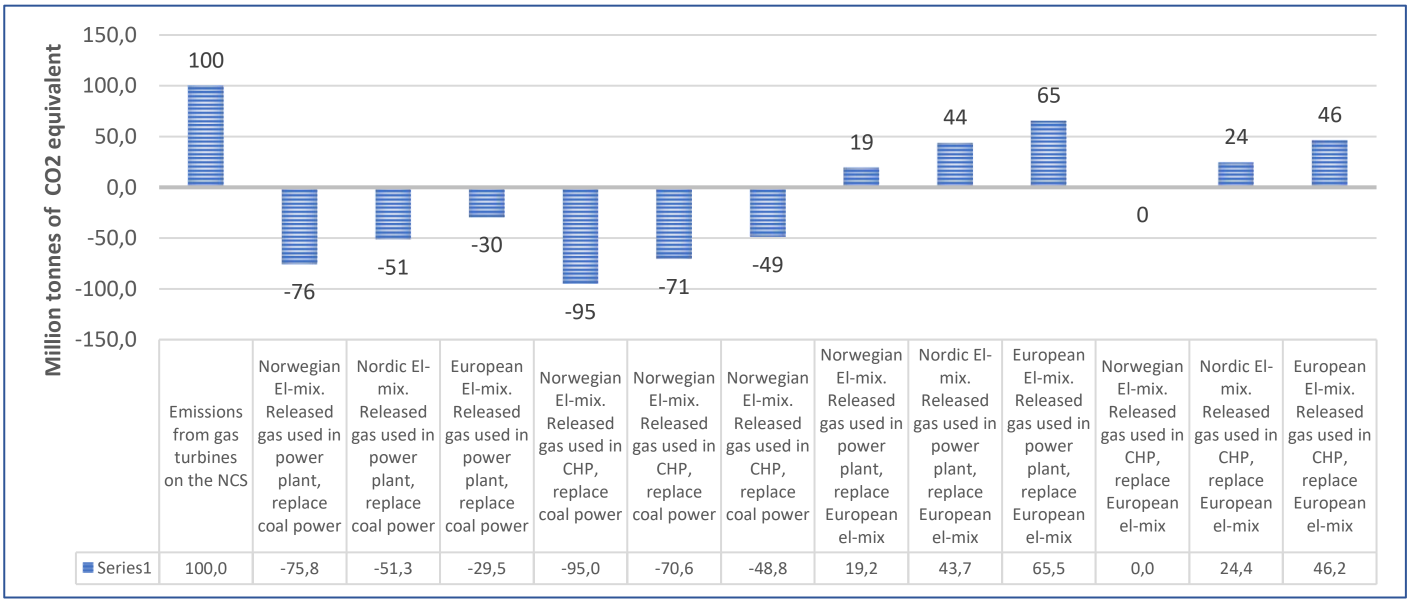


*Figure 25 – Net $CO_2$ impact from importing electricity offshore with different El-mix emission intensities compared to offshore gas turbine emissions. The released gas is used onshore and replaces average European El-mix or electricity generated from coal power (Appendix 2).*

# 6 Economic Sensitivity Analysis Data

Find the method overview in Chapter 3.7 and Appendix 1 for the complete dataset. The mean input variables and $CO_2$ abatement cost is shown in Table 4 and Table 5. The data is based on the findings in 2021 energy prices with an implemented margin of error depending on the historical and projected values presented in Chapter 4.2.

*Table 4 - Mean Parameters used in the $CO_2$ abatement cost analysis (Appendix 1 – Economic Sensitivity Analysis).*

| **Parameters** | **Value** | **Unit** |
|---|---|---|
| **Discount rate:** | **7 %** | % |
| **Gas turbine efficiency on the platform:** | **30 %** | % |
| **Electricity price (incl. grid rent):** | **0,6** | NOK/kWh |
| **Gas price (incl. tariffs):** | **2,4** | NOK/$Sm^3$ |
| **$CO_2$ price:** | **1600** | NOK/tonne |
| | | |
| **Mean $CO_2$ Abatement Cost:** | **2 417** | NOK/tonne $CO_2$ |

*Table 5 - Parameter intervals in the $CO_2$ abatement cost sensitivity analysis (Appendix 1 – Economic Sensitivity Analysis).*

| **Parameter** | **Min Value** | **Mean value** | **Max Value** | **Unit** |
|---|---|---|---|---|
| **Electricity price (incl. grid rent):** | 0,3 | **0,6** | 0,9 | NOK/MWh |
| **Gas price (incl. tariffs):** | 1,2 | **2,4** | 3,6 | NOK/$Sm^3$ |
| **$CO_2$ price:** | 800 | **1600** | 2400 | NOK/tonne |
| **Gas turbine efficiency** | 0,25 | **0,3** | 0,35 | % |
| **Discount rate** | 0,06 | **0,07** | 0,08 | % |

Energy prices have a large margin of error of ±50% to hedge uncertainties around future prices. Petroleum investments in connection with the preparation of development plans by the authorities are commonly evaluated at a real interest rate of 7% with a ±1% margin of error (NPD, 2020). The efficiency of gas turbines on the NCS ranges from 25 to 35 %, depending on the plant's design, age, and operation (KonKraft, 2021; Torvanger & Ericson, 2013). Since the field is hypothetical, the analysis uses a gas turbine's average efficiency on the NCS, with a ±5% margin of error because efficiency may vary over time (Saravanamuttoo, Rogers, & Cohen, 2001). The mean $CO_2$ abatement cost serves solely as a base value for the sensitivity analysis to determine how much the input affects the cost.

## 6.1 Economic Sensitivity Results

Figure 26 illustrates the sensitivity of the CO2 abatement cost to each input variable as they change over their allowed intervals. The figure shows all the input variables in order of their impact on the cost. The gas turbine efficiency has the greatest impact on the $CO_2$ abatement cost because it affects the amount of gas released for sale and $CO_2$ avoided as a result of the implementation. Then the gas price, followed by the electricity price and discount rate. The $CO_2$ price has no impact on the $CO_2$ abatement cost.

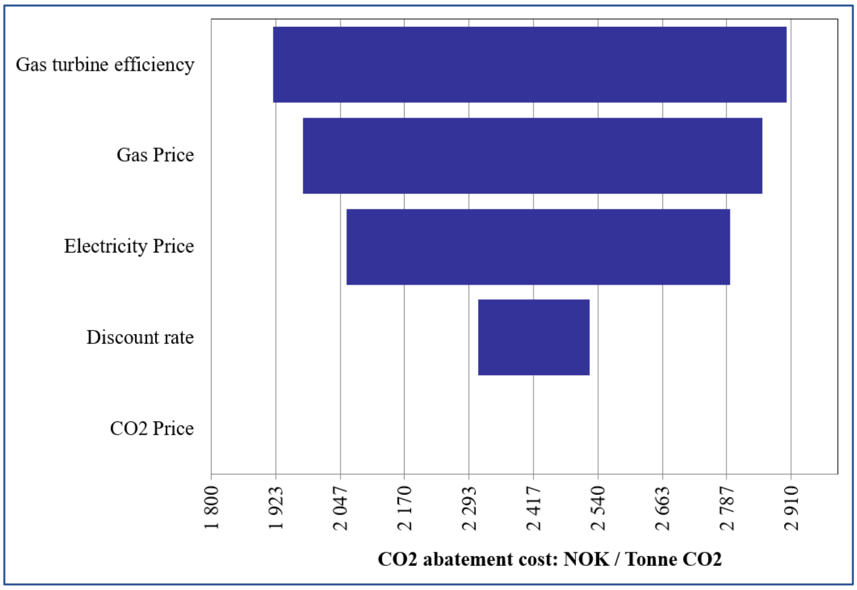


*Figure 26 - Sensitivity tornado of the $CO_2$ abatement cost (Appendix 3).*

Figure 27 shows that the gas turbine efficiency has the steepest line, indicating the most significant impact on the $CO_2$ abatement cost. The figure illustrates that when the gas turbine efficiency increases, so do the abatement cost because higher efficiency results in less gas for sale and less $CO_2$ avoided. The results show an inverse correlation between the prices of electricity and gas. As the price of gas rises, the $CO_2$ abatement cost decreases, and vice versa for the price of electricity. An increase in the discount rate results in an increase in abatement cost.

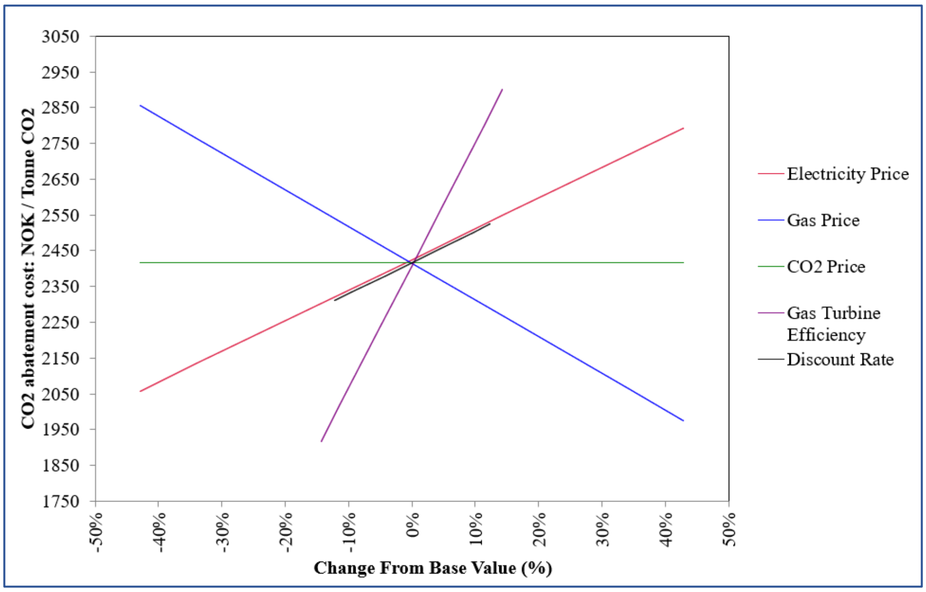


*Figure 27 - Spider diagram of the $CO_2$ abatement cost (Appendix 3).*

# 7 Discussion

International politics are crucial when addressing global warming. Global warming is an international issue that requires cross-national collaboration and that all governments implement emission-reduction measures. The Paris Agreement is an international law that binds governments to deliver new and improved climate targets every five years that reflect the country's highest possible ambition, referred to as the "progression principle" (Chapter 4.5.3). Norway is committed to reduce emissions by at least 50% up to 55% by 2030 and net-zero by 2050, relative to 1990 levels (UNFCCC, 2020). Norway's domestic $CO_2$ emissions are very low on a global scale due to its small population and 99% renewable electricity output (Figure 2, p. 5). Norway already achieved this extraordinary clean electricity in 1990, which is why it is still far from meeting its binding climate targets, with only a 4.2% reduction in $CO_2$ emissions in 2020 compared to 1990 levels (SSB, 2021).

Norwegian forests captured over 23 million tonnes of $CO_2$ equivalent in 2019, accounting for nearly half of Norway's total $CO_2$ emissions in 2021. (Figure 4, p. 7). If Norway estimates net $CO_2$ reduction, forest $CO_2$ capture counts in the climate equation, raising the emission reduction to 20% compared to 1990 levels (Figure 5, p. 8). Norway has therefore made greater progress towards the net-zero 2050 target than reducing emissions by 50% to 55% by 2030. Norway will break the Paris Agreement under the progression principle since changing the 2030 climate targets to net reduction puts Norway in a better position. According to Chapter 5.3.1-

Environmental Impact of Gas Turbines result, full-scale future electrification will reduce $CO_2$ emissions in Norway by 10,8 million tonnes of $CO_2$ equivalent compared to 2021 levels (Figure 22, p. 39). The findings demonstrate that electrification reduces Norway's upstream emissions while increasing downstream emissions. As a result, electrification's net environmental impact depends on several uncertain factors. Forest $CO_2$ capture, on the other hand, will be 2.2 times more effective than full-scale electrification of domestic emissions without requiring new investments.

Today, oil and gas extraction has the highest $CO_2$ emissions in Norway, where electrification provides significant $CO_2$ reductions that are critical to meeting national climate targets. The environmental impact analysis results suggest that electrification in Norway will lower net domestic emissions by 96 % if the electricity comes from the Norwegian electricity mix instead of a gas turbine (Figure 23, p. 40). If electricity is imported from a coal power station rather than combusted in an offshore gas turbine, net $CO_2$ emissions increase by at least 55%. Installing offshore electricity cables is expensive, and oil fields have a limited operation time. Increasing $CO_2$ price has historically been a driving force for further development of electrification on the NCS. This is obvious from a business point of view because oil and gas companies will save billions of NOK. An increase in $CO_2$ price may result in the opposite outcome of what is intended. The high $CO_2$ price in 2021 has driven up energy prices, prompting the reopening of new coal-fired power plants as a gas and electricity price-cutting measure (Figure 17, p. 26). Coal power has a high emission intensity, resulting in increased emissions associated with electricity generation in Nordic and European countries (Rystad Energy, 2022). The re-opening of numerous coal power plants in Europe increases Norway's likelihood of importing coal-generated electricity (Figure 17, p. 26).

The EU recently amended the market for tradable $CO_2$ quotas in 2021. The new EU ETS includes buildings and transportation, making electrification less likely to have a net environmental impact. The electrification of the NCS will have no effect on $CO_2$ emissions in the 30 EU ETS member countries if the released gas is used for quota-controlled activities. Since the amount of allowed quota emissions is fixed, any reduction in $CO_2$ emissions from one activity will be compensated by increasing emissions from another (Torvanger & Ericson, 2013). If the released gas can substitute less efficient energy use in facilities outside the quota system, the net $CO_2$ would be lower such as through gas exports to countries outside of Europe.

Power from shore technology has advanced significantly since 1996, with smaller and lighter equipment capable of transporting more electricity over greater distances at a lower cost (Chapter 4.4). Power from shore has become more available due to technology improvements, allowing exploration of new power-intensive strategies for increased oil recovery or across market different segments, such as offshore wind. Converter equipment can now be installed on the seafloor, saving space and weight on the infrastructure. The power from shore technology also contributes to reducing electricity transmission losses. The technology advancements are beneficial since significant investments in power grid infrastructure are required for Norway to achieve large-scale electrification of the NCS.

Electricity transmission has become increasingly relevant as Norway integrated more into the European electricity market. The energy market is fast evolving as it becomes increasingly weather-dependent as renewable energy sources replace fossil fuels, and demand rises as a result of societal electrification (Chapter 4.2.1.3). The transfer of excess energy from one region to another requires international cooperation. Norway's integration provides significant power security in import capacity and makes the country more reliant on electricity imports (NVE, 2022). 2021 has shown that Norway's recent improved integration into the European electricity market has resulted in water reservoir depletion and rising electricity prices in Norway. Given that Norway has poor years with little precipitation, the integration improves electrical security; however, if Europe has a poor year with little wind and precipitation, Norway will still be affected by high electricity prices. The results in Chapter 5.3.2 reveal that importing power from a Nordic country or Europe has a bad environmental impact due to a higher average emission intensity of electricity generation and transmission loss. Power from the Norwegian El-mix, where the released gas is used in a Combined Heat and Power Plant (CHP) or building heating, has the greatest impact, with a 60% reduction in $CO_2$ emissions when replacing offshore gas turbines. CHP has an energy efficiency of 85%, and the gas utilised in buildings has an energy efficiency of 90%. It is a positive result that natural gas combustion in buildings is efficient because it provides basic needs such as cooking and heating, with few feasible short-term substitutes (Rystad Energy, 2022). A weakness of the environmental impact analysis is that it utilises 2021 average emission intensity numbers that change year by year, reducing the validity of the research over time.

Figure 25, p. 42, illustrates the international net $CO_2$ emission reduction due to power from shore. The results are determined by the El-mix delivered offshore, the use of the released gas, and the subtraction of the emission intensity of the electricity-generating substitute. The results show that replacing electricity generated by a coal power plant results in increased net $CO_2$ emissions. The findings demonstrate that reducing net emissions will be more difficult with power from shore when the Nordic and European El-mixes have lower emission intensity. Due to the released gas must replace electricity generation with higher emission intensity to have a good net environmental impact. The lack of other feasible gas substitutes makes it more logical to use gas in buildings as heat rather than generate electricity. Utilizing released gas in buildings reduces the likelihood of Norway importing electricity, which is unfavourable since the net energy transmission loss from Europe to the NCS is around 20%. According to the analysis findings, electrification results in a lower net energy export due to the lower total transmission loss when exporting electricity rather than natural gas. The green Norwegian electricity mix emits far less than the natural gas combustion and thus has a more significant environmental impact.

The NPD uses the $CO_2$ abatement cost to determine whether a power from shore project should get executed if it exceeds the $CO_2$ price. The Norwegian government plan to increase the $CO_2$ price as an incentive for oil and gas companies to conduct electrification projects (KonKraft, 2021). The rise in $CO_2$ price makes it easier for the NPD to justify a power from shore project as socioeconomic beneficial, despite extremely high energy prices. The economic sensitivity analysis results show that the $CO_2$ price has no direct impact on the $CO_2$ abatement cost (Figure 26, p. 44). However, the increased $CO_2$ price was a driving factor in the significant increase in natural energy prices in 2021 (Figure 17, p. 26). The $CO_2$ abatement cost is affected by natural gas and electricity prices. As a result, an increase in the price of $CO_2$ has an indirect impact on the $CO_2$ abatement cost. The sensitivity analysis shows an inverse correlation between the gas and electricity price that hedges the $CO_2$ abatement cost, making it less volatile (Figure 27, p. 45). The purchased electricity releases gas for sale, providing economic security for the investing field operator.

The gas turbine efficiency has the greatest impact on the $CO_2$ abatement cost due to the significant impact on the amount of gas released and abatement of $CO_2$ (Figure 26, p. 44). Improving the efficiency of gas turbines will thus have a significant environmental impact, limiting the improvement potential of power from shore and reducing the likelihood that the

$CO_2$ abatement cost will get evaluated as socioeconomic beneficial. There is nothing specific in NPD's report "Power from Shore to the Norwegian Continental Shelf," which forms the basis of the economic sensitivity analysis, about whether they analyse the efficiency of the gas tubes on the platforms (NPD, 2020). When conducting a cost-benefit analysis of a power from shore project, the NPD should consider the environmental impact and cost of upgrading gas turbines to Combined Heat and Power Plants (CHP). The efficiency then improves dramatically, making power from shore less profitable.

Installing offshore electricity cables is prohibitively expensive, and oil fields have a limited production lifetime. Increasing $CO_2$ price has historically been a driving force for further development of electrification on the NCS. This is obvious from oil and gas companies' business point of view. The temporary modification of the petroleum tax system has resulted in even better economic conditions, with a 73% investment return in the first year. Assuming that full-scale NCS electrification will cost 50 billion NOK, the Norwegian government will bear 45.72 billion NOK, or 91.44% of the cost (NPD, 2022c). As a result, a record number of plans for developing power from shore are expected to be delivered within 2022 (Rystad Energy, 2021).

Power from shore to the NCS reduces $CO_2$ emissions related to oil and gas extraction, the green electricity surplus in Norway, net energy exports to Europe, and increases the electricity prices in Norway. Despite the high electricity prices, the development of power from shore receives broad support from Norwegian political parties (Figure 12, p. 19). According to NPD assessments, around two-thirds of Norway's natural gas resources have yet to be extracted. (NPD, 2022a). Further electrification of the NCS contributes positively to reaching Norway's domestic climate target and justifying the continuation of oil and gas extraction. The rationale is that the petroleum industry is the most important source of government revenue(Meld. St. 13, 2021), and they want it to continue for many years. As a result of the conflict in Ukraine, Norway now plays an even more critical role in meeting Europe's energy demand. The petroleum industry is essential to meeting basic human needs and preventing countries from falling into energy poverty. Global energy demand will continue to rise, so oil and gas will remain critical components of the global energy mix for decades (SINTEF, 2019).

Increased public climate awareness has resulted in significant changes in politics and within the petroleum industry. Environmental activists, Norwegian industry, and petroleum employees all agree that emissions must be reduced and investments in low-carbon solutions are required. When it comes to electrification, however, the statistics are conclusive. According to the public survey results, the Norwegian citizens want to cease further electrification development on the NCS (Figure 19, p. 31). The exact reason for this is uncertain because social knowledge and awareness regarding electrification are both individual and variable. The public may believe that electrification is too costly and that taxpayer funds are more useful when spent elsewhere. Electrification contributes to increased electricity prices, reducing Norwegian citizens' purchasing power. Another reason could be that electrification's environmental impact is not considered worth the investments required.

## 7.1 Discussion: Research questions

### 1. What is the most critical driver and barrier for electrifying the Norwegian continental shelf with power from shore?

The political legislation is the most powerful driver and barrier to electrifying the Norwegian continental shelf with power from shore. The Paris Agreement and the European Climate Law are crucial drivers for Norway to continue developing power from shore to meet its national climate targets. Global warming is an international issue that requires cross-national collaboration and that all governments implement emission-reduction measures. The Energy Act and the Petroleum Law aim to ensure that the value generated by petroleum resources benefits Norwegian citizens. It is essential that all significant social concerns are taken into account (NPD, 2022e). Before new power from shore projects can be implemented, they must be considered socioeconomically beneficial, and the conclusion may change during the licencing process. Norway has the legal authority to decline and revoke development authorisation for power from shore projects, thereby halting further electrification development of the NCS.

### 2. Does electrification of the Norwegian Continental Shelf reduce $CO_2$ emissions?

The environmental impact analysis shows that electrification will lower Norway's upstream and domestic emissions while increasing downstream emissions that are not included in Norway's national climate targets. The EU Emissions Trading System (EU ETS) implies that electrification has no net environmental impact on $CO_2$ emissions in the 30 member countries if the released gas is used for quota-controlled activities. The number of allowed quota emissions is fixed, and companies receive or buy emission allowances, which they can trade as needed (European Comission, 2022). Any reduction of $CO_2$ emissions from one activity will be compensated by increasing emissions from another. The environmental impact of power from shore is determined by electricity transmission distance, the emission intensity of the electricity transferred to the Norwegian continental shelf, and the combustion method of the natural gas released. If the released gas can substitute less efficient energy use in facilities outside the quota system, the net $CO_2$ would be lower such as through gas exports to countries outside of EU ETS. Power from shore has the best environmental impact when the electricity is from the Norwegian electricity mix, and the released gas is used in a CHP or building and substitutes for coal power. The Norwegian El-mix has a lower emission intensity and reduced transmission loss, making it ideal for electrifying the NCS. Power from shore increases net $CO_2$ emissions when the electricity transmitted offshore is imported from a Nordic and European average electricity mix.

### 3. How do political and economic frameworks facilitate power from shore development?

According to the Norwegian climate plan, the most important measure is raising the $CO_2$ price and incentivising the energy companies to reduce emissions by implementing power from shore (KonKraft, 2021). The power from shore implementation is socioeconomically beneficial if the $CO_2$ price exceeds the $CO_2$ abatement cost and should be executed (NPD, 2020). The high $CO_2$ price increases the cost limit for $CO_2$ reduction incentives, making power from shore projects more likely to be approved. The Petroleum Tax system provides favourable economic conditions for oil and gas companies to implement power from shore. The temporary modification in the petroleum tax system has resulted in even more lucrative economic conditions, with the Norwegian government bearing 91,44 % of the investment costs (NPD, 2022c), significantly lowering the developer's economic risks. The political and economic framework facilitates good conditions for oil and gas companies to electrify the Norwegian continental shelf.

# 8 Conclusion

The purpose of this thesis is to investigate whether Norway should continue the development of power from shore to the Norwegian continental shelf. The conclusion is based on the three separate analyses and a comprehensive literature study.

Power from shore to the Norwegian continental shelf has a large domestic environmental impact potential, while the international environmental impact is limited and depends on several uncertain factors. The environmental impact analysis shows that electrification will lower Norway's upstream emissions while increasing downstream emissions that are not included in Norway's national climate targets. The recently amended EU Emissions Trading System (EU ETS) implies that electrification has no net environmental impact in the 30 EU ETS member countries if the released gas is used for quota-controlled activities. If the released gas can substitute less efficient energy use in facilities outside the quota system, the net $CO_2$ would be lower such as through gas exports to countries outside of Europe.

The PESTL analysis studies which factors drive electrification development and which create barriers. The political legislation is the most powerful driver and barrier to electrifying the Norwegian continental shelf with power from shore. The Paris Agreement and the European Climate Law are crucial drivers for Norway to continue developing power from shore to meet its national climate targets. In contrast, the Energy Act and the Petroleum Law aim to ensure that the value generated by petroleum resources benefits Norwegian citizens. Norway has legal permission to decline and revoke development authorisation for power from shore projects, thereby stopping further electrification development of the NCS.

According to the Norwegian climate plan, the most important measure is raising the $CO_2$ price and incentivising the energy companies to reduce emissions by implementing power from shore. Increased $CO_2$ price increases the cost limit for $CO_2$ reduction incentives, making power from shore projects more likely to be approved. The political and economic framework facilitates excellent conditions for oil and gas companies to electrify the Norwegian continental shelf. The economic sensitivity analysis results show that the gas turbine efficiency has the most significant impact on the $CO_2$ abatement cost. Improving the efficiency of gas turbines will thus have a significant environmental impact, limiting the improvement potential of power from shore.

Norway should stop the development of the Norwegian Continental Shelf with power from shore to protect Norwegian citizens from an uncertain energy future, based on the Energy Act and the Petroleum Law. The energy market is fast evolving as it becomes increasingly weather-dependent as renewable energy sources replace fossil fuels. Oil fields have a limited lifetime, and power from shore reduces the power surplus in Norway, net energy exports to Europe, and increases the electricity prices in Norway. 2021 has shown that rising $CO_2$ prices can significantly increase energy prices, reducing Norwegians' purchasing power. The Norwegian government should improve gas turbine efficiency offshore, instead of raising $CO_2$ prices, and renegotiate the Paris Agreement and the European Climate Law's 2030 targets for net $CO_2$ reduction. Then forest $CO_2$ capture is included in the climate equation, making Norway well-positioned to meet the 2030 climate target without further electrification development. By aligning 2030 and the 2050 climate targets to net $CO_2$ reduction, it will secure better long-term investments toward the ultimate net-zero society target.

## Future Research

According to Norway's Climate Plan, power from shore is critical for meeting national climate targets. Investigating if Norway is capable of meeting climate targets without further electrification development will provide valuable information on how Norway can achieve a net-zero society. I recommend including research on the significance of Norwegian forests and their $CO_2$ capture potential.

The conflict in Ukraine has resulted in heavy sanctions against the Russian economy and energy. Simultaneously, the energy sector is rapidly shifting as it becomes more weather-dependent as renewable energy sources replace fossil fuels. It would be interesting to study how much renewable energy investment is required per year to meet rising energy demand without relying on Russian energy imports by 2030, as the EU intends. In addition, what would happen to Europe if Norway ceased producing oil and gas for export?

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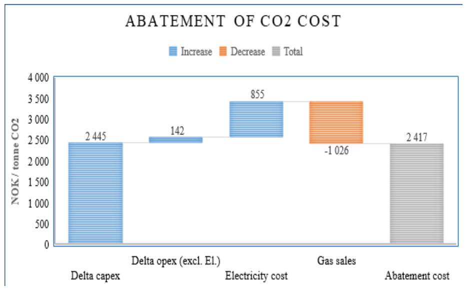
# Appendix 1 – Economic Sensitivity Analysis

## $CO_2$ Abatement cost analysis – Hypothetical petroleum field - Conducted in Excel

| Parameters assumptions (You can change the numbers) | Value | Unit |
|---|---|---|
| **Total life-time electricity demand [TWh]:** | 2 | TWh |
| **Discount rate:** | 7 % | % |
| **Gas turbine efficiency on platform:** | 30 % | % |
| **Electricity spot-price (incl. grid rent):** | 0,6 | NOK/kWh |
| **Gas price (incl. tariffs):** | 2,4 | NOK/Sm3 |
| **CO2 price:** | 1600 | NOK/tonne |

| Other parameters | Value | Unit | Source |
|---|---|---|---|
| 1 MWh | 1 000 | kWh | (NPD,2022b) |
| 1 Sm3 gas | 11,11 | kWh | (NPD,2022b) |
| 1 million | 1 000 000 | | |
| 1 tonne | 1 000 | kg | |
| Average gas combustion emission, 1 sm3 gas | 2,34 | kg CO2 | (Torvanger and Ericson, 2013; SSB,2017) |


ABATEMENT OF CO2 COST

### Results

| | Value | Unit | |
|---|---|---|---|
| **CO2 abatement cost:** | **2 417** | NOK/tonne CO2 | |
| | **NPV** | | **SUM** |
| **Cashflow net cost, excl. CO2-cost:** | **2 082** | MNOK | **2 300** |
| **Cashflow, incl. saved CO2-cost:** | **-703** | MNOK | **-53** |
| **Total CO2-cost savings:** | **1 378** | MNOK | **2 247** |

| CAPEX Assumptions | Unit | NPV | Sum | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cost Offshore (excl. Cable cost) | MNOK | -634 | -710 | -60 | -250 | -250 | -150 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cost Onshore | MNOK | -447 | -470 | -200 | -200 | -50 | -20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cable Cost | MNOK | -1 025 | -1 160 | -60 | -300 | -550 | -250 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sum | MNOK | -2 106 | -2 340 | -320 | -750 | -850 | -420 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| OPEX Assumptions | Unit | NPV | Sum | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Opex with power from shore (excl. electricity cost) | MNOK | -123 | -200 | 0 | 0 | 0 | -20,0 | -20,0 | -20,0 | -20,0 | -20,0 | -20,0 | -20,0 | -20,0 | -20,0 | -20,0 | 0 | 0 | 0 | 0 | 0 |
| Delta opex (excl. electricity cost) | MNOK | -123 | -200,00 | 0,0 | 0,0 | 0,0 | -20,0 | -20,0 | -20,0 | -20,0 | -20,0 | -20,0 | -20,0 | -20,0 | -20,0 | -20,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |

| Electricity demand and extra gas relased | Unit | NPV | Sum | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electricity demand | MWh/År | 1 404 716 | 2 000 000 | | | | 200 000 | 200 000 | 200 000 | 200 000 | 200 000 | 200 000 | 200 000 | 200 000 | 200 000 | 200 000 | | | | | |
| Gas Released (40MJ/Sm3) | Mill Sm3/år | 368 | 600 | 0,0 | 0,0 | 0,0 | 60,0 | 60,0 | 60,0 | 60,0 | 60,0 | 60,0 | 60,0 | 60,0 | 60,0 | 60,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |

| Emission Assumption (Disregards NOx) | Unit | NPV (CO2 emissions) | Sum | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CO2-utslipp ved elektrifisering | Mill tonne/år | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| CO2-emissions ved turbiner | Mill tonne/år | 0,86 | 1,40 | 0,00 | 0,00 | 0,00 | 0,14 | 0,14 | 0,14 | 0,14 | 0,14 | 0,14 | 0,14 | 0,14 | 0,14 | 0,14 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Delta CO2-emissions | Mill tonne/år | 0,86 | 1,40 | 0,00 | 0,00 | 0,00 | 0,14 | 0,14 | 0,14 | 0,14 | 0,14 | 0,14 | 0,14 | 0,14 | 0,14 | 0,14 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |

| Energy Prices | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electricity price (incl. grid rent): | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 |
| Gas price (incl. tariffer): | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 | 0,60 |
| CO2 price: | 1600 | 1600 | 1600 | 1600 | 1600 | 1600 | 1600 | 1600 | 1600 | 1600 | 1600 | 1600 | 1600 | 1600 | 1600 | 1600 | 1600 | 1600 | 1600 | 1600 | 1600 |

| Parameters | Unit | | NPV | Sum | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Delta capex | MNOK | | -2 106 | -2 340 | -320 | -750 | -850 | -420 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Delta opex (excl. electricity cost) | MNOK | | -123 | -200 | 0 | 0 | 0 | -20 | -20 | -20 | -20 | -20 | -20 | -20 | -20 | -20 | -20 | 0 | 0 | 0 | 0 |
| Gas sales | MNOK | | 883 | 1 440 | 0 | 0 | 0 | 144 | 144 | 144 | 144 | 144 | 144 | 144 | 144 | 144 | 144 | 0 | 0 | 0 | 0 |
| Electricity cost | MNOK | | -736 | -1 200 | 0 | 0 | 0 | -120 | -120 | -120 | -120 | -120 | -120 | -120 | -120 | -120 | -120 | 0 | 0 | 0 | 0 |
| **Cashflow net cost** | MNOK | | **2 082** | **2 300** | **320** | **750** | **850** | **416** | **-4** | **-4** | **-4** | **-4** | **-4** | **-4** | **-4** | **-4** | **-4** | **0** | **0** | **0** | **0** |
| CO2-cost savings | MNOK | | 1 378 | 2 247 | 0 | 0 | 0 | 225 | 225 | 225 | 225 | 225 | 225 | 225 | 225 | 225 | 225 | 0 | 0 | 0 | 0 |
| **Cashflow net cost, included saveings CO2-cost** | MNOK | | **-703** | **-53** | -320 | -750 | -850 | -191 | 229 | 229 | 229 | 229 | 229 | 229 | 229 | 229 | 229 | 0 | 0 | 0 | 0 |

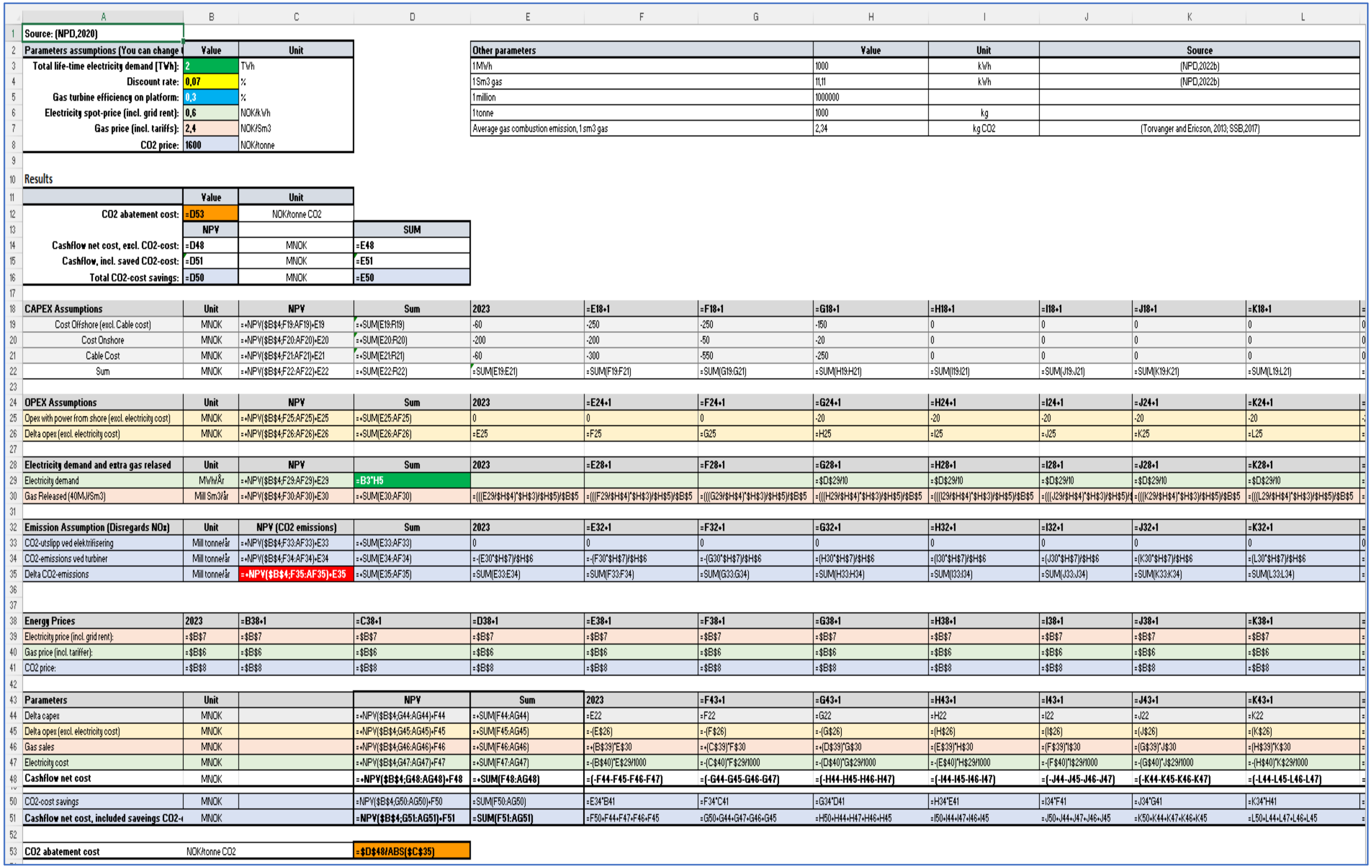
| | | |
|---|---|---|
| **CO2 abatement cost** | NOK/tonne CO2 | **2 417** |

### Results

| Parameter | Value | Unit |
|---|---|---|
| Delta capex | 2 445 | MNOK |
| Delta opex (excl. El.) | 142 | MNOK |
| Electricity cost | 855 | MNOK |
| Gas sales | -1 026 | MNOK |
| **Abatement cost** | **2 417** | **MNOK** |

# Formulas used in the analysis:

Formulas used in the analysis:

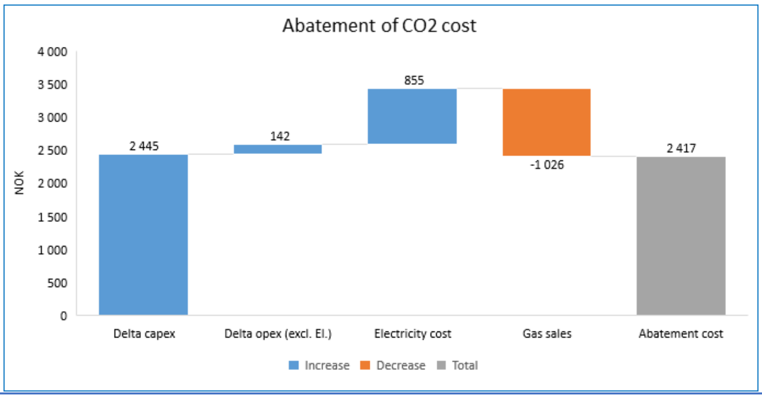


| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Source: (NPD,2020) | | | | | | | | | | | |
| 2 | Parameters assumptions (You can change | Value | Unit | | Other parameters | | | Value | Unit | Source | | |
| 3 | Total life-time electricity demand [TWh]: | 2 | TWh | | 1MWh | | | 1000 | kWh | (NPD,2022b) | | |
| 4 | Discount rate: | 0,07 | % | | 1Sm3 gas | | | 11,11 | kWh | (NPD,2022b) | | |
| 5 | Gas turbine efficiency on platform: | 0,3 | % | | 1million | | | 1000000 | | | | |
| 6 | Electricity spot-price (incl. grid rent): | 0,6 | NOK/kWh | | 1tonne | | | 1000 | kg | | | |
| 7 | Gas price (incl. tariffs): | 2,4 | NOK/Sm3 | | Average gas combustion emission, 1sm3 gas | | | 2,34 | kg CO2 | (Torvanger and Ericson, 2013; SSB,2017) | | |
| 8 | CO2 price: | 1600 | NOK/tonne | | | | | | | | | |
| 9 | | | | | | | | | | | | |
| 10 | Results | | | | | | | | | | | |
| 11 | | Value | Unit | | | | | | | | | |
| 12 | CO2 abatement cost: | =D53 | NOK/tonne CO2 | | | | | | | | | |
| 13 | | NPV | | SUM | | | | | | | | |
| 14 | Cashflow net cost, excl. CO2-cost: | =D48 | MNOK | =E48 | | | | | | | | |
| 15 | Cashflow, incl. saved CO2-cost: | =D51 | MNOK | =E51 | | | | | | | | |
| 16 | Total CO2-cost savings: | =D50 | MNOK | =E50 | | | | | | | | |
| 17 | | | | | | | | | | | | |
| 18 | CAPEX Assumptions | Unit | NPV | Sum | 2023 | =E18+1 | =F18+1 | =G18+1 | =H18+1 | =I18+1 | =J18+1 | =K18+1 |
| 19 | Cost Offshore (excl. Cable cost) | MNOK | =+NPV($B$4;F19:AF19)+E19 | =+SUM(E19:R19) | -60 | -250 | -250 | -150 | 0 | 0 | 0 | 0 |
| 20 | Cost Onshore | MNOK | =+NPV($B$4;F20:AF20)+E20 | =+SUM(E20:R20) | -200 | -200 | -50 | -20 | 0 | 0 | 0 | 0 |
| 21 | Cable Cost | MNOK | =+NPV($B$4;F21:AF21)+E21 | =+SUM(E21:R21) | -60 | -300 | -550 | -250 | 0 | 0 | 0 | 0 |
| 22 | Sum | MNOK | =+NPV($B$4;F22:AF22)+E22 | =+SUM(E22:R22) | =SUM(E19:E21) | =SUM(F19:F21) | =SUM(G19:G21) | =SUM(H19:H21) | =SUM(I19:I21) | =SUM(J19:J21) | =SUM(K19:K21) | =SUM(L19:L21) |
| 23 | | | | | | | | | | | | |
| 24 | OPEX Assumptions | Unit | NPV | Sum | 2023 | =E24+1 | =F24+1 | =G24+1 | =H24+1 | =I24+1 | =J24+1 | =K24+1 |
| 25 | Opex with power from shore (excl. electricity cost) | MNOK | =+NPV($B$4;F25:AF25)+E25 | =+SUM(E25:AF25) | 0 | 0 | 0 | -20 | -20 | -20 | -20 | -20 |
| 26 | Delta opex (excl. electricity cost) | MNOK | =+NPV($B$4;F26:AF26)+E26 | =+SUM(E26:AF26) | =E25 | =F25 | =G25 | =H25 | =I25 | =J25 | =K25 | =L25 |
| 27 | | | | | | | | | | | | |
| 28 | Electricity demand and extra gas relased | Unit | NPV | Sum | 2023 | =E28+1 | =F28+1 | =G28+1 | =H28+1 | =I28+1 | =J28+1 | =K28+1 |
| 29 | Electricity demand | MWh/År | =+NPV($B$4;F29:AF29)+E29 | =B3*H5 | | | | =$D$29/10 | =$D$29/10 | =$D$29/10 | =$D$29/10 | =$D$29/10 |
| 30 | Gas Released (40MJ/Sm3) | Mill Sm3/år | =+NPV($B$4;F30:AF30)+E30 | =+SUM(E30:AF30) | =(((E29/$H$4)*$H$3)/$H$5)/$B$5 | =(((F29/$H$4)*$H$3)/$H$5)/$B$5 | =(((G29/$H$4)*$H$3)/$H$5)/$B$5 | =(((H29/$H$4)*$H$3)/$H$5)/$B$5 | =(((I29/$H$4)*$H$3)/$H$5)/$B$5 | =(((J29/$H$4)*$H$3)/$H$5)/$ | =(((K29/$H$4)*$H$3)/$H$5)/$B$5 | =(((L29/$H$4)*$H$3)/$H$5)/$B$5 |
| 31 | | | | | | | | | | | | |
| 32 | Emission Assumption (Disregards NOx) | Unit | NPV (CO2 emissions) | Sum | 2023 | =E32+1 | =F32+1 | =G32+1 | =H32+1 | =I32+1 | =J32+1 | =K32+1 |
| 33 | CO2-utslipp ved elektrifisering | Mill tonne/år | =+NPV($B$4;F33:AF33)+E33 | =+SUM(E33:AF33) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34 | CO2-emissions ved turbiner | Mill tonne/år | =+NPV($B$4;F34:AF34)+E34 | =+SUM(E34:AF34) | =-(E30*$H$7)/$H$6 | =-(F30*$H$7)/$H$6 | =-(G30*$H$7)/$H$6 | =(H30*$H$7)/$H$6 | =(I30*$H$7)/$H$6 | =(J30*$H$7)/$H$6 | =(K30*$H$7)/$H$6 | =(L30*$H$7)/$H$6 |
| 35 | Delta CO2-emissions | Mill tonne/år | =+NPV($B$4;F35:AF35)+E35 | =+SUM(E35:AF35) | =SUM(E33:E34) | =SUM(F33:F34) | =SUM(G33:G34) | =SUM(H33:H34) | =SUM(I33:I34) | =SUM(J33:J34) | =SUM(K33:K34) | =SUM(L33:L34) |
| 36 | | | | | | | | | | | | |
| 37 | | | | | | | | | | | | |
| 38 | Energy Prices | 2023 | =B38+1 | =C38+1 | =D38+1 | =E38+1 | =F38+1 | =G38+1 | =H38+1 | =I38+1 | =J38+1 | =K38+1 |
| 39 | Electricity price (incl. grid rent): | =$B$7 | =$B$7 | =$B$7 | =$B$7 | =$B$7 | =$B$7 | =$B$7 | =$B$7 | =$B$7 | =$B$7 | =$B$7 |
| 40 | Gas price (incl. tariffer): | =$B$6 | =$B$6 | =$B$6 | =$B$6 | =$B$6 | =$B$6 | =$B$6 | =$B$6 | =$B$6 | =$B$6 | =$B$6 |
| 41 | CO2 price: | =$B$8 | =$B$8 | =$B$8 | =$B$8 | =$B$8 | =$B$8 | =$B$8 | =$B$8 | =$B$8 | =$B$8 | =$B$8 |
| 42 | | | | | | | | | | | | |
| 43 | Parameters | Unit | | NPV | Sum | 2023 | =F43+1 | =G43+1 | =H43+1 | =I43+1 | =J43+1 | =K43+1 |
| 44 | Delta capex | MNOK | | =+NPV($B$4;G44:AG44)+F44 | =+SUM(F44:AG44) | =E22 | =F22 | =G22 | =H22 | =I22 | =J22 | =K22 |
| 45 | Delta opex (excl. electricity cost) | MNOK | | =+NPV($B$4;G45:AG45)+F45 | =+SUM(F45:AG45) | =-(E$26) | =-(F$26) | =-(G$26) | =(H$26) | =(I$26) | =(J$26) | =(K$26) |
| 46 | Gas sales | MNOK | | =+NPV($B$4;G46:AG46)+F46 | =+SUM(F46:AG46) | =+(B$39)*E$30 | =+(C$39)*F$30 | =+(D$39)*G$30 | =(E$39)*H$30 | =(F$39)*I$30 | =(G$39)*J$30 | =(H$39)*K$30 |
| 47 | Electricity cost | MNOK | | =+NPV($B$4;G47:AG47)+F47 | =+SUM(F47:AG47) | =-(B$40)*E$29/1000 | =-(C$40)*F$29/1000 | =-(D$40)*G$29/1000 | =-(E$40)*H$29/1000 | =-(F$40)*I$29/1000 | =-(G$40)*J$29/1000 | =-(H$40)*K$29/1000 |
| 48 | Cashflow net cost | MNOK | | =+NPV($B$4;G48:AG48)+F48 | =+SUM(F48:AG48) | =(-F44-F45-F46-F47) | =(-G44-G45-G46-G47) | =(-H44-H45-H46-H47) | =(-I44-I45-I46-I47) | =(-J44-J45-J46-J47) | =(-K44-K45-K46-K47) | =(-L44-L45-L46-L47) |
| 50 | CO2-cost savings | MNOK | | =NPV($B$4;G50:AG50)+F50 | =SUM(F50:AG50) | =E34*B41 | =F34*C41 | =G34*D41 | =H34*E41 | =I34*F41 | =J34*G41 | =K34*H41 |
| 51 | Cashflow net cost, included saveings CO2- | MNOK | | =NPV($B$4;G51:AG51)+F51 | =SUM(F51:AG51) | =F50+F44+F47+F46+F45 | =G50+G44+G47+G46+G45 | =H50+H44+H47+H46+H45 | =I50+I44+I47+I46+I45 | =J50+J44+J47+J46+J45 | =K50+K44+K47+K46+K45 | =L50+L44+L47+L46+L45 |
| 52 | | | | | | | | | | | | |
| 53 | CO2 abatement cost | NOK/tonne CO2 | | =$D$48/ABS($C$35) | | | | | | | | |

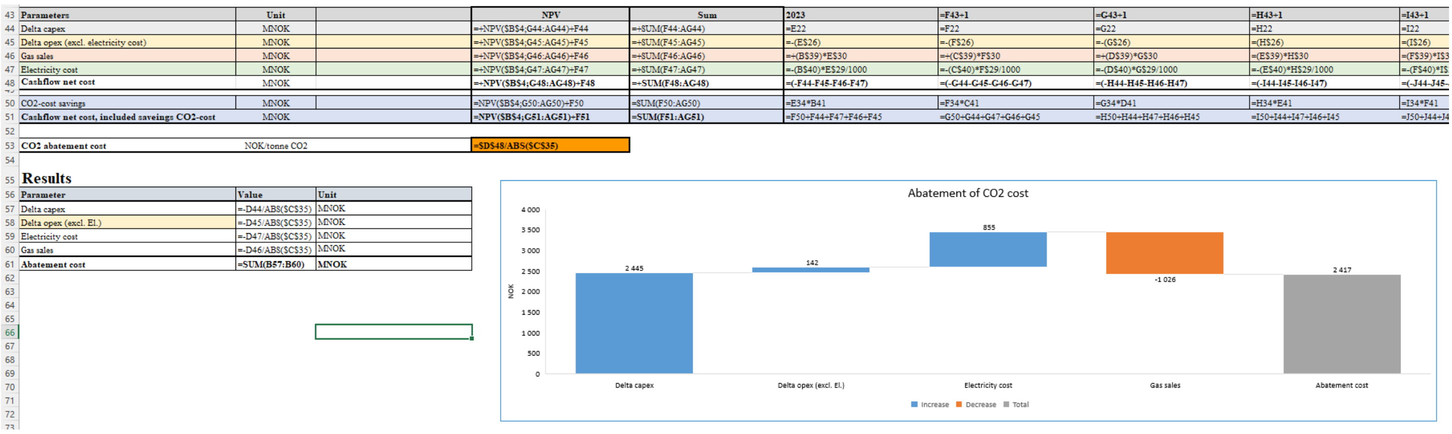
## CO₂ abatement cost Figure input:

**Results**

| Parameter | Value | Unit |
|---|---|---|
| Delta capex | 2 445 | MNOK |
| Delta opex (excl. El.) | 142 | MNOK |
| Electricity cost | 855 | MNOK |
| Gas sales | -1 026 | MNOK |
| **Abatement cost** | **2 417** | **MNOK** |



## CO₂ abatement cost Figure formulas:

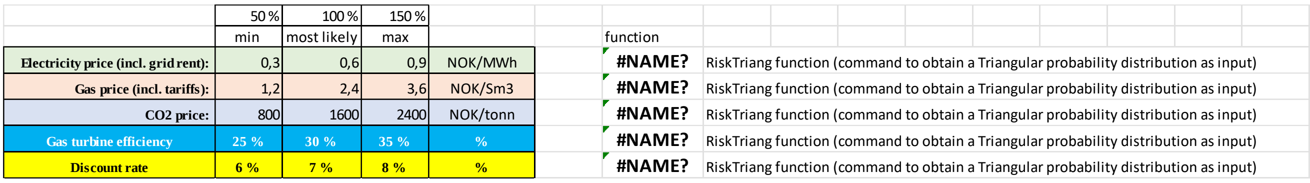


| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 43 | **Parameters** | **Unit** | | **NPV** | **Sum** | **2023** | **=F43+1** | **=G43+1** | **=H43+1** | **=I43+1** |
| 44 | Delta capex | MNOK | | =+NPV($B$4;G44:AG44)+F44 | =+SUM(F44:AG44) | =E22 | =F22 | =G22 | =H22 | =I22 |
| 45 | Delta opex (excl. electricity cost) | MNOK | | =+NPV($B$4;G45:AG45)+F45 | =+SUM(F45:AG45) | =-(E$26) | =-(F$26) | =-(G$26) | =(H$26) | =(I$26) |
| 46 | Gas sales | MNOK | | =+NPV($B$4;G46:AG46)+F46 | =+SUM(F46:AG46) | =+(B$39)*E$30 | =+(C$39)*F$30 | =+(D$39)*G$30 | =(E$39)*H$30 | =(F$39)*I$3 |
| 47 | Electricity cost | MNOK | | =+NPV($B$4;G47:AG47)+F47 | =+SUM(F47:AG47) | =-(B$40)*E$29/1000 | =-(C$40)*F$29/1000 | =-(D$40)*G$29/1000 | =-(E$40)*H$29/1000 | =-(F$40)*I$ |
| 48 | **Cashflow net cost** | MNOK | | **=+NPV($B$4;G48:AG48)+F48** | **=+SUM(F48:AG48)** | **=(-F44-F45-F46-F47)** | **=(-G44-G45-G46-G47)** | **=(-H44-H45-H46-H47)** | **=(-I44-I45-I46-I47)** | **=(-J44-J45-** |
| 50 | CO2-cost savings | MNOK | | =NPV($B$4;G50:AG50)+F50 | =SUM(F50:AG50) | =E34*B41 | =F34*C41 | =G34*D41 | =H34*E41 | =I34*F41 |
| 51 | **Cashflow net cost, included saveings CO2-cost** | MNOK | | **=NPV($B$4;G51:AG51)+F51** | **=SUM(F51:AG51)** | =F50+F44+F47+F46+F45 | =G50+G44+G47+G46+G45 | =H50+H44+H47+H46+H45 | =I50+I44+I47+I46+I45 | =J50+J44+J4 |
| 52 | | | | | | | | | | |
| 53 | **CO2 abatement cost** | NOK/tonne CO2 | | **=$D$48/ABS($C$35)** | | | | | | |

55 **Results**

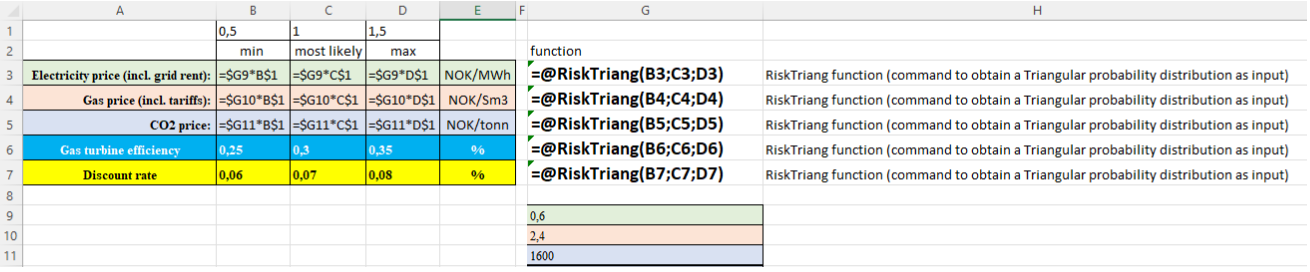
| | Parameter | Value | Unit |
|---|---|---|---|
| 56 | **Parameter** | **Value** | **Unit** |
| 57 | Delta capex | =-D44/ABS($C$35) | MNOK |
| 58 | Delta opex (excl. El.) | =-D45/ABS($C$35) | MNOK |
| 59 | Electricity cost | =-D47/ABS($C$35) | MNOK |
| 60 | Gas sales | =-D46/ABS($C$35) | MNOK |
| 61 | **Abatement cost** | **=SUM(B57:B60)** | **MNOK** |

## @Risk Input sheet:



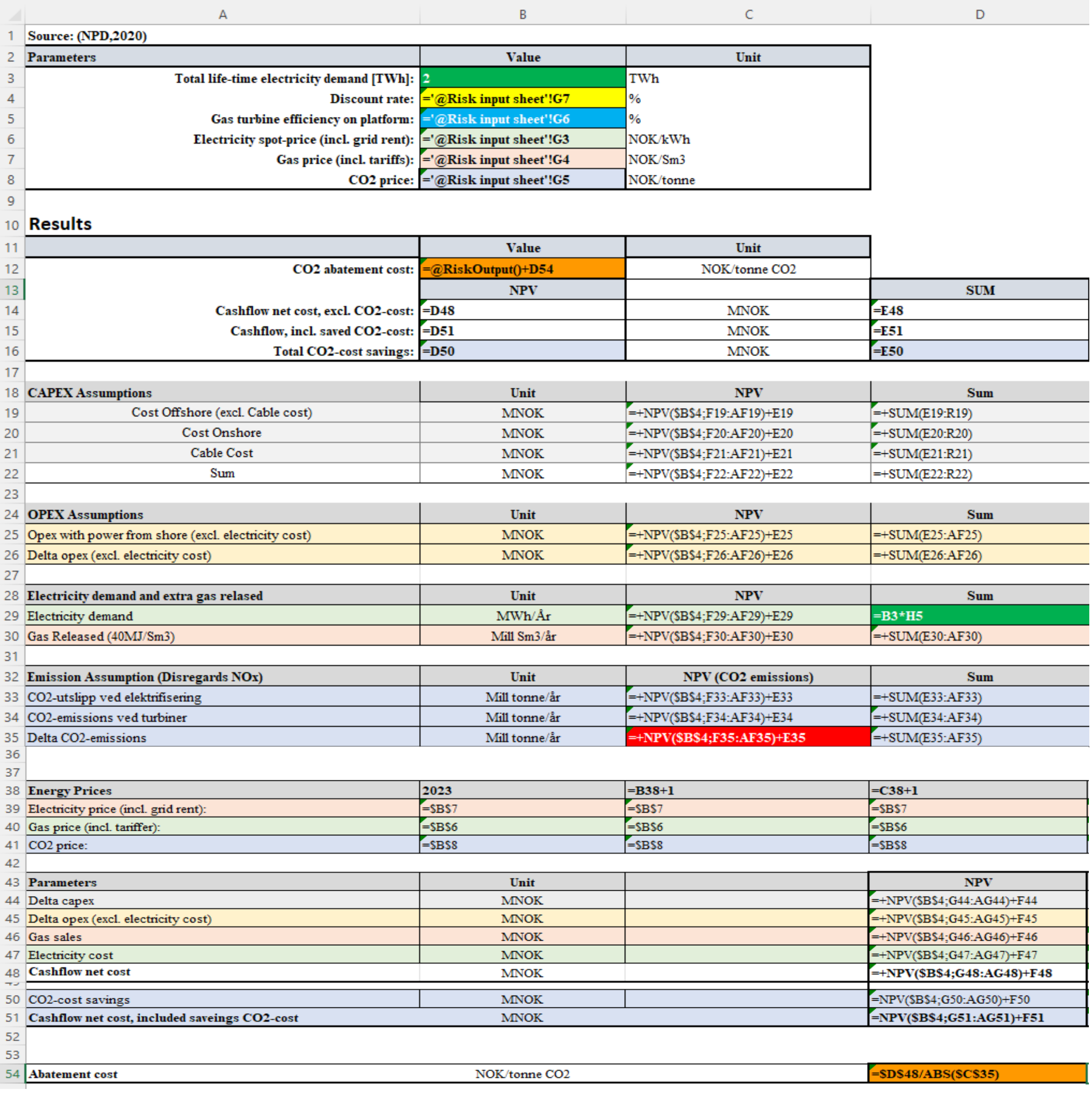
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 50 % | 100 % | 150 % | | | | |
| | min | most likely | max | | | function | |
| **Electricity price (incl. grid rent):** | 0,3 | 0,6 | 0,9 | NOK/MWh | | **#NAME?** | RiskTriang function (command to obtain a Triangular probability distribution as input) |
| **Gas price (incl. tariffs):** | 1,2 | 2,4 | 3,6 | NOK/Sm3 | | **#NAME?** | RiskTriang function (command to obtain a Triangular probability distribution as input) |
| **CO2 price:** | 800 | 1600 | 2400 | NOK/tonn | | **#NAME?** | RiskTriang function (command to obtain a Triangular probability distribution as input) |
| **Gas turbine efficiency** | 25 % | 30 % | 35 % | % | | **#NAME?** | RiskTriang function (command to obtain a Triangular probability distribution as input) |
| **Discount rate** | 6 % | 7 % | 8 % | % | | **#NAME?** | RiskTriang function (command to obtain a Triangular probability distribution as input) |

## Formulas:



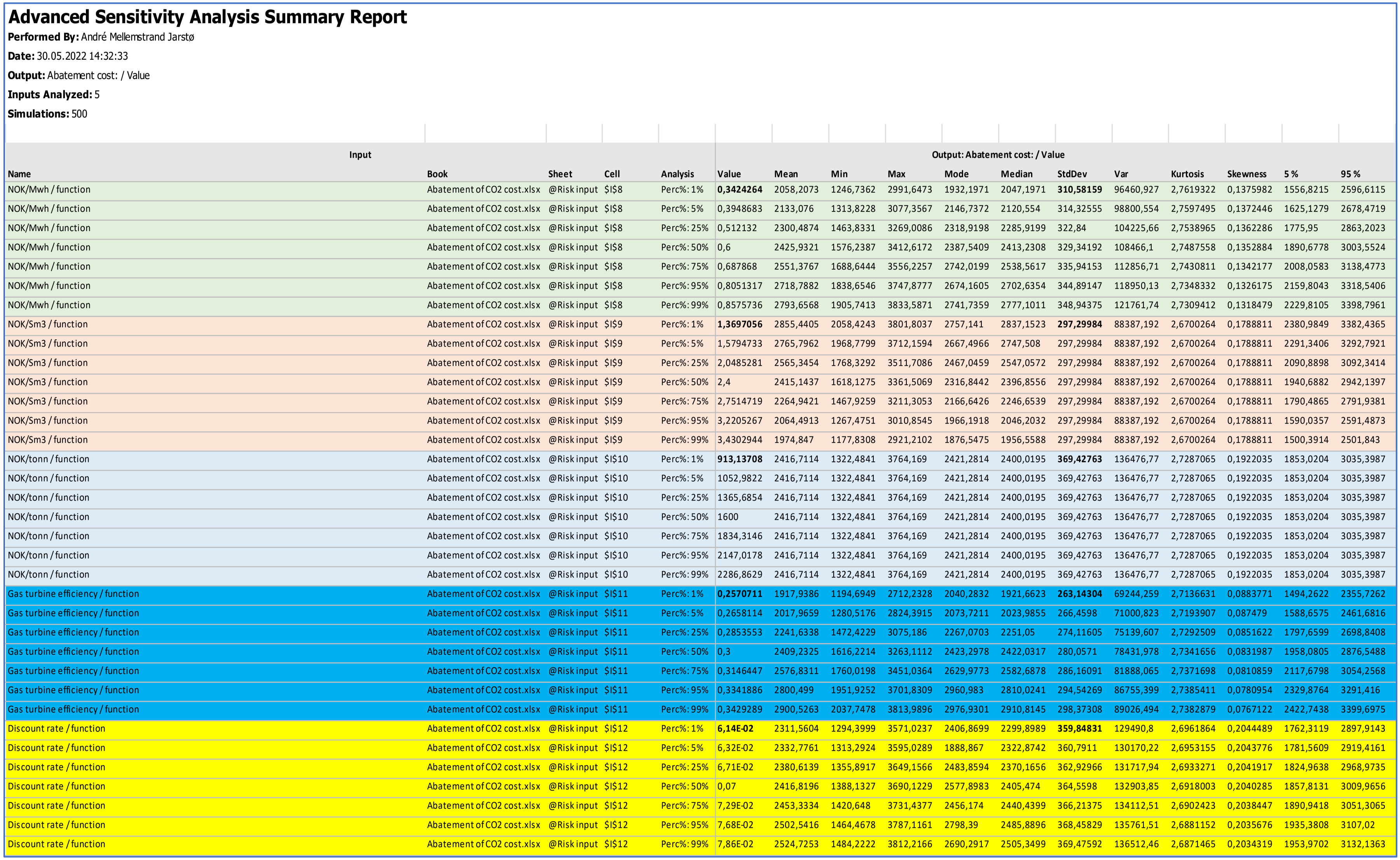
| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | | 0,5 | 1 | 1,5 | | | | |
| 2 | | min | most likely | max | | | function | |
| 3 | **Electricity price (incl. grid rent):** | =$G9*B$1 | =$G9*C$1 | =$G9*D$1 | NOK/MWh | | **=@RiskTriang(B3;C3;D3)** | RiskTriang function (command to obtain a Triangular probability distribution as input) |
| 4 | **Gas price (incl. tariffs):** | =$G10*B$1 | =$G10*C$1 | =$G10*D$1 | NOK/Sm3 | | **=@RiskTriang(B4;C4;D4)** | RiskTriang function (command to obtain a Triangular probability distribution as input) |
| 5 | **CO2 price:** | =$G11*B$1 | =$G11*C$1 | =$G11*D$1 | NOK/tonn | | **=@RiskTriang(B5;C5;D5)** | RiskTriang function (command to obtain a Triangular probability distribution as input) |
| 6 | **Gas turbine efficiency** | 0,25 | 0,3 | 0,35 | % | | **=@RiskTriang(B6;C6;D6)** | RiskTriang function (command to obtain a Triangular probability distribution as input) |
| 7 | **Discount rate** | 0,06 | 0,07 | 0,08 | % | | **=@RiskTriang(B7;C7;D7)** | RiskTriang function (command to obtain a Triangular probability distribution as input) |
| 8 | | | | | | | | |
| 9 | | | | | | | 0,6 | |
| 10 | | | | | | | 2,4 | |
| 11 | | | | | | | 1600 | |

## @Risk Output sheet (The entire Excel sheet is found on Page 64):



| | A | B | C | D |
|---|---|---|---|---|
| 1 | Source: (NPD,2020) | | | |
| 2 | **Parameters** | **Value** | **Unit** | |
| 3 | **Total life-time electricity demand [TWh]:** | 2 | TWh | |
| 4 | **Discount rate:** | ='@Risk input sheet'!G7 | % | |
| 5 | **Gas turbine efficiency on platform:** | ='@Risk input sheet'!G6 | % | |
| 6 | **Electricity spot-price (incl. grid rent):** | ='@Risk input sheet'!G3 | NOK/kWh | |
| 7 | **Gas price (incl. tariffs):** | ='@Risk input sheet'!G4 | NOK/Sm3 | |
| 8 | **CO2 price:** | ='@Risk input sheet'!G5 | NOK/tonne | |
| 9 | | | | |
| 10 | **Results** | | | |
| 11 | | **Value** | **Unit** | |
| 12 | **CO2 abatement cost:** | =@RiskOutput()+D54 | NOK/tonne CO2 | |
| 13 | | **NPV** | | **SUM** |
| 14 | **Cashflow net cost, excl. CO2-cost:** | =D48 | MNOK | =E48 |
| 15 | **Cashflow, incl. saved CO2-cost:** | =D51 | MNOK | =E51 |
| 16 | **Total CO2-cost savings:** | =D50 | MNOK | =E50 |
| 17 | | | | |
| 18 | **CAPEX Assumptions** | **Unit** | **NPV** | **Sum** |
| 19 | Cost Offshore (excl. Cable cost) | MNOK | =+NPV($B$4;F19:AF19)+E19 | =+SUM(E19:R19) |
| 20 | Cost Onshore | MNOK | =+NPV($B$4;F20:AF20)+E20 | =+SUM(E20:R20) |
| 21 | Cable Cost | MNOK | =+NPV($B$4;F21:AF21)+E21 | =+SUM(E21:R21) |
| 22 | Sum | MNOK | =+NPV($B$4;F22:AF22)+E22 | =+SUM(E22:R22) |
| 23 | | | | |
| 24 | **OPEX Assumptions** | **Unit** | **NPV** | **Sum** |
| 25 | Opex with power from shore (excl. electricity cost) | MNOK | =+NPV($B$4;F25:AF25)+E25 | =+SUM(E25:AF25) |
| 26 | Delta opex (excl. electricity cost) | MNOK | =+NPV($B$4;F26:AF26)+E26 | =+SUM(E26:AF26) |
| 27 | | | | |
| 28 | **Electricity demand and extra gas relased** | **Unit** | **NPV** | **Sum** |
| 29 | Electricity demand | MWh/År | =+NPV($B$4;F29:AF29)+E29 | =B3*H5 |
| 30 | Gas Released (40MJ/Sm3) | Mill Sm3/år | =+NPV($B$4;F30:AF30)+E30 | =+SUM(E30:AF30) |
| 31 | | | | |
| 32 | **Emission Assumption (Disregards NOx)** | **Unit** | **NPV (CO2 emissions)** | **Sum** |
| 33 | CO2-utslipp ved elektrifisering | Mill tonne/år | =+NPV($B$4;F33:AF33)+E33 | =+SUM(E33:AF33) |
| 34 | CO2-emissions ved turbiner | Mill tonne/år | =+NPV($B$4;F34:AF34)+E34 | =+SUM(E34:AF34) |
| 35 | Delta CO2-emissions | Mill tonne/år | **=+NPV($B$4;F35:AF35)+E35** | =+SUM(E35:AF35) |
| 36 | | | | |
| 37 | | | | |
| 38 | **Energy Prices** | **2023** | **=B38+1** | **=C38+1** |
| 39 | Electricity price (incl. grid rent): | =$B$7 | =$B$7 | =$B$7 |
| 40 | Gas price (incl. tariffer): | =$B$6 | =$B$6 | =$B$6 |
| 41 | CO2 price: | =$B$8 | =$B$8 | =$B$8 |
| 42 | | | | |
| 43 | **Parameters** | **Unit** | | **NPV** |
| 44 | Delta capex | MNOK | | =+NPV($B$4;G44:AG44)+F44 |
| 45 | Delta opex (excl. electricity cost) | MNOK | | =+NPV($B$4;G45:AG45)+F45 |
| 46 | Gas sales | MNOK | | =+NPV($B$4;G46:AG46)+F46 |
| 47 | Electricity cost | MNOK | | =+NPV($B$4;G47:AG47)+F47 |
| 48 | **Cashflow net cost** | MNOK | | **=+NPV($B$4;G48:AG48)+F48** |
| 50 | CO2-cost savings | MNOK | | =NPV($B$4;G50:AG50)+F50 |
| 51 | **Cashflow net cost, included saveings CO2-cost** | MNOK | | **=NPV($B$4;G51:AG51)+F51** |
| 52 | | | | |
| 53 | | | | |
| 54 | **Abatement cost** | NOK/tonne CO2 | | **=$D$48/ABS($C$35)** |

# Advanced Sensitivity Analysis Summary Report:



## Advanced Sensitivity Analysis Summary Report

**Performed By:** André Mellemstrand Jarstø

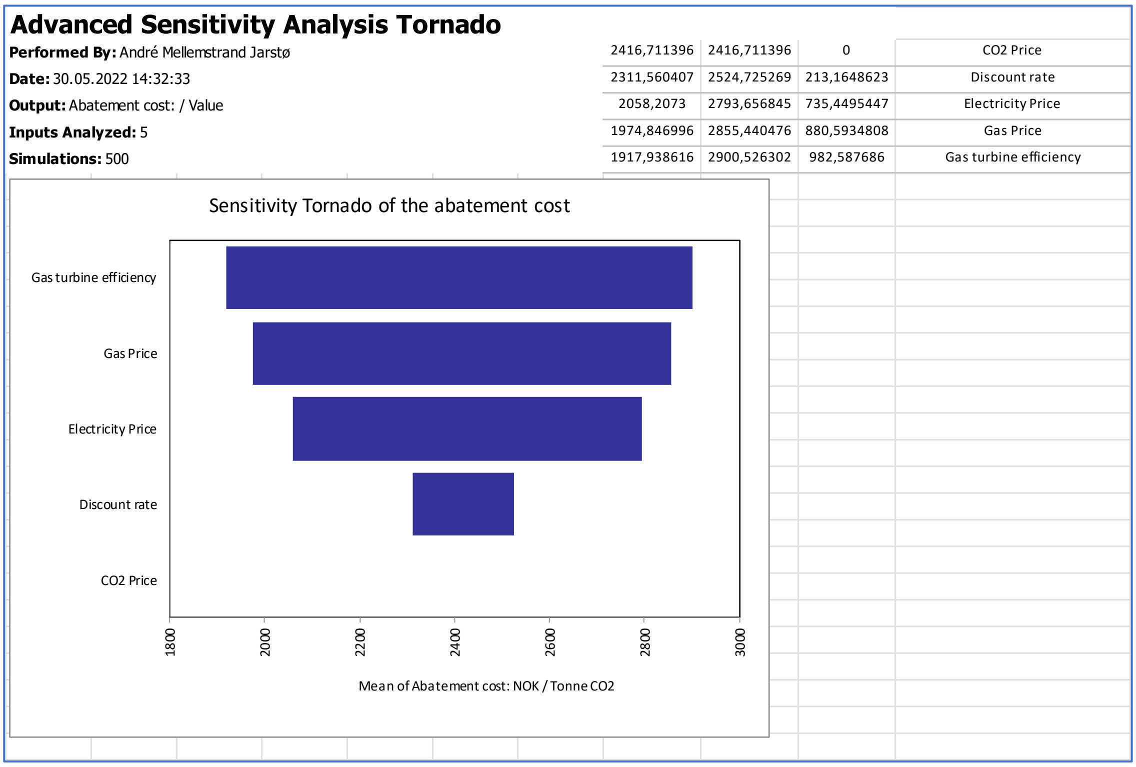
**Date:** 30.05.2022 14:32:33

**Output:** Abatement cost: / Value

**Inputs Analyzed:** 5

**Simulations:** 500

| Input | | | | | Output: Abatement cost: / Value | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Name** | **Book** | **Sheet** | **Cell** | **Analysis** | **Value** | **Mean** | **Min** | **Max** | **Mode** | **Median** | **StdDev** | **Var** | **Kurtosis** | **Skewness** | **5 %** | **95 %** |
| NOK/Mwh / function | Abatement of CO2 cost.xlsx | @Risk input | $I$8 | Perc%: 1% | **0,3424264** | 2058,2073 | 1246,7362 | 2991,6473 | 1932,1971 | 2047,1971 | **310,58159** | 96460,927 | 2,7619322 | 0,1375982 | 1556,8215 | 2596,6115 |
| NOK/Mwh / function | Abatement of CO2 cost.xlsx | @Risk input | $I$8 | Perc%: 5% | 0,3948683 | 2133,076 | 1313,8228 | 3077,3567 | 2146,7372 | 2120,554 | 314,32555 | 98800,554 | 2,7597495 | 0,1372446 | 1625,1279 | 2678,4719 |
| NOK/Mwh / function | Abatement of CO2 cost.xlsx | @Risk input | $I$8 | Perc%: 25% | 0,512132 | 2300,4874 | 1463,8331 | 3269,0086 | 2318,9198 | 2285,9199 | 322,84 | 104225,66 | 2,7538965 | 0,1362286 | 1775,95 | 2863,2023 |
| NOK/Mwh / function | Abatement of CO2 cost.xlsx | @Risk input | $I$8 | Perc%: 50% | 0,6 | 2425,9321 | 1576,2387 | 3412,6172 | 2387,5409 | 2413,2308 | 329,34192 | 108466,1 | 2,7487558 | 0,1352884 | 1890,6778 | 3003,5524 |
| NOK/Mwh / function | Abatement of CO2 cost.xlsx | @Risk input | $I$8 | Perc%: 75% | 0,687868 | 2551,3767 | 1688,6444 | 3556,2257 | 2742,0199 | 2538,5617 | 335,94153 | 112856,71 | 2,7430811 | 0,1342177 | 2008,0583 | 3138,4773 |
| NOK/Mwh / function | Abatement of CO2 cost.xlsx | @Risk input | $I$8 | Perc%: 95% | 0,8051317 | 2718,7882 | 1838,6546 | 3747,8777 | 2674,1605 | 2702,6354 | 344,89147 | 118950,13 | 2,7348332 | 0,1326175 | 2159,8043 | 3318,5406 |
| NOK/Mwh / function | Abatement of CO2 cost.xlsx | @Risk input | $I$8 | Perc%: 99% | 0,8575736 | 2793,6568 | 1905,7413 | 3833,5871 | 2741,7359 | 2777,1011 | 348,94375 | 121761,74 | 2,7309412 | 0,1318479 | 2229,8105 | 3398,7961 |
| NOK/Sm3 / function | Abatement of CO2 cost.xlsx | @Risk input | $I$9 | Perc%: 1% | **1,3697056** | 2855,4405 | 2058,4243 | 3801,8037 | 2757,141 | 2837,1523 | **297,29984** | 88387,192 | 2,6700264 | 0,1788811 | 2380,9849 | 3382,4365 |
| NOK/Sm3 / function | Abatement of CO2 cost.xlsx | @Risk input | $I$9 | Perc%: 5% | 1,5794733 | 2765,7962 | 1968,7799 | 3712,1594 | 2667,4966 | 2747,508 | 297,29984 | 88387,192 | 2,6700264 | 0,1788811 | 2291,3406 | 3292,7921 |
| NOK/Sm3 / function | Abatement of CO2 cost.xlsx | @Risk input | $I$9 | Perc%: 25% | 2,0485281 | 2565,3454 | 1768,3292 | 3511,7086 | 2467,0459 | 2547,0572 | 297,29984 | 88387,192 | 2,6700264 | 0,1788811 | 2090,8898 | 3092,3414 |
| NOK/Sm3 / function | Abatement of CO2 cost.xlsx | @Risk input | $I$9 | Perc%: 50% | 2,4 | 2415,1437 | 1618,1275 | 3361,5069 | 2316,8442 | 2396,8556 | 297,29984 | 88387,192 | 2,6700264 | 0,1788811 | 1940,6882 | 2942,1397 |
| NOK/Sm3 / function | Abatement of CO2 cost.xlsx | @Risk input | $I$9 | Perc%: 75% | 2,7514719 | 2264,9421 | 1467,9259 | 3211,3053 | 2166,6426 | 2246,6539 | 297,29984 | 88387,192 | 2,6700264 | 0,1788811 | 1790,4865 | 2791,9381 |
| NOK/Sm3 / function | Abatement of CO2 cost.xlsx | @Risk input | $I$9 | Perc%: 95% | 3,2205267 | 2064,4913 | 1267,4751 | 3010,8545 | 1966,1918 | 2046,2032 | 297,29984 | 88387,192 | 2,6700264 | 0,1788811 | 1590,0357 | 2591,4873 |
| NOK/Sm3 / function | Abatement of CO2 cost.xlsx | @Risk input | $I$9 | Perc%: 99% | 3,4302944 | 1974,847 | 1177,8308 | 2921,2102 | 1876,5475 | 1956,5588 | 297,29984 | 88387,192 | 2,6700264 | 0,1788811 | 1500,3914 | 2501,843 |
| NOK/tonn / function | Abatement of CO2 cost.xlsx | @Risk input | $I$10 | Perc%: 1% | **913,13708** | 2416,7114 | 1322,4841 | 3764,169 | 2421,2814 | 2400,0195 | **369,42763** | 136476,77 | 2,7287065 | 0,1922035 | 1853,0204 | 3035,3987 |
| NOK/tonn / function | Abatement of CO2 cost.xlsx | @Risk input | $I$10 | Perc%: 5% | 1052,9822 | 2416,7114 | 1322,4841 | 3764,169 | 2421,2814 | 2400,0195 | 369,42763 | 136476,77 | 2,7287065 | 0,1922035 | 1853,0204 | 3035,3987 |
| NOK/tonn / function | Abatement of CO2 cost.xlsx | @Risk input | $I$10 | Perc%: 25% | 1365,6854 | 2416,7114 | 1322,4841 | 3764,169 | 2421,2814 | 2400,0195 | 369,42763 | 136476,77 | 2,7287065 | 0,1922035 | 1853,0204 | 3035,3987 |
| NOK/tonn / function | Abatement of CO2 cost.xlsx | @Risk input | $I$10 | Perc%: 50% | 1600 | 2416,7114 | 1322,4841 | 3764,169 | 2421,2814 | 2400,0195 | 369,42763 | 136476,77 | 2,7287065 | 0,1922035 | 1853,0204 | 3035,3987 |
| NOK/tonn / function | Abatement of CO2 cost.xlsx | @Risk input | $I$10 | Perc%: 75% | 1834,3146 | 2416,7114 | 1322,4841 | 3764,169 | 2421,2814 | 2400,0195 | 369,42763 | 136476,77 | 2,7287065 | 0,1922035 | 1853,0204 | 3035,3987 |
| NOK/tonn / function | Abatement of CO2 cost.xlsx | @Risk input | $I$10 | Perc%: 95% | 2147,0178 | 2416,7114 | 1322,4841 | 3764,169 | 2421,2814 | 2400,0195 | 369,42763 | 136476,77 | 2,7287065 | 0,1922035 | 1853,0204 | 3035,3987 |
| NOK/tonn / function | Abatement of CO2 cost.xlsx | @Risk input | $I$10 | Perc%: 99% | 2286,8629 | 2416,7114 | 1322,4841 | 3764,169 | 2421,2814 | 2400,0195 | 369,42763 | 136476,77 | 2,7287065 | 0,1922035 | 1853,0204 | 3035,3987 |
| Gas turbine efficiency / function | Abatement of CO2 cost.xlsx | @Risk input | $I$11 | Perc%: 1% | **0,2570711** | 1917,9386 | 1194,6949 | 2712,2328 | 2040,2832 | 1921,6623 | **263,14304** | 69244,259 | 2,7136631 | 0,0883771 | 1494,2622 | 2355,7262 |
| Gas turbine efficiency / function | Abatement of CO2 cost.xlsx | @Risk input | $I$11 | Perc%: 5% | 0,2658114 | 2017,9659 | 1280,5176 | 2824,3915 | 2073,7211 | 2023,9855 | 266,4598 | 71000,823 | 2,7193907 | 0,087479 | 1588,6575 | 2461,6816 |
| Gas turbine efficiency / function | Abatement of CO2 cost.xlsx | @Risk input | $I$11 | Perc%: 25% | 0,2853553 | 2241,6338 | 1472,4229 | 3075,186 | 2267,0703 | 2251,05 | 274,11605 | 75139,607 | 2,7292509 | 0,0851622 | 1797,6599 | 2698,8408 |
| Gas turbine efficiency / function | Abatement of CO2 cost.xlsx | @Risk input | $I$11 | Perc%: 50% | 0,3 | 2409,2325 | 1616,2214 | 3263,1112 | 2423,2978 | 2422,0317 | 280,0571 | 78431,978 | 2,7341656 | 0,0831987 | 1958,0805 | 2876,5488 |
| Gas turbine efficiency / function | Abatement of CO2 cost.xlsx | @Risk input | $I$11 | Perc%: 75% | 0,3146447 | 2576,8311 | 1760,0198 | 3451,0364 | 2629,9773 | 2582,6878 | 286,16091 | 81888,065 | 2,7371698 | 0,0810859 | 2117,6798 | 3054,2568 |
| Gas turbine efficiency / function | Abatement of CO2 cost.xlsx | @Risk input | $I$11 | Perc%: 95% | 0,3341886 | 2800,499 | 1951,9252 | 3701,8309 | 2960,983 | 2810,0241 | 294,54269 | 86755,399 | 2,7385411 | 0,0780954 | 2329,8764 | 3291,416 |
| Gas turbine efficiency / function | Abatement of CO2 cost.xlsx | @Risk input | $I$11 | Perc%: 99% | 0,3429289 | 2900,5263 | 2037,7478 | 3813,9896 | 2976,9301 | 2910,8145 | 298,37308 | 89026,494 | 2,7382879 | 0,0767122 | 2422,7438 | 3399,6975 |
| Discount rate / function | Abatement of CO2 cost.xlsx | @Risk input | $I$12 | Perc%: 1% | **6,14E-02** | 2311,5604 | 1294,3999 | 3571,0237 | 2406,8699 | 2299,8989 | **359,84831** | 129490,8 | 2,6961864 | 0,2044489 | 1762,3119 | 2897,9143 |
| Discount rate / function | Abatement of CO2 cost.xlsx | @Risk input | $I$12 | Perc%: 5% | 6,32E-02 | 2332,7761 | 1313,2924 | 3595,0289 | 1888,867 | 2322,8742 | 360,7911 | 130170,22 | 2,6953155 | 0,2043776 | 1781,5609 | 2919,4161 |
| Discount rate / function | Abatement of CO2 cost.xlsx | @Risk input | $I$12 | Perc%: 25% | 6,71E-02 | 2380,6139 | 1355,8917 | 3649,1566 | 2483,8594 | 2370,1656 | 362,92966 | 131717,94 | 2,6933271 | 0,2041917 | 1824,9638 | 2968,9735 |
| Discount rate / function | Abatement of CO2 cost.xlsx | @Risk input | $I$12 | Perc%: 50% | 0,07 | 2416,8196 | 1388,1327 | 3690,1229 | 2577,8983 | 2405,474 | 364,5598 | 132903,85 | 2,6918003 | 0,2040285 | 1857,8131 | 3009,9656 |
| Discount rate / function | Abatement of CO2 cost.xlsx | @Risk input | $I$12 | Perc%: 75% | 7,29E-02 | 2453,3334 | 1420,648 | 3731,4377 | 2456,174 | 2440,4399 | 366,21375 | 134112,51 | 2,6902423 | 0,2038447 | 1890,9418 | 3051,3065 |
| Discount rate / function | Abatement of CO2 cost.xlsx | @Risk input | $I$12 | Perc%: 95% | 7,68E-02 | 2502,5416 | 1464,4678 | 3787,1161 | 2798,39 | 2485,8896 | 368,45829 | 135761,51 | 2,6881152 | 0,2035676 | 1935,3808 | 3107,02 |
| Discount rate / function | Abatement of CO2 cost.xlsx | @Risk input | $I$12 | Perc%: 99% | 7,86E-02 | 2524,7253 | 1484,2222 | 3812,2166 | 2690,2917 | 2505,3499 | 369,47592 | 136512,46 | 2,6871465 | 0,2034319 | 1953,9702 | 3132,1363 |



## Advanced Sensitivity Analysis Tornado

**Performed By:** André Mellemstrand Jarstø

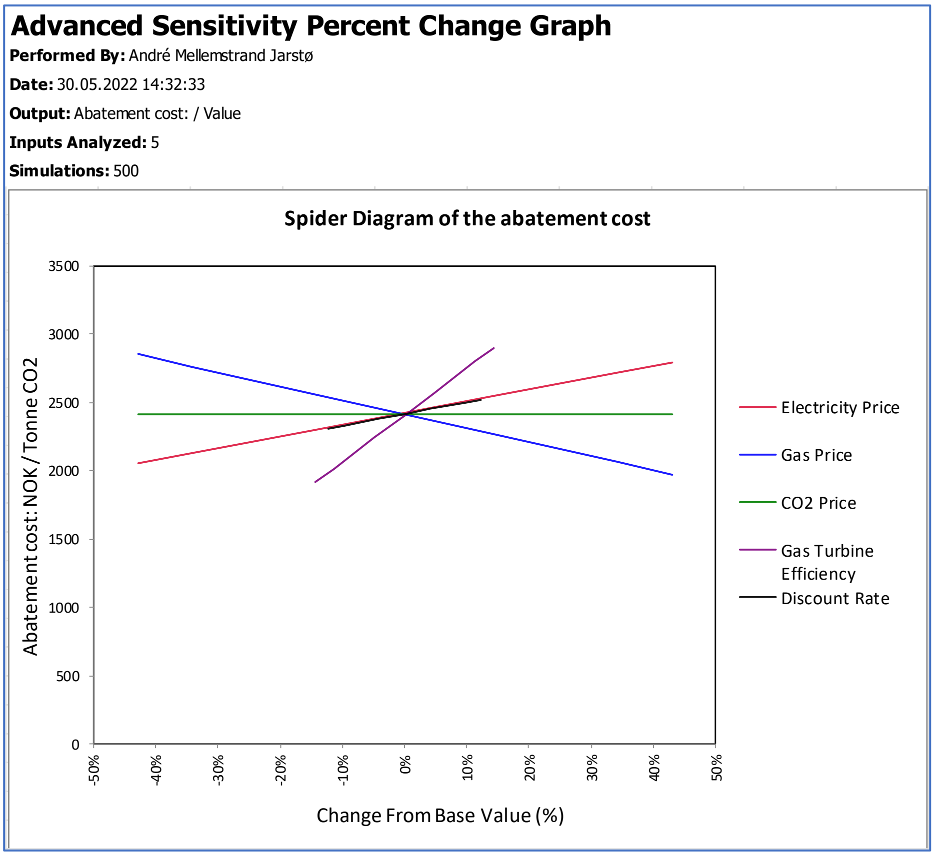
**Date:** 30.05.2022 14:32:33

**Output:** Abatement cost: / Value

**Inputs Analyzed:** 5

**Simulations:** 500

| | | | |
|---|---|---|---|
| 2416,711396 | 2416,711396 | 0 | CO2 Price |
| 2311,560407 | 2524,725269 | 213,1648623 | Discount rate |
| 2058,2073 | 2793,656845 | 735,4495447 | Electricity Price |
| 1974,846996 | 2855,440476 | 880,5934808 | Gas Price |
| 1917,938616 | 2900,526302 | 982,587686 | Gas turbine efficiency |



## Advanced Sensitivity Percent Change Graph

**Performed By:** André Mellemstrand Jarstø

**Date:** 30.05.2022 14:32:33

**Output:** Abatement cost: / Value

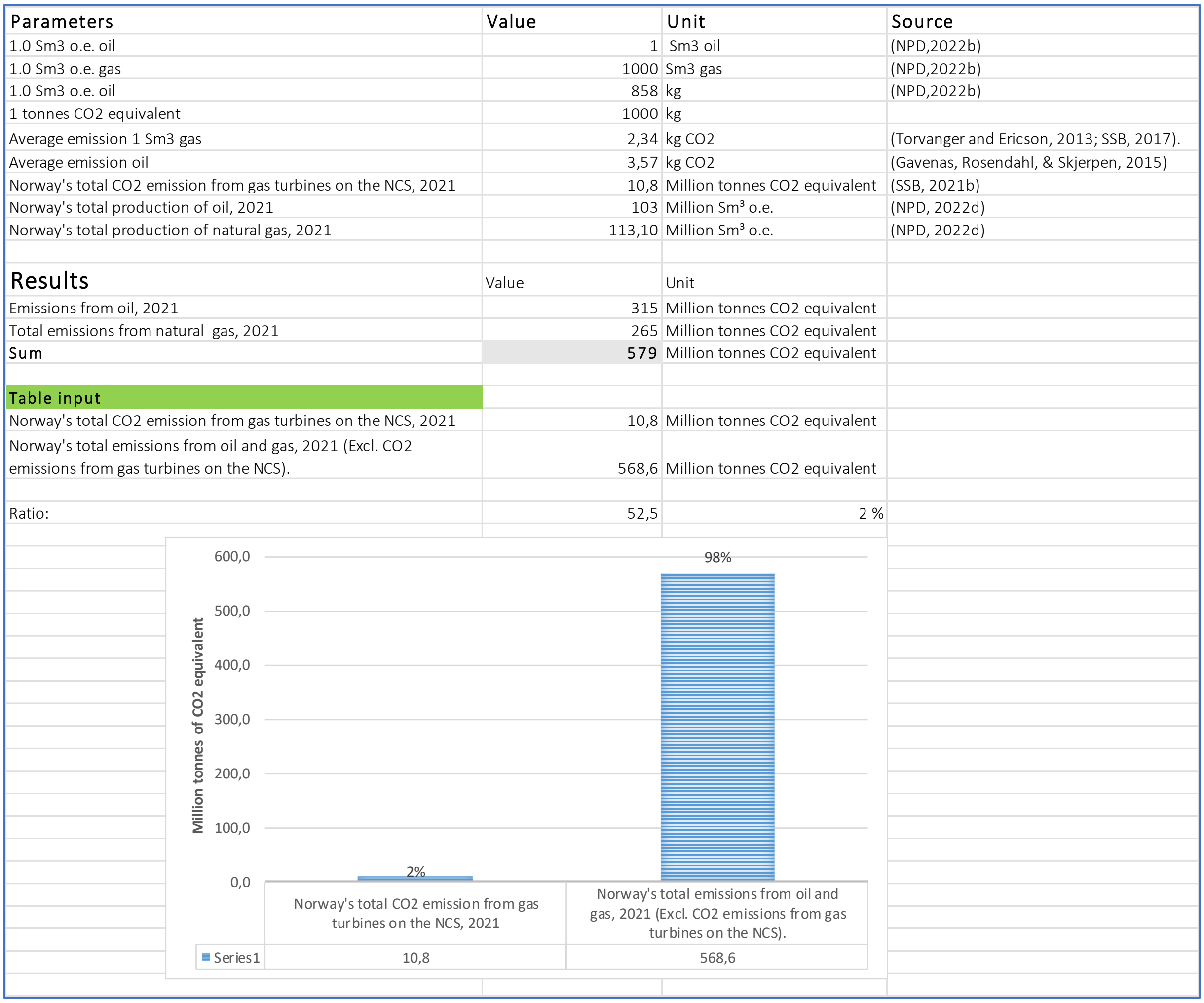
**Inputs Analyzed:** 5

**Simulations:** 500

# Appendix 2 – Environmental Impact Analysis

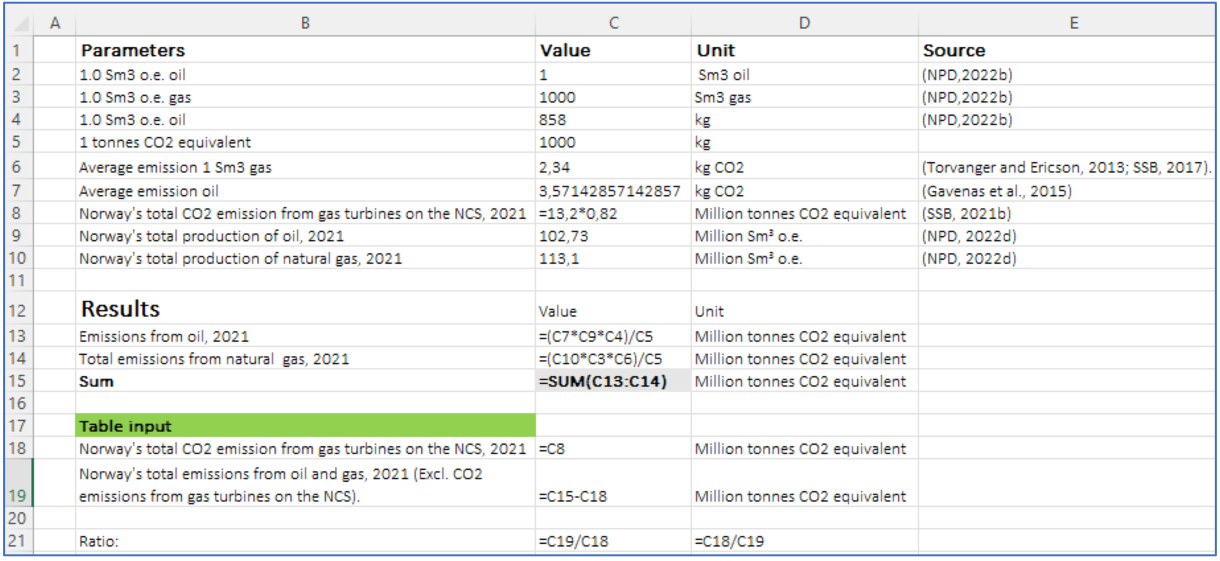
**Conducted in Excel.**

## Environmental Impact of Gas Turbines, Including upstream and downstream emissions:



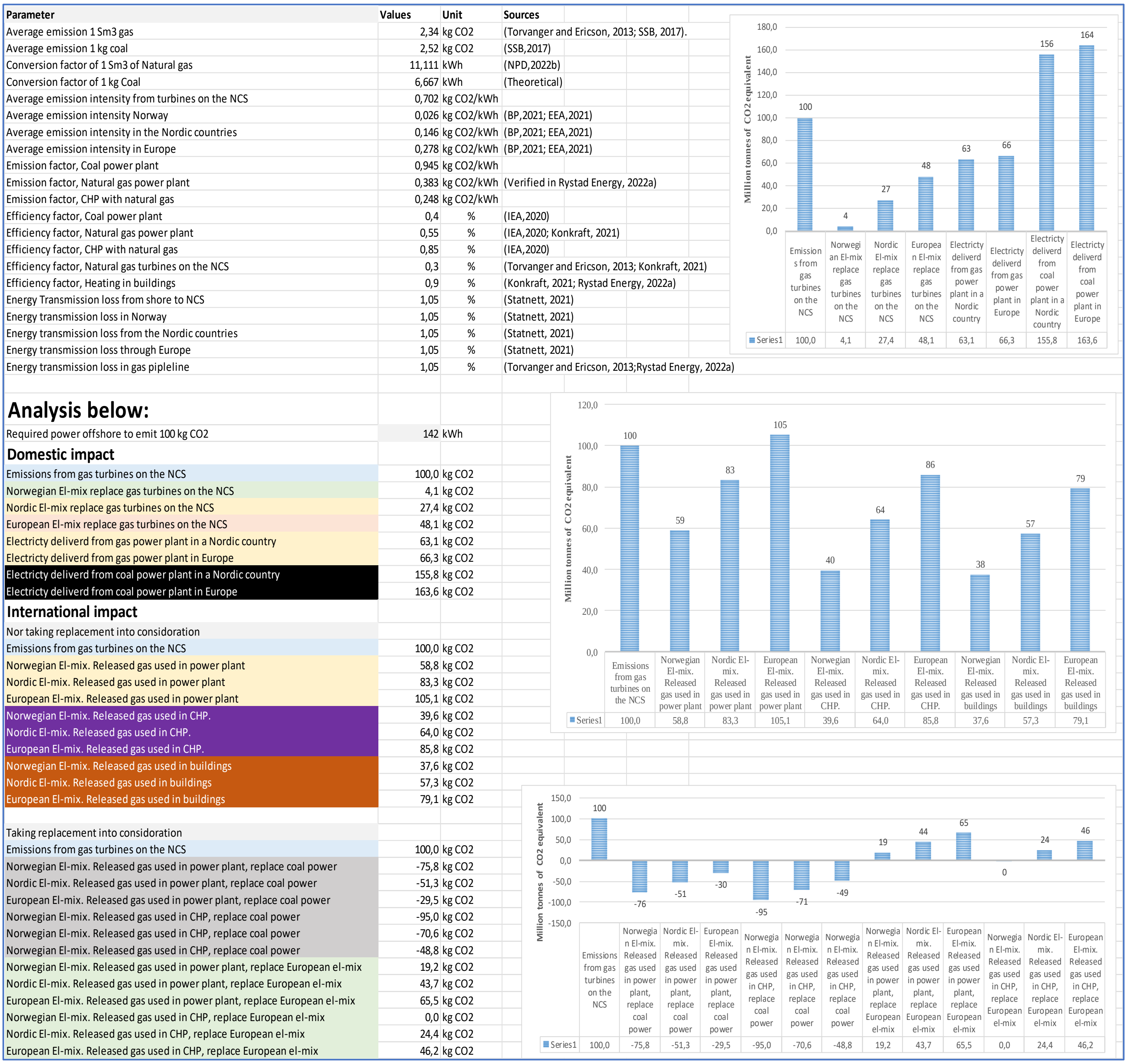
| Parameters | Value | Unit | Source |
|---|---|---|---|
| 1.0 Sm3 o.e. oil | 1 | Sm3 oil | (NPD,2022b) |
| 1.0 Sm3 o.e. gas | 1000 | Sm3 gas | (NPD,2022b) |
| 1.0 Sm3 o.e. oil | 858 | kg | (NPD,2022b) |
| 1 tonnes CO2 equivalent | 1000 | kg | |
| Average emission 1 Sm3 gas | 2,34 | kg CO2 | (Torvanger and Ericson, 2013; SSB, 2017). |
| Average emission oil | 3,57 | kg CO2 | (Gavenas, Rosendahl, & Skjerpen, 2015) |
| Norway's total CO2 emission from gas turbines on the NCS, 2021 | 10,8 | Million tonnes CO2 equivalent | (SSB, 2021b) |
| Norway's total production of oil, 2021 | 103 | Million Sm³ o.e. | (NPD, 2022d) |
| Norway's total production of natural gas, 2021 | 113,10 | Million Sm³ o.e. | (NPD, 2022d) |
| | | | |
| **Results** | Value | Unit | |
| Emissions from oil, 2021 | 315 | Million tonnes CO2 equivalent | |
| Total emissions from natural gas, 2021 | 265 | Million tonnes CO2 equivalent | |
| Sum | 579 | Million tonnes CO2 equivalent | |
| | | | |
| Table input | | | |
| Norway's total CO2 emission from gas turbines on the NCS, 2021 | 10,8 | Million tonnes CO2 equivalent | |
| Norway's total emissions from oil and gas, 2021 (Excl. CO2 emissions from gas turbines on the NCS). | 568,6 | Million tonnes CO2 equivalent | |
| | | | |
| Ratio: | 52,5 | 2 % | |

## Formulas used in the analysis:



| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | | **Parameters** | **Value** | **Unit** | **Source** |
| 2 | | 1.0 Sm3 o.e. oil | 1 | Sm3 oil | (NPD,2022b) |
| 3 | | 1.0 Sm3 o.e. gas | 1000 | Sm3 gas | (NPD,2022b) |
| 4 | | 1.0 Sm3 o.e. oil | 858 | kg | (NPD,2022b) |
| 5 | | 1 tonnes CO2 equivalent | 1000 | kg | |
| 6 | | Average emission 1 Sm3 gas | 2,34 | kg CO2 | (Torvanger and Ericson, 2013; SSB, 2017). |
| 7 | | Average emission oil | 3,57142857142857 | kg CO2 | (Gavenas et al., 2015) |
| 8 | | Norway's total CO2 emission from gas turbines on the NCS, 2021 | =13,2*0,82 | Million tonnes CO2 equivalent | (SSB, 2021b) |
| 9 | | Norway's total production of oil, 2021 | 102,73 | Million Sm³ o.e. | (NPD, 2022d) |
| 10 | | Norway's total production of natural gas, 2021 | 113,1 | Million Sm³ o.e. | (NPD, 2022d) |
| 11 | | | | | |
| 12 | | **Results** | Value | Unit | |
| 13 | | Emissions from oil, 2021 | =(C7*C9*C4)/C5 | Million tonnes CO2 equivalent | |
| 14 | | Total emissions from natural gas, 2021 | =(C10*C3*C6)/C5 | Million tonnes CO2 equivalent | |
| 15 | | **Sum** | **=SUM(C13:C14)** | Million tonnes CO2 equivalent | |
| 16 | | | | | |
| 17 | | **Table input** | | | |
| 18 | | Norway's total CO2 emission from gas turbines on the NCS, 2021 | =C8 | Million tonnes CO2 equivalent | |
| 19 | | Norway's total emissions from oil and gas, 2021 (Excl. CO2 emissions from gas turbines on the NCS). | =C15-C18 | Million tonnes CO2 equivalent | |
| 20 | | | | | |
| 21 | | Ratio: | =C19/C18 | =C18/C19 | |

# Environmental impact of the electricity mix and source:

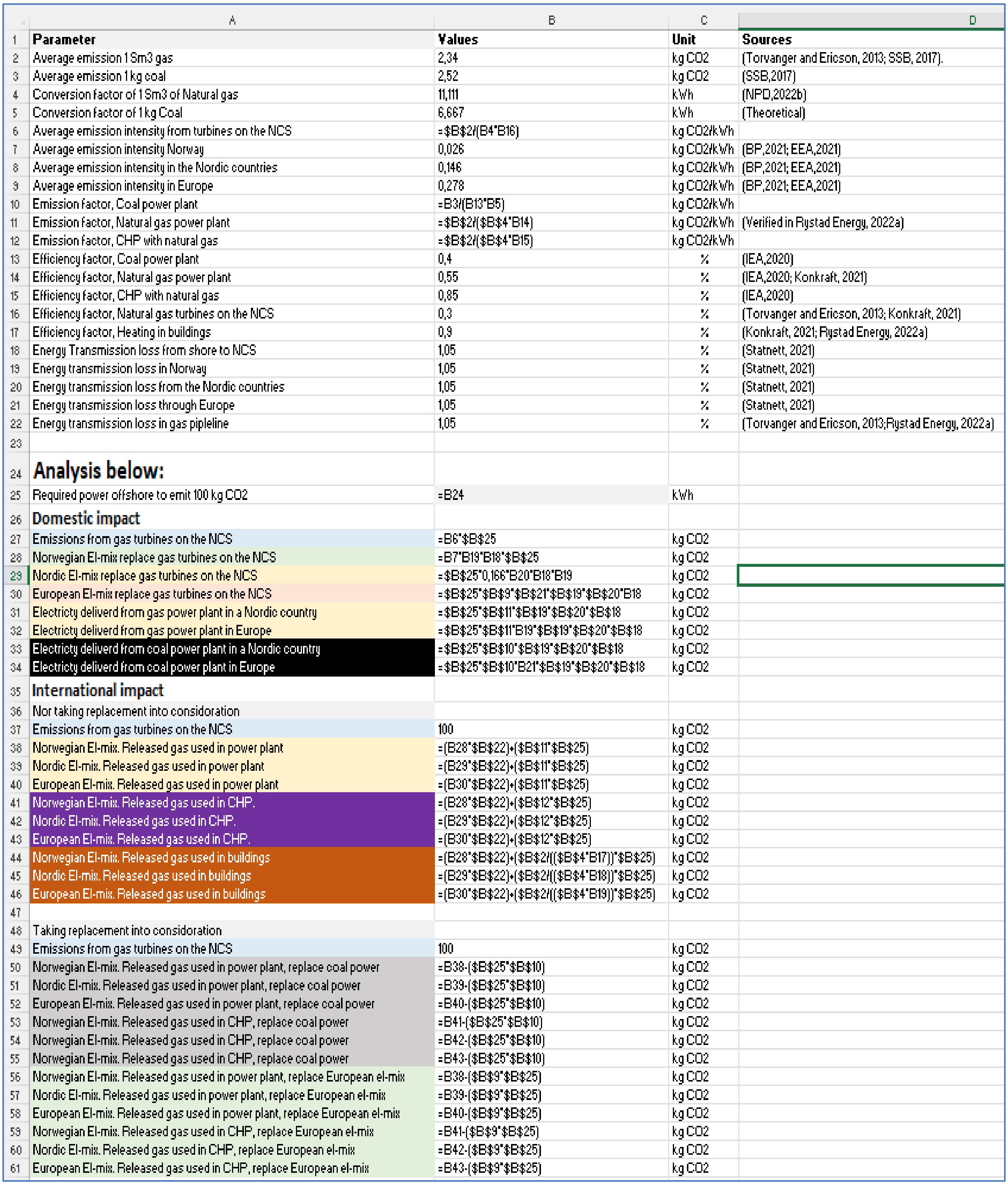


| Parameter | Values | Unit | Sources |
|---|---|---|---|
| Average emission 1 Sm3 gas | 2,34 | kg CO2 | (Torvanger and Ericson, 2013; SSB, 2017). |
| Average emission 1 kg coal | 2,52 | kg CO2 | (SSB,2017) |
| Conversion factor of 1 Sm3 of Natural gas | 11,111 | kWh | (NPD,2022b) |
| Conversion factor of 1 kg Coal | 6,667 | kWh | (Theoretical) |
| Average emission intensity from turbines on the NCS | 0,702 | kg CO2/kWh | |
| Average emission intensity Norway | 0,026 | kg CO2/kWh | (BP,2021; EEA,2021) |
| Average emission intensity in the Nordic countries | 0,146 | kg CO2/kWh | (BP,2021; EEA,2021) |
| Average emission intensity in Europe | 0,278 | kg CO2/kWh | (BP,2021; EEA,2021) |
| Emission factor, Coal power plant | 0,945 | kg CO2/kWh | |
| Emission factor, Natural gas power plant | 0,383 | kg CO2/kWh | (Verified in Rystad Energy, 2022a) |
| Emission factor, CHP with natural gas | 0,248 | kg CO2/kWh | |
| Efficiency factor, Coal power plant | 0,4 | % | (IEA,2020) |
| Efficiency factor, Natural gas power plant | 0,55 | % | (IEA,2020; Konkraft, 2021) |
| Efficiency factor, CHP with natural gas | 0,85 | % | (IEA,2020) |
| Efficiency factor, Natural gas turbines on the NCS | 0,3 | % | (Torvanger and Ericson, 2013; Konkraft, 2021) |
| Efficiency factor, Heating in buildings | 0,9 | % | (Konkraft, 2021; Rystad Energy, 2022a) |
| Energy Transmission loss from shore to NCS | 1,05 | % | (Statnett, 2021) |
| Energy transmission loss in Norway | 1,05 | % | (Statnett, 2021) |
| Energy transmission loss from the Nordic countries | 1,05 | % | (Statnett, 2021) |
| Energy transmission loss through Europe | 1,05 | % | (Statnett, 2021) |
| Energy transmission loss in gas pipleline | 1,05 | % | (Torvanger and Ericson, 2013;Rystad Energy, 2022a) |

## Analysis below:

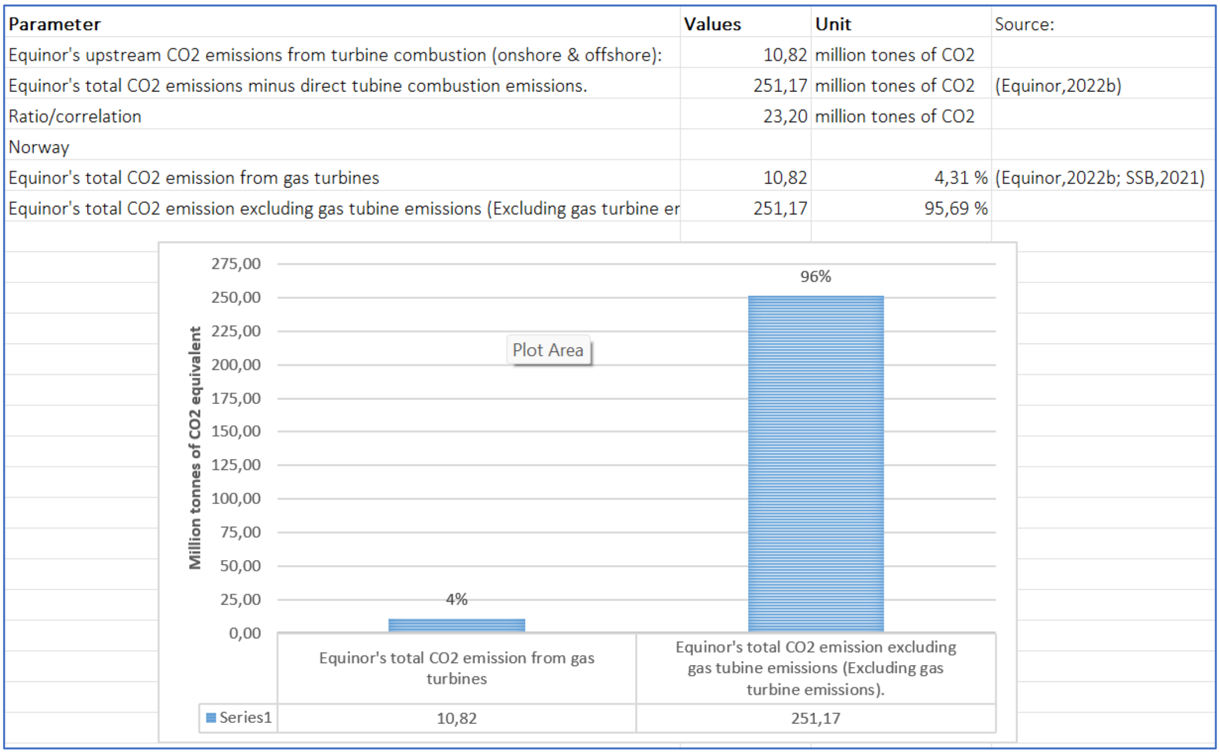
| | | |
|---|---|---|
| Required power offshore to emit 100 kg CO2 | 142 | kWh |
| **Domestic impact** | | |
| Emissions from gas turbines on the NCS | 100,0 | kg CO2 |
| Norwegian El-mix replace gas turbines on the NCS | 4,1 | kg CO2 |
| Nordic El-mix replace gas turbines on the NCS | 27,4 | kg CO2 |
| European El-mix replace gas turbines on the NCS | 48,1 | kg CO2 |
| Electricty deliverd from gas power plant in a Nordic country | 63,1 | kg CO2 |
| Electricty deliverd from gas power plant in Europe | 66,3 | kg CO2 |
| Electricty deliverd from coal power plant in a Nordic country | 155,8 | kg CO2 |
| Electricty deliverd from coal power plant in Europe | 163,6 | kg CO2 |
| **International impact** | | |
| Nor taking replacement into considoration | | |
| Emissions from gas turbines on the NCS | 100,0 | kg CO2 |
| Norwegian El-mix. Released gas used in power plant | 58,8 | kg CO2 |
| Nordic El-mix. Released gas used in power plant | 83,3 | kg CO2 |
| European El-mix. Released gas used in power plant | 105,1 | kg CO2 |
| Norwegian El-mix. Released gas used in CHP. | 39,6 | kg CO2 |
| Nordic El-mix. Released gas used in CHP. | 64,0 | kg CO2 |
| European El-mix. Released gas used in CHP. | 85,8 | kg CO2 |
| Norwegian El-mix. Released gas used in buildings | 37,6 | kg CO2 |
| Nordic El-mix. Released gas used in buildings | 57,3 | kg CO2 |
| European El-mix. Released gas used in buildings | 79,1 | kg CO2 |
| | | |
| Taking replacement into considoration | | |
| Emissions from gas turbines on the NCS | 100,0 | kg CO2 |
| Norwegian El-mix. Released gas used in power plant, replace coal power | -75,8 | kg CO2 |
| Nordic El-mix. Released gas used in power plant, replace coal power | -51,3 | kg CO2 |
| European El-mix. Released gas used in power plant, replace coal power | -29,5 | kg CO2 |
| Norwegian El-mix. Released gas used in CHP, replace coal power | -95,0 | kg CO2 |
| Norwegian El-mix. Released gas used in CHP, replace coal power | -70,6 | kg CO2 |
| Norwegian El-mix. Released gas used in CHP, replace coal power | -48,8 | kg CO2 |
| Norwegian El-mix. Released gas used in power plant, replace European el-mix | 19,2 | kg CO2 |
| Nordic El-mix. Released gas used in power plant, replace European el-mix | 43,7 | kg CO2 |
| European El-mix. Released gas used in power plant, replace European el-mix | 65,5 | kg CO2 |
| Norwegian El-mix. Released gas used in CHP, replace European el-mix | 0,0 | kg CO2 |
| Nordic El-mix. Released gas used in CHP, replace European el-mix | 24,4 | kg CO2 |
| European El-mix. Released gas used in CHP, replace European el-mix | 46,2 | kg CO2 |

# Formulas used in the analysis:



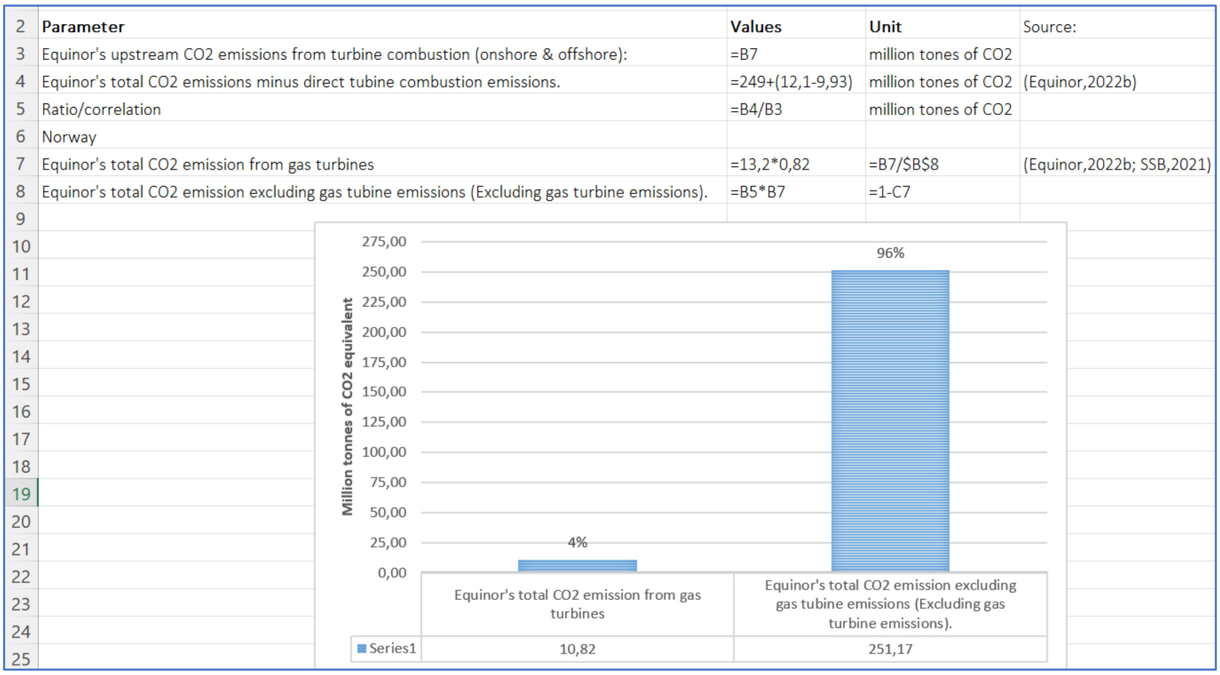
| | A | B | C | D |
|---|---|---|---|---|
| 1 | **Parameter** | **Values** | **Unit** | **Sources** |
| 2 | Average emission 1 Sm3 gas | 2,34 | kg CO2 | (Torvanger and Ericson, 2013; SSB, 2017). |
| 3 | Average emission 1 kg coal | 2,52 | kg CO2 | (SSB,2017) |
| 4 | Conversion factor of 1 Sm3 of Natural gas | 11,111 | kWh | (NPD,2022b) |
| 5 | Conversion factor of 1 kg Coal | 6,667 | kWh | (Theoretical) |
| 6 | Average emission intensity from turbines on the NCS | =$B$2/(B4*B16) | kg CO2/kWh | |
| 7 | Average emission intensity Norway | 0,026 | kg CO2/kWh | (BP,2021; EEA,2021) |
| 8 | Average emission intensity in the Nordic countries | 0,146 | kg CO2/kWh | (BP,2021; EEA,2021) |
| 9 | Average emission intensity in Europe | 0,278 | kg CO2/kWh | (BP,2021; EEA,2021) |
| 10 | Emission factor, Coal power plant | =B3/(B13*B5) | kg CO2/kWh | |
| 11 | Emission factor, Natural gas power plant | =$B$2/($B$4*B14) | kg CO2/kWh | (Verified in Rystad Energy, 2022a) |
| 12 | Emission factor, CHP with natural gas | =$B$2/($B$4*B15) | kg CO2/kWh | |
| 13 | Efficiency factor, Coal power plant | 0,4 | % | (IEA,2020) |
| 14 | Efficiency factor, Natural gas power plant | 0,55 | % | (IEA,2020; Konkraft, 2021) |
| 15 | Efficiency factor, CHP with natural gas | 0,85 | % | (IEA,2020) |
| 16 | Efficiency factor, Natural gas turbines on the NCS | 0,3 | % | (Torvanger and Ericson, 2013; Konkraft, 2021) |
| 17 | Efficiency factor, Heating in buildings | 0,9 | % | (Konkraft, 2021; Rystad Energy, 2022a) |
| 18 | Energy Transmission loss from shore to NCS | 1,05 | % | (Statnett, 2021) |
| 19 | Energy transmission loss in Norway | 1,05 | % | (Statnett, 2021) |
| 20 | Energy transmission loss from the Nordic countries | 1,05 | % | (Statnett, 2021) |
| 21 | Energy transmission loss through Europe | 1,05 | % | (Statnett, 2021) |
| 22 | Energy transmission loss in gas pipleline | 1,05 | % | (Torvanger and Ericson, 2013;Rystad Energy, 2022a) |
| 23 | | | | |
| 24 | **Analysis below:** | | | |
| 25 | Required power offshore to emit 100 kg CO2 | =B24 | kWh | |
| 26 | **Domestic impact** | | | |
| 27 | Emissions from gas turbines on the NCS | =B6*$B$25 | kg CO2 | |
| 28 | Norwegian El-mix replace gas turbines on the NCS | =B7*B19*B18*$B$25 | kg CO2 | |
| 29 | Nordic El-mix replace gas turbines on the NCS | =$B$25*0,166*B20*B18*B19 | kg CO2 | |
| 30 | European El-mix replace gas turbines on the NCS | =$B$25*$B$9*$B$21*$B$19*$B$20*B18 | kg CO2 | |
| 31 | Electricty deliverd from gas power plant in a Nordic country | =$B$25*$B$11*$B$19*$B$20*$B$18 | kg CO2 | |
| 32 | Electricty deliverd from gas power plant in Europe | =$B$25*$B$11*B19*$B$19*$B$20*$B$18 | kg CO2 | |
| 33 | Electricty deliverd from coal power plant in a Nordic country | =$B$25*$B$10*$B$19*$B$20*$B$18 | kg CO2 | |
| 34 | Electricty deliverd from coal power plant in Europe | =$B$25*$B$10*B21*$B$19*$B$20*$B$18 | kg CO2 | |
| 35 | **International impact** | | | |
| 36 | Nor taking replacement into consideration | | | |
| 37 | Emissions from gas turbines on the NCS | 100 | kg CO2 | |
| 38 | Norwegian El-mix. Released gas used in power plant | =(B28*$B$22)+($B$11*$B$25) | kg CO2 | |
| 39 | Nordic El-mix. Released gas used in power plant | =(B29*$B$22)+($B$11*$B$25) | kg CO2 | |
| 40 | European El-mix. Released gas used in power plant | =(B30*$B$22)+($B$11*$B$25) | kg CO2 | |
| 41 | Norwegian El-mix. Released gas used in CHP. | =(B28*$B$22)+($B$12*$B$25) | kg CO2 | |
| 42 | Nordic El-mix. Released gas used in CHP. | =(B29*$B$22)+($B$12*$B$25) | kg CO2 | |
| 43 | European El-mix. Released gas used in CHP. | =(B30*$B$22)+($B$12*$B$25) | kg CO2 | |
| 44 | Norwegian El-mix. Released gas used in buildings | =(B28*$B$22)+($B$2/(($B$4*B17))*$B$25) | kg CO2 | |
| 45 | Nordic El-mix. Released gas used in buildings | =(B29*$B$22)+($B$2/(($B$4*B18))*$B$25) | kg CO2 | |
| 46 | European El-mix. Released gas used in buildings | =(B30*$B$22)+($B$2/(($B$4*B19))*$B$25) | kg CO2 | |
| 47 | | | | |
| 48 | Taking replacement into consideration | | | |
| 49 | Emissions from gas turbines on the NCS | 100 | kg CO2 | |
| 50 | Norwegian El-mix. Released gas used in power plant, replace coal power | =B38-($B$25*$B$10) | kg CO2 | |
| 51 | Nordic El-mix. Released gas used in power plant, replace coal power | =B39-($B$25*$B$10) | kg CO2 | |
| 52 | European El-mix. Released gas used in power plant, replace coal power | =B40-($B$25*$B$10) | kg CO2 | |
| 53 | Norwegian El-mix. Released gas used in CHP, replace coal power | =B41-($B$25*$B$10) | kg CO2 | |
| 54 | Norwegian El-mix. Released gas used in CHP, replace coal power | =B42-($B$25*$B$10) | kg CO2 | |
| 55 | Norwegian El-mix. Released gas used in CHP, replace coal power | =B43-($B$25*$B$10) | kg CO2 | |
| 56 | Norwegian El-mix. Released gas used in power plant, replace European el-mix | =B38-($B$9*$B$25) | kg CO2 | |
| 57 | Nordic El-mix. Released gas used in power plant, replace European el-mix | =B39-($B$9*$B$25) | kg CO2 | |
| 58 | European El-mix. Released gas used in power plant, replace European el-mix | =B40-($B$9*$B$25) | kg CO2 | |
| 59 | Norwegian El-mix. Released gas used in CHP, replace European el-mix | =B41-($B$9*$B$25) | kg CO2 | |
| 60 | Nordic El-mix. Released gas used in CHP, replace European el-mix | =B42-($B$9*$B$25) | kg CO2 | |
| 61 | European El-mix. Released gas used in CHP, replace European el-mix | =B43-($B$9*$B$25) | kg CO2 | |

## Equinor’s upstream and downstream emissions (Includes domestic and international emissions):



| Parameter | Values | Unit | Source: |
|---|---|---|---|
| Equinor's upstream CO2 emissions from turbine combustion (onshore & offshore): | 10,82 | million tones of CO2 | |
| Equinor's total CO2 emissions minus direct tubine combustion emissions. | 251,17 | million tones of CO2 | (Equinor,2022b) |
| Ratio/correlation | 23,20 | million tones of CO2 | |
| Norway | | | |
| Equinor's total CO2 emission from gas turbines | 10,82 | 4,31 % | (Equinor,2022b; SSB,2021) |
| Equinor's total CO2 emission excluding gas tubine emissions (Excluding gas turbine er | 251,17 | 95,69 % | |

## Formulas:

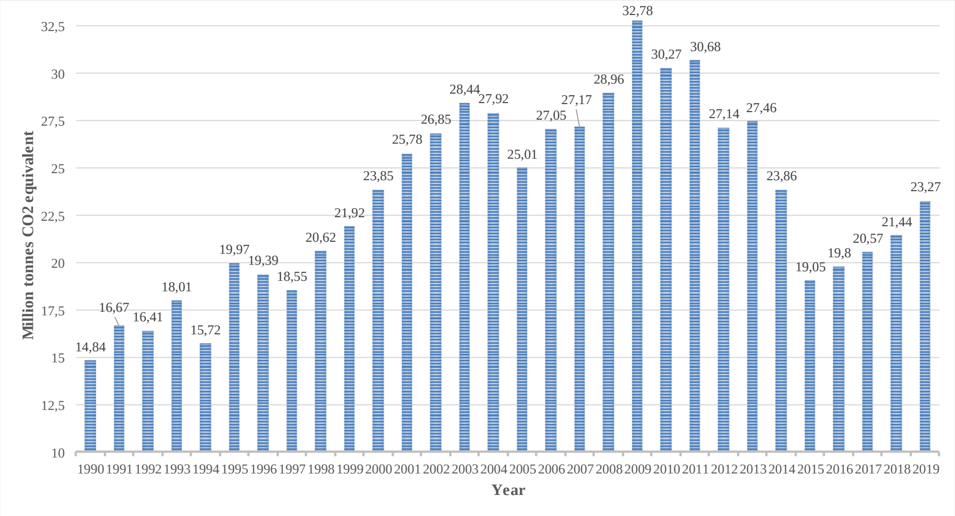


| | Parameter | Values | Unit | Source: |
|---|---|---|---|---|
| 2 | Parameter | Values | Unit | Source: |
| 3 | Equinor's upstream CO2 emissions from turbine combustion (onshore & offshore): | =B7 | million tones of CO2 | |
| 4 | Equinor's total CO2 emissions minus direct tubine combustion emissions. | =249+(12,1-9,93) | million tones of CO2 | (Equinor,2022b) |
| 5 | Ratio/correlation | =B4/B3 | million tones of CO2 | |
| 6 | Norway | | | |
| 7 | Equinor's total CO2 emission from gas turbines | =13,2*0,82 | =B7/$B$8 | (Equinor,2022b; SSB,2021) |
| 8 | Equinor's total CO2 emission excluding gas tubine emissions (Excluding gas turbine emissions). | =B5*B7 | =1-C7 | |
| 9 | | | | |

# Appendix 3 - Other

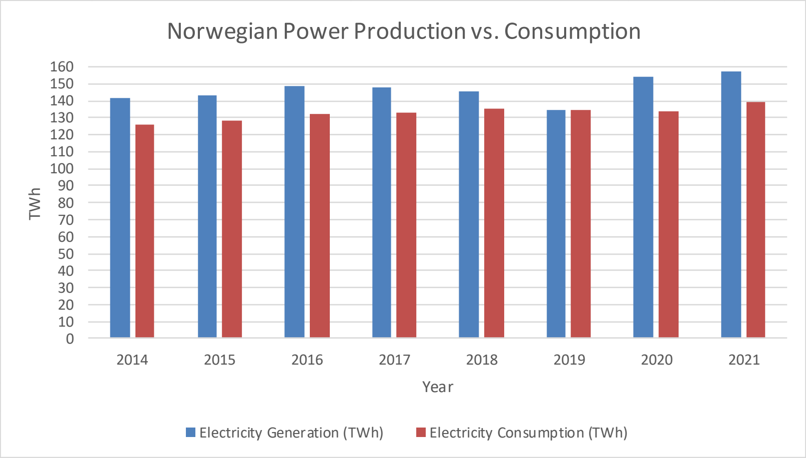
## CO2 capture by Norwegian Forests, 1990-2021:

| **Source: (Nibio,2021)** | |
|---|---|
| Year | Forest |
| 1990 | 14,84 |
| 1991 | 16,67 |
| 1992 | 16,41 |
| 1993 | 18,01 |
| 1994 | 15,72 |
| 1995 | 19,97 |
| 1996 | 19,39 |
| 1997 | 18,55 |
| 1998 | 20,62 |
| 1999 | 21,92 |
| 2000 | 23,85 |
| 2001 | 25,78 |
| 2002 | 26,85 |
| 2003 | 28,44 |
| 2004 | 27,92 |
| 2005 | 25,01 |
| 2006 | 27,05 |
| 2007 | 27,17 |
| 2008 | 28,96 |
| 2009 | 32,78 |
| 2010 | 30,27 |
| 2011 | 30,68 |
| 2012 | 27,14 |
| 2013 | 27,46 |
| 2014 | 23,86 |
| 2015 | 19,05 |
| 2016 | 19,8 |
| 2017 | 20,57 |
| 2018 | 21,44 |
| 2019 | 23,27 |



## Norwegian Power production and consumption:

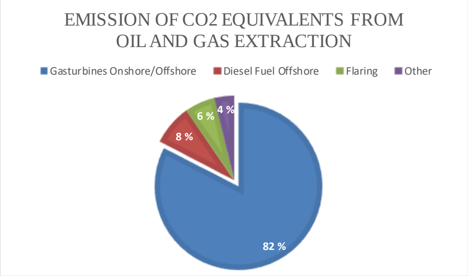
| **Source:** | **(Statnett,2022)** | |
|---|---|---|
| Year | Electricity Generation (TWh) | Electricity Consumption (TWh) |
| 2014 | 141,6 | 125,9 |
| 2015 | 143,4 | 128,6 |
| 2016 | 148,8 | 132,3 |
| 2017 | 148,2 | 132,9 |
| 2018 | 145,7 | 135,4 |
| 2019 | 134,6 | 134,7 |
| 2020 | 154,2 | 133,7 |
| 2021 | 157,1 | 139,5 |

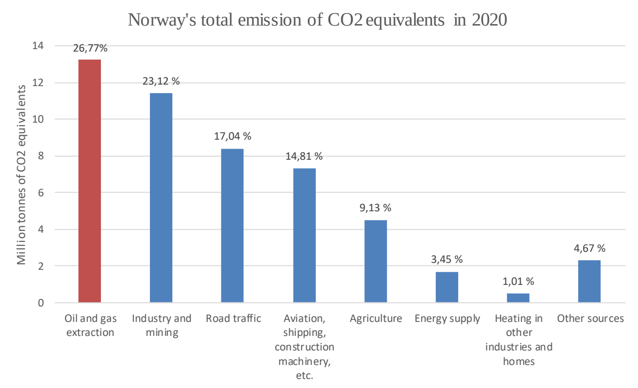


## Norway’s total CO$_2$ emissions in 2020 and Emissions from oil and gas extraction:

| Source: (SSB, 2021b) | Millioner tonn CO2-ekvivalenter | CO2-andel i prosent | Endring i prosent | |
|---|---|---|---|---|
| | 2020 | | 1990 - 2020 | 2019 - 2020 |
| Totalt utslipp av klimagasser | 49,3 | | -4,2 | -3,5 |
| Oil and gas extraction | 13,2 | 26,77 % | 61,5 | -5,2 |
| Industry and mining | 11,4 | 23,12 % | -42,2 | -1,5 |
| Road traffic | 8,4 | 17,04 % | 294,6 | -2,5 |
| Aviation, shipping, construction machinery, etc. | 7,3 | 14,81 % | -80,3 | -8,6 |
| Agriculture | 4,5 | 9,13 % | 12,8 | -4 |
| Energy supply | 1,7 | 3,45 % | 37,2 | -4,7 |
| Heating in other industries and homes | 0,5 | 1,01 % | -6,4 | -0,2 |
| Other sources | 2,3 | 4,67 % | -18,1 | -4,4 |

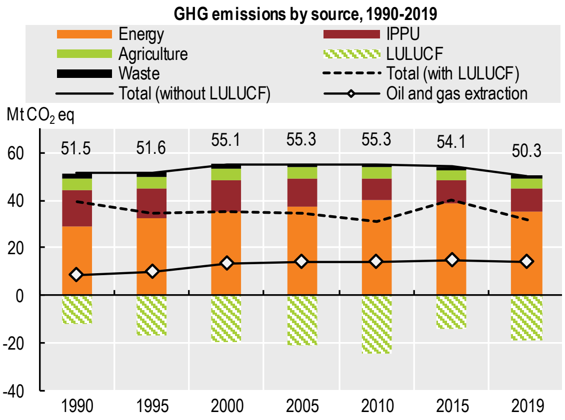
| | |
|---|---|
| Gasturbines Onshore/Offshore | 11,49 |
| Diesel Fuel Offshore | 1,09 |
| Flaring | 0,83 |
| Other | 0,51 |
| **Total** | **13,92** |

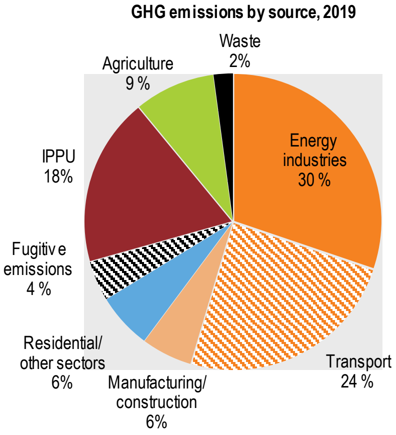




## Norway’s CO$_2$ emissions by source, 1990-2019:

***Source*: IEA (2021), *IEA World Energy Statistics and Balances* (database).**





Note: IPPU = industrial processes and product use. LULUCF = land use, land-use change and forestry.

*Source*: UNFCCC (2021), *Greenhouse Gas Inventory* (database).

### CO2 emissions by source, 1990-2019

| | Energy | IPPU | Agriculture | LULUCF | Waste | Total (with LULUCF) | Total (without LULUCF) | Oil and gas extraction |
|---|---|---|---|---|---|---|---|---|
| 1990 | 29 094 | 15 377 | 4 776 | -11 968 | 2 229 | 39 507 | 51 475 | 8 179 |
| 1995 | 32 359 | 12 436 | 4 717 | -16 886 | 2 111 | 34 738 | 51 624 | 10 135 |
| 2000 | 35 529 | 13 220 | 4 558 | -19 588 | 1 810 | 35 529 | 55 117 | 13 032 |
| 2005 | 37 503 | 11 669 | 4 535 | -21 032 | 1 563 | 34 237 | 55 270 | 14 073 |
| 2010 | 40 343 | 9 103 | 4 322 | -24 273 | 1 497 | 30 992 | 55 266 | 13 934 |
| 2015 | 39 014 | 9 322 | 4 491 | -14 079 | 1 298 | 40 046 | 54 125 | 14 890 |
| 2019 | 35 556 | 9 271 | 4 442 | -18 637 | 1 064 | 31 697 | 50 334 | 13 928 |

**Input to Figure 6 - Historical and expected oil and gas production in Norway, 1970-2026** (NPD, 2022d).

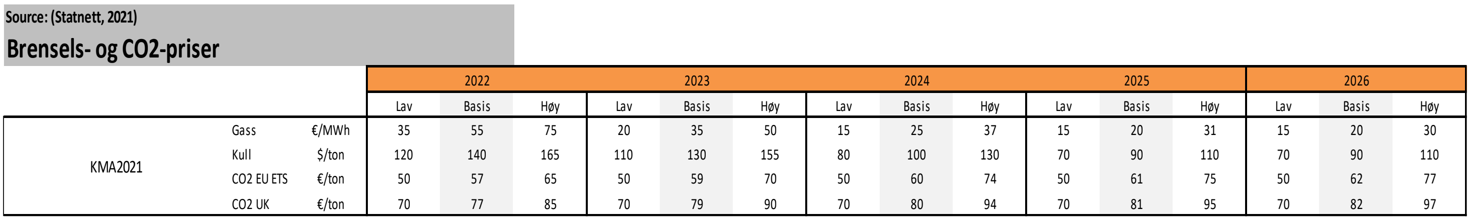
**Source: (NPD, 2022d)**

Million Sm$^3$ o.e.

Million barrels o.e. per day

| Year | Oil | Condensate | NGL | Gas (40 MJ) | Total | Total liquids | Natural gas per day |
|---|---|---|---|---|---|---|---|
| 1970 | 0,00 | | | | 0,00 | 0,00 | 0,00 |
| 1971 | 0,36 | 0,00 | 0,00 | 0,00 | 0,36 | 0,36 | 0,00 |
| 1972 | 1,93 | 0,00 | 0,00 | 0,00 | 1,93 | 1,93 | 0,00 |
| 1973 | 1,87 | 0,00 | 0,00 | 0,00 | 1,87 | 1,87 | 0,00 |
| 1974 | 2,01 | 0,00 | 0,00 | 0,00 | 2,01 | 2,01 | 0,00 |
| 1975 | 11,00 | 0,00 | 0,00 | 0,00 | 11,00 | 11,00 | 0,00 |
| 1976 | 16,23 | 0,00 | 0,00 | 0,00 | 16,23 | 16,23 | 0,00 |
| 1977 | 16,64 | 0,00 | 0,00 | 2,72 | 19,36 | 16,64 | 0,05 |
| 1978 | 20,64 | 0,02 | 0,00 | 14,62 | 35,28 | 20,66 | 0,25 |
| 1979 | 22,48 | 0,04 | 1,13 | 21,11 | 44,76 | 23,65 | 0,36 |
| 1980 | 28,22 | 0,05 | 2,44 | 25,64 | 56,35 | 30,71 | 0,44 |
| 1981 | 27,48 | 0,05 | 2,17 | 25,28 | 54,98 | 29,70 | 0,44 |
| 1982 | 28,53 | 0,04 | 2,29 | 24,06 | 54,92 | 30,86 | 0,41 |
| 1983 | 35,65 | 0,04 | 2,68 | 23,17 | 61,54 | 38,37 | 0,40 |
| 1984 | 41,09 | 0,06 | 2,64 | 25,63 | 69,42 | 43,79 | 0,44 |
| 1985 | 44,76 | 0,08 | 2,97 | 25,51 | 73,32 | 47,81 | 0,44 |
| 1986 | 48,77 | 0,06 | 3,85 | 26,15 | 78,83 | 52,68 | 0,45 |
| 1987 | 56,96 | 0,05 | 4,12 | 28,40 | 89,53 | 61,13 | 0,49 |
| 1988 | 64,72 | 0,05 | 4,85 | 28,58 | 98,20 | 69,62 | 0,49 |
| 1989 | 85,98 | 0,05 | 4,90 | 29,08 | 120,01 | 90,93 | 0,50 |
| 1990 | 94,54 | 0,05 | 5,01 | 25,99 | 125,59 | 99,60 | 0,45 |
| 1991 | 108,51 | 0,06 | 4,90 | 25,56 | 139,03 | 113,47 | 0,44 |
| 1992 | 124,00 | 0,05 | 4,96 | 26,50 | 155,51 | 129,01 | 0,46 |
| 1993 | 131,84 | 0,47 | 5,52 | 25,56 | 163,39 | 137,83 | 0,44 |
| 1994 | 146,28 | 2,40 | 7,12 | 27,88 | 183,68 | 155,80 | 0,48 |
| 1995 | 156,78 | 3,18 | 7,94 | 29,07 | 196,97 | 167,90 | 0,50 |
| 1996 | 175,50 | 3,78 | 8,23 | 38,75 | 226,26 | 187,51 | 0,67 |
| 1997 | 175,91 | 5,38 | 8,07 | 44,36 | 233,72 | 189,36 | 0,76 |
| 1998 | 168,74 | 5,05 | 7,39 | 47,06 | 228,24 | 181,18 | 0,81 |
| 1999 | 168,69 | 5,51 | 6,99 | 48,70 | 229,89 | 181,19 | 0,84 |
| 2000 | 181,18 | 5,41 | 7,23 | 47,43 | 241,25 | 193,82 | 0,82 |
| 2001 | 180,88 | 5,67 | 10,92 | 54,15 | 251,62 | 197,47 | 0,93 |
| 2002 | 173,65 | 7,32 | 11,80 | 65,53 | 258,30 | 192,77 | 1,13 |
| 2003 | 165,48 | 10,34 | 12,93 | 72,93 | 261,68 | 188,75 | 1,26 |
| 2004 | 162,78 | 8,67 | 13,64 | 79,10 | 264,19 | 185,09 | 1,36 |
| 2005 | 148,14 | 7,95 | 15,81 | 85,67 | 257,57 | 171,90 | 1,48 |
| 2006 | 136,58 | 7,63 | 16,70 | 88,23 | 249,14 | 160,91 | 1,52 |
| 2007 | 128,28 | 3,13 | 16,63 | 89,51 | 237,55 | 148,04 | 1,54 |
| 2008 | 122,66 | 3,92 | 16,94 | 99,46 | 242,98 | 143,52 | 1,71 |
| 2009 | 114,94 | 4,44 | 16,96 | 103,68 | 240,02 | 136,34 | 1,79 |
| 2010 | 104,39 | 4,17 | 15,55 | 106,53 | 230,64 | 124,11 | 1,84 |
| 2011 | 97,46 | 4,58 | 16,31 | 100,30 | 218,65 | 118,35 | 1,73 |
| 2012 | 89,20 | 4,58 | 17,80 | 113,06 | 224,64 | 111,58 | 1,94 |
| 2013 | 84,94 | 3,99 | 17,72 | 107,05 | 213,70 | 106,65 | 1,84 |
| 2014 | 87,70 | 2,91 | 18,95 | 106,80 | 216,36 | 109,56 | 1,84 |
| 2015 | 90,85 | 2,47 | 19,60 | 114,92 | 227,84 | 112,92 | 1,98 |
| 2016 | 93,90 | 1,93 | 20,18 | 114,65 | 230,66 | 116,01 | 1,97 |
| 2017 | 92,28 | 1,71 | 20,39 | 122,37 | 236,75 | 114,38 | 2,11 |
| 2018 | 86,27 | 1,71 | 19,46 | 119,89 | 227,33 | 107,44 | 2,07 |
| 2019 | 81,73 | 1,66 | 17,37 | 113,23 | 213,99 | 100,76 | 1,95 |
| 2020 | 98,39 | 1,28 | 16,77 | 110,09 | 226,53 | 116,44 | 1,89 |
| 2021 | 102,73 | 0,71 | 14,43 | 113,10 | 230,97 | 117,87 | 1,95 |
| 2022 | 104,09 | 1,12 | 16,82 | 115,02 | 237,05 | 122,03 | 1,98 |
| 2023 | 114,13 | 1,19 | 16,50 | 116,29 | 248,11 | 131,82 | 2,00 |
| 2024 | 117,01 | 1,03 | 16,88 | 118,14 | 253,06 | 134,92 | 2,03 |
| 2025 | 115,19 | 0,93 | 17,06 | 118,66 | 251,84 | 133,18 | 2,04 |
| 2026 | 108,61 | 0,89 | 16,68 | 118,51 | 244,69 | 126,18 | 2,04 |

## Projected energy and $CO_2$ prices:

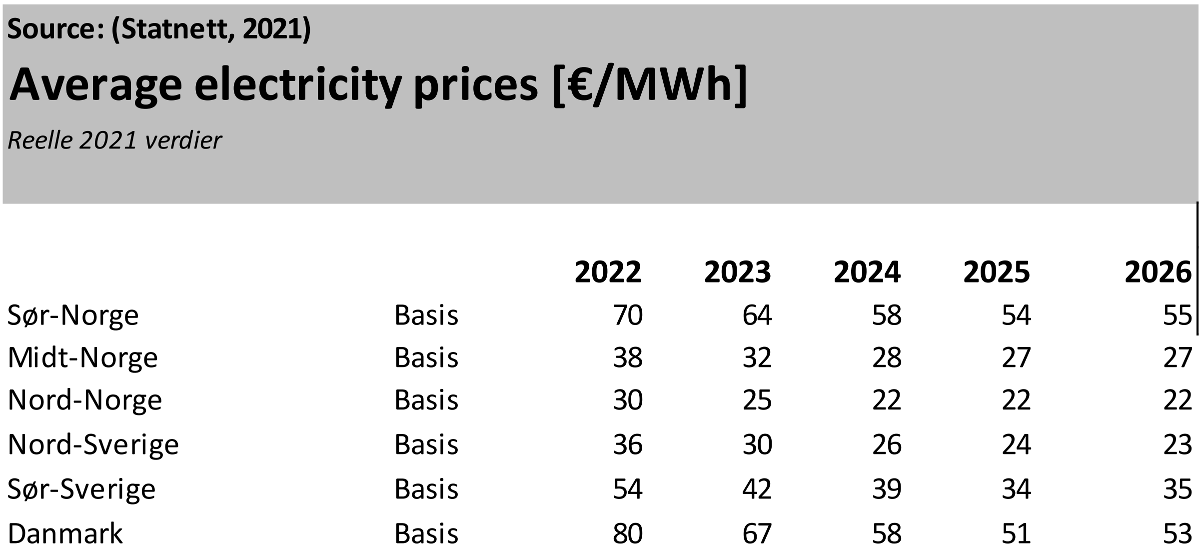


Source: (Statnett, 2021)

**Brensels- og CO2-priser**

| | | | 2022 | | | 2023 | | | 2024 | | | 2025 | | | 2026 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Lav | Basis | Høy | Lav | Basis | Høy | Lav | Basis | Høy | Lav | Basis | Høy | Lav | Basis | Høy |
| KMA2021 | Gass | €/MWh | 35 | 55 | 75 | 20 | 35 | 50 | 15 | 25 | 37 | 15 | 20 | 31 | 15 | 20 | 30 |
| | Kull | $/ton | 120 | 140 | 165 | 110 | 130 | 155 | 80 | 100 | 130 | 70 | 90 | 110 | 70 | 90 | 110 |
| | CO2 EU ETS | €/ton | 50 | 57 | 65 | 50 | 59 | 70 | 50 | 60 | 74 | 50 | 61 | 75 | 50 | 62 | 77 |
| | CO2 UK | €/ton | 70 | 77 | 85 | 70 | 79 | 90 | 70 | 80 | 94 | 70 | 81 | 95 | 70 | 82 | 97 |

## Projected Nordic electricity prices:



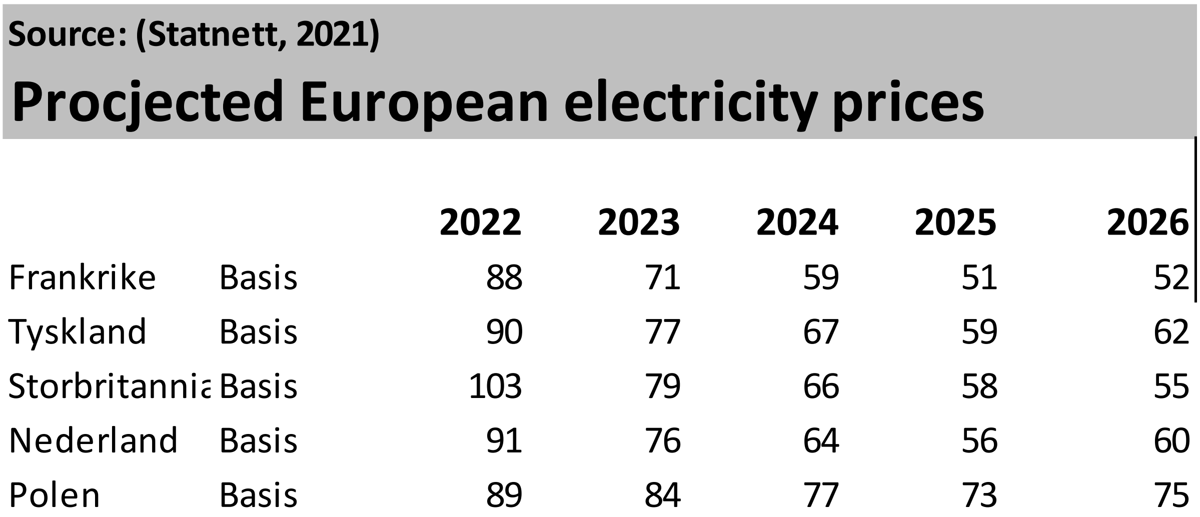
Source: (Statnett, 2021)

**Average electricity prices [€/MWh]**

*Reelle 2021 verdier*

| | | 2022 | 2023 | 2024 | 2025 | 2026 |
|---|---|---|---|---|---|---|
| Sør-Norge | Basis | 70 | 64 | 58 | 54 | 55 |
| Midt-Norge | Basis | 38 | 32 | 28 | 27 | 27 |
| Nord-Norge | Basis | 30 | 25 | 22 | 22 | 22 |
| Nord-Sverige | Basis | 36 | 30 | 26 | 24 | 23 |
| Sør-Sverige | Basis | 54 | 42 | 39 | 34 | 35 |
| Danmark | Basis | 80 | 67 | 58 | 51 | 53 |

## Projected European electricity prices:



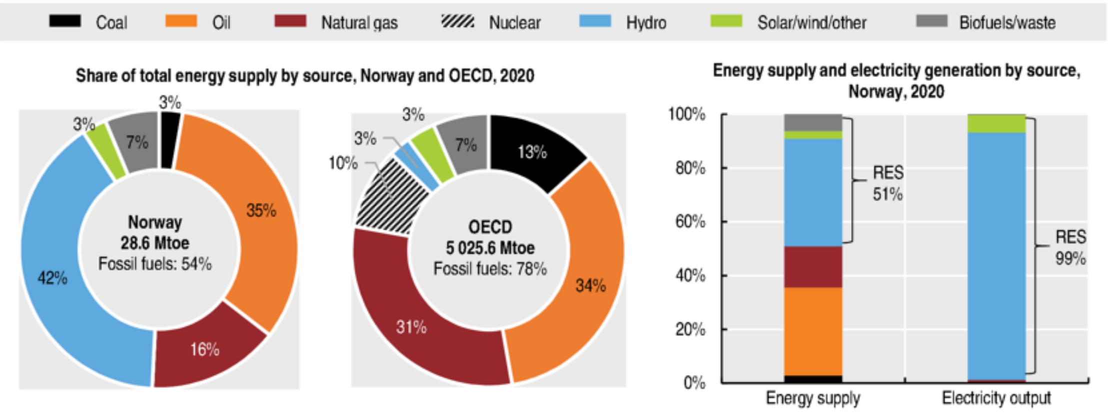
Source: (Statnett, 2021)

**Procjected European electricity prices**

| | | 2022 | 2023 | 2024 | 2025 | 2026 |
|---|---|---|---|---|---|---|
| Frankrike | Basis | 88 | 71 | 59 | 51 | 52 |
| Tyskland | Basis | 90 | 77 | 67 | 59 | 62 |
| Storbritanni | Basis | 103 | 79 | 66 | 58 | 55 |
| Nederland | Basis | 91 | 76 | 64 | 56 | 60 |
| Polen | Basis | 89 | 84 | 77 | 73 | 75 |

## Norway’s energy and electricity generation overview:

*Source*: IEA (2021), *IEA World Energy Statistics and Balances* (database).



Note: The breakdown of energy supply excludes heat and electricity trade but percentages shown reflect ratios calculated on total energy supply. Biofuel and waste include negligible quantities of non-renewable waste.

*Source*: IEA (2021), *IEA World Energy Statistics and Balances* (database).

**Share of total energy supply by source, Norway and OECD, 2020**

| | Norway |
|---|---|
| Coal | 2,9% |
| Oil | 34,7% |
| Natural gas | 16,2% |
| Nuclear | .. |
| Hydro | 42,4% |
| Solar/wind/other | 3,0% |
| Biofuels/waste | 6,7% |

| | OECD |
|---|---|
| Coal | 13 % |
| Oil | 34 % |
| Natural gas | 31 % |
| Nuclear | 10 % |
| Hydro | 3 % |
| Solar/wind/other | 3 % |
| Biofuels/waste | 7 % |

| | Coal | Oil | Natural gas | Hydro | Solar/wind/other | Biofuels and waste |
|---|---|---|---|---|---|---|
| Energy supply | 824 | 9 918 | 4 622 | 12 118 | 854 | 1 903 |
| Electricity output | 181 | 219 | 1 312 | 140 927 | 9 937 | 434 |

## Norway’s Energy production, supply and consumption in 2019:

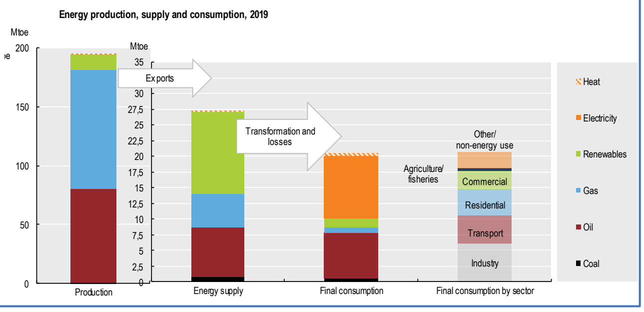
*Source*: IEA (2021), *IEA World Energy Statistics and Balances* (database).

| | Coal | Oil | Gas | Renewables | Electricity | Heat | Sum |
|---|---|---|---|---|---|---|---|
| Production | 7 | 6 928 | 8 674 | 1 080 | 0 | 10 | 16 700 |
| Energy supply | 69 | 677 | 457 | 1 122 | 0 | 10 | 2 335 |
| Final consumption | 51 | 619 | 83 | 116 | 855 | 44 | 1 768 |
| Final consumption by sector | 528 | 381 | 350 | 258 | 36 | 224 | 1 777 |

Note: Data presented in the chart exclude negligible quantities of non-renewable waste.

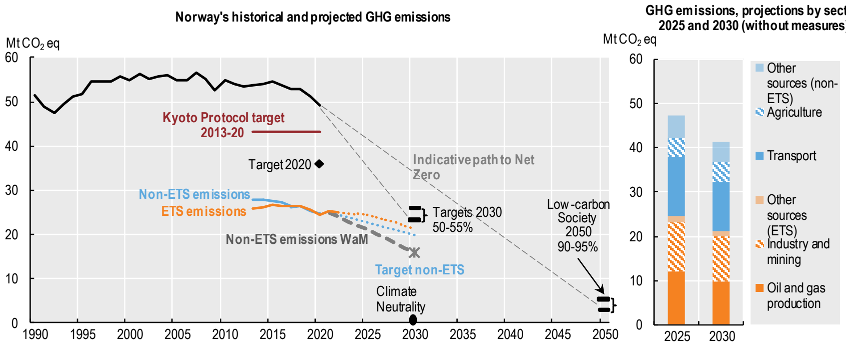
| | Coal | Oil | Gas | Renewables | Electricity | Heat | |
|---|---|---|---|---|---|---|---|
| Production | 81 | 80 562 | 100 866 | 12 561 | 0 | 121 | 0,0860 |

| | Coal | Oil | Gas | Renewables | Electricity | Heat |
|---|---|---|---|---|---|---|
| Energy supply | 801 | 7 870 | 5 309 | 13 048 | 4 | 121 |
| Final consumption | 597 | 7 195 | 965 | 1 349 | 9 942 | 510 |
| Final consumption by sector | 6 134 | 4 427 | 4 065 | 3 004 | 422 | 2 609 |



# Norway’s historical and projected CO2 emissions:

***Source*** **: IEA (2021),** ***IEA World Energy Statistics and Balances*** **(database).**



**Norway's historical and projected GHG emissions**

| | Kyoto target 2013-20 (84% base year) | Non-ETS Line | Non-ETS WaM line | ETS line | Total GHG emissions (without LULUCF) | Target 2030 (50%) | 2020 target (-30%) | Target Net Zero 95% | Target Net Zero 90% | Non-ETS target | Target 2030 (55%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | | | | | 51 427 | | | | | | |
| 1991 | | | | | 49 022 | | | | | | |
| 1992 | | | | | 47 364 | | | | | | |
| 1993 | | | | | 49 328 | | | | | | |
| 1994 | | | | | 51 232 | | | | | | |
| 1995 | | | | | 51 631 | | | | | | |
| 1996 | | | | | 54 511 | | | | | | |
| 1997 | | | | | 54 528 | | | | | | |
| 1998 | | | | | 54 556 | | | | | | |
| 1999 | | | | | 55 580 | | | | | | |
| 2000 | | | | | 54 918 | | | | | | |
| 2001 | | | | | 56 189 | | | | | | |
| 2002 | | | | | 55 007 | | | | | | |
| 2003 | | | | | 55 612 | | | | | | |
| 2004 | | | | | 56 013 | | | | | | |
| 2005 | | | | | 54 944 | | | | | | |
| 2006 | | | | | 54 934 | | | | | | |
| 2007 | | | | | 56 605 | | | | | | |
| 2008 | | | | | 55 131 | | | | | | |
| 2009 | | | | | 52 672 | | | | | | |
| 2010 | | | | | 54 938 | | | | | | |
| 2011 | | | | | 53 990 | | | | | | |
| 2012 | | | | | 53 417 | | | | | | |
| 2013 | 43 239 | 27 900 | | 25 800 | 53 671 | | | | | | |
| 2014 | 43 239 | 27 900 | | 26 200 | 54 041 | | | | | | |
| 2015 | 43 239 | 27 700 | | 26 800 | 54 489 | | | | | | |
| 2016 | 43 239 | 27 300 | | 26 300 | 53 586 | | | | | | |
| 2017 | 43 239 | 26 300 | | 26 500 | 52 840 | | | | | | |
| 2018 | 43 239 | 26 500 | | 26 300 | 52 871 | | | | | | |
| 2019 | 43 239 | 25 400 | | 25 700 | 51 086 | | | | | | |
| 2020 | 43 239 | 24 800 | | 24 500 | 49 283 | | 36 033 | | | | |
| 2021 | | 25 001 | 24 765 | 25 147 | | | | | | | |
| 2022 | | 24 484 | 23 921 | 24 982 | | | | | | | |
| 2023 | | 23 964 | 22 997 | 24 817 | | | | | | | |
| 2024 | | 23 405 | 22 089 | 24 652 | | | | | | | |
| 2025 | | 22 815 | 21 023 | 24 487 | | | | | | | |
| 2026 | | 22 238 | 20 014 | 23 857 | | | | | | | |
| 2027 | | 21 663 | 19 036 | 23 228 | | | | | | | |
| 2028 | | 21 084 | 18 008 | 22 598 | | | | | | | |
| 2029 | | 20 489 | 16 968 | 21 968 | | | | | | | |
| 2030 | | 19 896 | 15 903 | 21 339 | | 25 738 | | | | 15 700 | 23 164 |
| 2031 | | | | | | | | | | | |
| 2032 | | | | | | | | | | | |
| 2033 | | | | | | | | | | | |
| 2034 | | | | | | | | | | | |
| 2035 | | | | | | | | | | | |
| 2036 | | | | | | | | | | | |
| 2037 | | | | | | | | | | | |
| 2038 | | | | | | | | | | | |
| 2039 | | | | | | | | | | | |
| 2040 | | | | | | | | | | | |
| 2041 | | | | | | | | | | | |
| 2042 | | | | | | | | | | | |
| 2043 | | | | | | | | | | | |
| 2044 | | | | | | | | | | | |
| 2045 | | | | | | | | | | | |
| 2046 | | | | | | | | | | | |
| 2047 | | | | | | | | | | | |
| 2048 | | | | | | | | | | | |
| 2049 | | | | | | | | | | | |
| 2050 | | | | | | | | 2 574 | 5 148 | | |

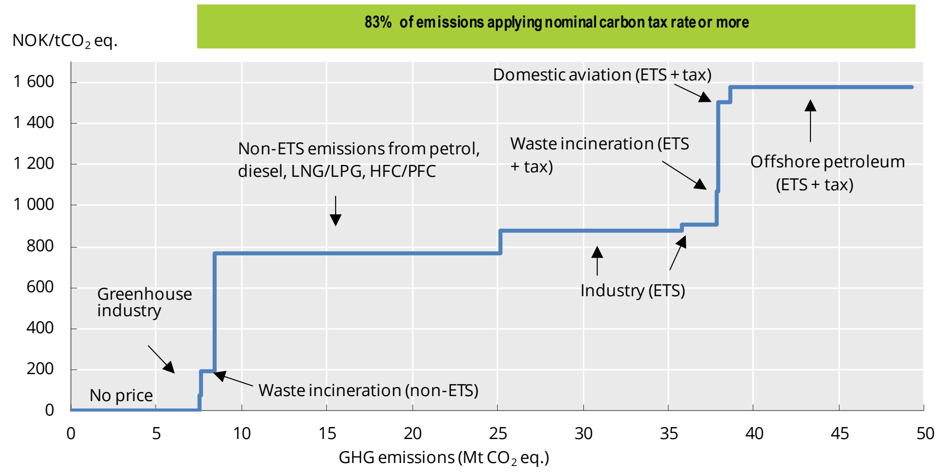
**GHG emissions, projections by sector, 2025 and 2030 (without measures)**

| | Oil and gas production | Industry and mining | Other sources (ETS) | Transport | Agriculture | Other sources (non-ETS) |
|---|---|---|---|---|---|---|
| 2025 | 12,1 | 11,1 | 1,3 | 13,3 | 4,4 | 5,1 |
| 2030 | 9,7 | 10,3 | 1,3 | 10,9 | 4,5 | 4,5 |

# Norwegian $CO_2$ prices per source in 2022:

***Source*** **: IEA (2021),** ***IEA World Energy Statistics and Balances*** **(database).**

**Prices of CO2 emissions in 2022**

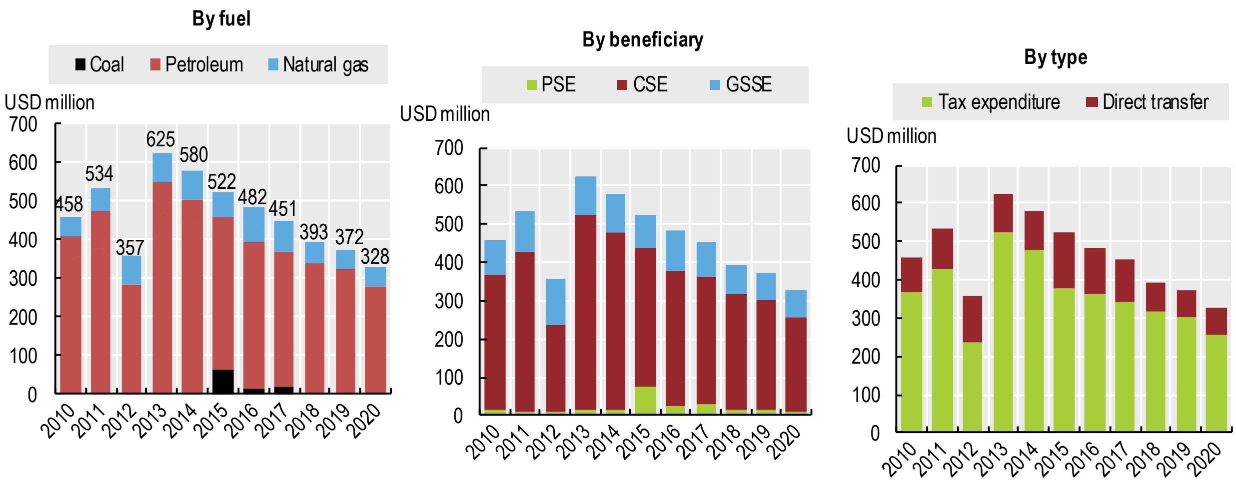


| | | Carbon price |
|---|---|---|
| | 49,28 | 1 579,27 |
| | 38,68 | 1 579,27 |
| | 38,68 | 1 505,27 |
| | 37,96 | 1 505,27 |
| | 37,96 | 1 067,27 |
| | 37,84 | 1 067,27 |
| | 37,84 | 907,27 |
| | 35,83 | 907,27 |
| | 35,83 | 874,27 |
| | 25,41 | 874,27 |
| | 25,31 | 874,27 |
| | 25,15 | 874,27 |
| | 25,15 | 769,00 |
| | 23,09 | 769,00 |
| | 23,09 | 770,00 |
| | 18,13 | 770,00 |
| | 18,13 | 767,00 |
| | 17,26 | 767,00 |
| | 17,26 | 770,00 |
| | 16,42 | 770,00 |
| | 16,42 | 768,00 |
| | 16,33 | 768,00 |
| | 16,33 | 765,50 |
| | 16,10 | 765,50 |
| | 16,099 | 770,000 |
| | 9,683 | 770,000 |
| | 9,683 | 770,000 |
| | 9,636 | 770,000 |
| | 9,636 | 766,000 |
| | 9,430 | 766,000 |
| | 9,430 | 766,000 |
| | 8,620 | 766,000 |
| | 8,620 | 770,000 |
| | 8,462 | 770,000 |
| | 8,462 | 193,000 |
| | 7,624 | 193,000 |
| | 7,624 | 76,000 |
| | 7,576 | 76,000 |
| | 7,576 | 2,000 |
| | 7,527 | 2,000 |
| | 7,527 | 2,000 |
| | 7,456 | 2,000 |
| | 7,456 | 2,000 |
| | 6,810 | 2,000 |
| | 2,304 | 2,000 |
| | 0,074 | 2,000 |
| | 0,074 | 2,000 |
| | 0,074 | 2,000 |
| | 0,000 | 2,000 |

## Combustion of fossil fuel support, 2010-2020:

**Source: OECD (2021), "Fossil Fuel Support", *OECD Environmental Indicators* (database).**

Composition of fossil fuel support, 2010-20



Source: OECD (2021), "Fossil Fuel Support", *OECD Environmental Indicators* (database).

### By beneficiary

| | PSE | CSE | GSSE |
|---|---|---|---|
| 2010 | 13 | 355 | 90 |
| 2011 | 12 | 415 | 107 |
| 2012 | 8 | 230 | 119 |
| 2013 | 14 | 510 | 101 |
| 2014 | 15 | 464 | 101 |
| 2015 | 73 | 365 | 85 |
| 2016 | 26 | 351 | 105 |
| 2017 | 32 | 328 | 91 |
| 2018 | 14 | 302 | 76 |
| 2019 | 12 | 288 | 71 |
| 2020 | 12 | 243 | 73 |

### By fuel

| | Coal | Petroleum | Natural gas | |
|---|---|---|---|---|
| 2010 | 0 | 408 | 50 | 346 |
| 2011 | 0 | 476 | 58 | 384 |
| 2012 | 0 | 283 | 75 | 278 |
| 2013 | 0 | 550 | 75 | 471 |
| 2014 | 0 | 505 | 75 | 437 |
| 2015 | 62 | 397 | 63 | 470 |
| 2016 | 13 | 382 | 87 | 436 |
| 2017 | 17 | 350 | 84 | 400 |
| 2018 | 0 | 340 | 53 | 333 |
| 2019 | 0 | 323 | 49 | 332 |
| 2020 | 0 | 278 | 49 | 288 |

### By type

| | Tax expenditure | Direct transfer |
|---|---|---|
| 2010 | 368 | 90 |
| 2011 | 427 | 107 |
| 2012 | 238 | 119 |
| 2013 | 525 | 101 |
| 2014 | 479 | 101 |
| 2015 | 375 | 147 |
| 2016 | 364 | 118 |
| 2017 | 343 | 108 |
| 2018 | 317 | 76 |
| 2019 | 301 | 71 |
| 2020 | 255 | 73 |