NTNU
Faculty of Natural Sciences
Department of Materials Science and Engineering

Measures to reduce emissions from offshore drilling units

Tiltak for å redusere utslipp fra offshore borerigger

Authors:
Kristina Nygaard Rølland, Vegar Hovdenakk Øye and Shayangi Govindapillai

External supervisors:
Axel Kelley and Astrid Pedersen

Internal supervisor:
Sverre Gullikstad Johnsen

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Preface

This bachelor thesis is written in connection with the final education as an oil and gas technology engineer at the Department of Materials Science and Engineering at NTNU. The main thesis consists of a written report which together with a final presentation gives 20 credits. The goal of the assignment is to gain a deeper insight into a specific area.

The thesis is an assignment on behalf of the Norwegian petroleum company Lundin Energy Norway with the intention to study measures to reduce emissions of CO_2 and NO_x from offshore drilling activity. Through the project, the project group has benefited greatly from their visit to Lundin Energy Norway´s office at Lysaker as well as a visit to the drilling rig West Bollsta at Hanøytangen outside Bergen. The project team has used Excel for illustrations and calculations.

Through the project, the project group has received excellent guidance and follow-up and obtained valuable knowledge of offshore drilling and petroleum production in general, and how green initiatives and focus on sustainability may positively change the industry. We therefore wish to thank the following persons:

Axel Kelley and Astrid Pedersen, external supervisors from Lundin Energy Norway on the project.

Sverre Gullikstad Johnsen, NTNU internal supervisor of the project.

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Kristina Nygaard Rølland

Vegar Hovdenakk Øye

Shayangi Govindapillai

Abstract

The purpose of this bachelor thesis has been to study how Lundin Energy Norway AS´s offshore drilling and petroleum production activity contributes to the company´s total emission of CO_2 and NO_x, both in a historic and future perspective, and to assess the effect of implemented measures. The project group have also identified additional measures that reduces these emissions of CO_2 and NO_x from offshore drilling rig activity on the Norwegian Continental Shelf and assessed how Lundin Energy Norway AS´s corporate targets support the national emission reduction targets for 2030 and 2050.

Through the literature study the main sources, lundin-energy.com as well as Norwegian Oil and Gas Association´s annual reports have been frequently used to gather information regarding the company and the future of the petroleum industry. Websites like miljostatus.miljodirektoratet.no has been basis for the more general information. The data collected in this thesis has been gathered through interviews at Lundin Energy Norway AS', Lysaker office, cell phone meeting with Norwegian Oil and Gas Association (NOROG) and a rig visit to the West Bollsta rig at Hanøytangen outside Bergen. Quotations and explanations from company experts has been written down on a continuous basis during the meetings, and business sensitive information is referenced to but not added to citations. The graphs represented are adaptations of the data collected and consist of several assumptions and estimations and therefore the uncertainty cannot be fully determined.

On the West Bollsta rig, the implemented Selective Catalytic Reduction shows a NO_x-reduction of up to 70%, which complies with any regulation. The Closed Bus-Tie technology optimizes the utilization of the diesel engines and cuts the total running hours. This reduces the diesel consumption on West Bollsta and thereby the CO_2 emission with 9%, while still maintaining safety regulations from DNV-GL. However, the technology must be further optimized to become essential for achieving the low-carbon society goal.

This thesis has concluded that electrification on platforms on the Norwegian Continental Shelf obtain substantial cuts in emission and will be an important initiative for the Norwegian petroleum industry in the coming years. Regarding drilling rigs, the future is more uncertain. The project group has concluded that energy management systems on drilling rigs will be crucial in reducing emissions over the next few years. For Lundin Energy Norway AS and the Norwegian petroleum industry to meet the defined environmental targets and requirements, drilling rigs must implement more efficient ways of reducing CO_2 and NO_x emissions. Energy management will greatly help but will not be enough to eliminate all emissions. Implementation of low-emission fuel as well as using fuel cells as a supplementary power supply may be the future for drilling rigs on the Norwegian Continental Shelf.

Sammendrag

Hensikten med denne bacheloroppgaven har vært å studere hvordan Lundin Energy Norge AS sin lete- og produksjons aktivitet bidrar selskapets totale utslipp av CO_2 og NO_x, både i et historisk og fremtidig perspektiv, og for å vurdere effekten av iverksatte tiltak. Prosjektgruppen har videre identifisert ytterlige tiltak som redusere utslipp av CO_2 og NO_x fra offshore boreraktivitet på norsk kontinentalsokkel og vurdert hvordan Lundin Energy Norge AS sine virksomhetsmål støtter de nasjonale utslippsreduksjonsmålene for 2030 og 2050.

Gjennom litteraturstudie ble informasjon om selskapet og fremtiden til olje-industrien fra lundin-energy.com og Norsk olje og gass (NOROG) sine årlige rapporter brukt som hovedkilder, der miljostatus.miljodirektoratet.no ble brukt som hovedkilde for mer generell informasjon. Dataene som er brukt som grunnlag for resultatene er hentet fra intervjuer med personell hos Lundin Energy Norway AS´, Lysaker kontor, telefonmøte med NOROG og et besøk på boreriggen som er brukt som eksempel i oppgaven (West Bollsta) på Hanøytangen utenfor Bergen. Estimater og sitarer fra selskapets eksperter er blitt notert fortløpende i møtereferater, og forretningssensitiv informasjon som er blitt behandlet og brukt er referert, men ikke lagt inn som kilder. Grafene som er presentert i resultater er tilpasninger fra dataene som er innsamlet og består av flere antagelser og estimater, og derfor er utregningene avrundet grunnet usikkerheten.

Om bord på West Bollsta er Selektiv Katalytisk Reduksjons-teknologi blitt installert, og har vist utslippsreduserende effekt på opptil 70% for NOx-gasser. «Closed Bus-Tie»-teknologien som er installert reduserer oppe-tiden til dieselmotorer, som igjen reduserer diesel-forbruket til West Bollsta, mens den samtidig opprettholder sikkerhetsreguleringene til DNV-GL. Denne teknologien må derimot optimaliseres bedre for å bli essensiell for overgangen mot et lav-karbons samfunn.

Konklusjonen fra oppgaven er at elektrifisering av plattformer vil være veien videre for norsk petroleum industri på norsk kontinental sokkel i fremtidige år, da det gir store utslippsreduksjoner. Når det gjelder fremtiden for bore-rigger er det en større usikkerhet. Prosjektgruppen har kommet frem til at energistyringssystemer på borerigger vil være avgjørende for å redusere utslipp i kommende år. For at både Lundin Energy Norway AS og Norge skal nå klimamålene og reguleringene, må borerigger effektiviseres ytterliggere. Energistyringssystem vil hjelpe stort, men er ikke nok til å fjerne alle utslipp. I fremtiden kan lav-utslipps drivstoff og brenselceller være noen av teknologiene som vil bli brukt i motorer på borerigger på norsk kontinental sokkel.

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Abbreviations for gases

CH_4	Methane
GHG	Greenhouse gases, the main GHG are CO_2, CH_4, N_2O, H_2O, O_3, CFCs
CFC's	Chloro- and fluorinated gases
CO_2	Carbon Dioxide
CO_2 equivalents	Carbon Dioxide equivalent is a measure used to compare emissions from various greenhouse gases based upon their global warming potential
HFC's	Hydrofluorocarbons
hv	photon
HO_2	Hydroperoxyl radical
H_20	Water
NO_x	Nitrogen Oxide gases
N_2O	Nitrous Oxide
nmVOC	Non-Methane Volatile Organic Compounds
O_3	Ozone
O(3P)	Atomic oxygen
OH	Hydroxyl radical
SO_x	Sulphur Oxide gases
SO_2	Sulfur Dioxide
CH_4N_20, $(NH_2)_2CO$	Urea, Carbamide
NH_3	Ammonia

Abbreviations

ABB	Asea Brown Boveri
AUX-derrick	Auxiliary Derrick
BAT	Best available technique
Boe	Barrel of oil equivalent. Boe is used to summarize the amount of energy that is equivalent to the amount of energy found in a barrel of crude oil
CBT	Closed Bus-Tie
CCS	Carbon Capture and Storage
COP	Conference and the parties
DNV-GL	Den Norske Veritas – Germanischer Lloyd
DP(S)	Dynamic Positioning (System)
EG	Edvard Grieg (field)
EMS	Energy Management System
ER	Set of thruster and generator connected to switchboard
GWP	Global Warming Potential
GWP-100	Global Warming Potential in a 100-year period
IMO	International Maritime Organization
IPCC	UN Climate Panel on Climate Change (Intergovernmental Panel on Climate Change)
LE	Leiv Eiriksson
LENO	Lundin Energy Norway AS
LUNE	Lundin Energy AB
MARPOL	Marine Pollution
NCS	Norwegian Continental Shelf
NOROG	
OED	Ministry of Petroleum and Energy
PSA	Petroleumstilsynet
R&D	Research and Development
SCR	Selective Catalytic Reduction
SSB	Statistisk Sentralbyrå
SWB	Switchboard(s)
TCM	Technical Centre Mongstad
UN	United Nations
UNFCC	United Nations Framework Convention on Climate Change
WWF	World Wildlife Fund

1. Introduction

The world’s population is continuously increasing, and therefore it is important that energy production increases proportionally and that access to energy is fairly distributed. Petroleum (Oil & Gas) are one of the most important resources for production of energy. Norway as a country experienced a tremendous shift in becoming a welfare state due to the discovery of oil and gas on the Norwegian Continental Shelf (NCS). The contribution from the petroleum industry to the Norwegian economy has provided an exponential cash generation and has created the fortune invested in the Oil Fund which is an important resource for the Norwegian society.

Producing energy from fossil fuels, including petroleum, results in emission of combustion gases of which carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3) and water vapor (H_2O) are greenhouse gases (GHG). GHG can be harmful to the planet and contributes to the global warming. [1]. Other hazardous gases that come from the petroleum industry is NO_x-gases, which is chemical compounds of nitrogen and oxygen and the product of combustion in hot conditions. NO_x-gases are toxic to humans and can lead to harmful changes in ecosystems [2].

Climate change is one of the world’s biggest challenges. The Paris Agreement is an UN-led agreement aimed at strengthening the work on reducing climate changes worldwide. The objective is to limit the temperature rise for this century below two degrees Celsius and in the long term limit the temperature increase to 1.5 degrees Celsius [3]. Cutting off all fossil energy production will not be possible today with regard to the world's energy needs. Therefore, all industry world-wide must contribute to reduce the emissions of GHG in order to meet the objectives in the Paris Agreement.

There is a strong attention on reducing fossil fuel combustion as an energy source. At the same time, it is accepted that petroleum will be relevant for several years to come. Due to this, it is important to reduce CO_2 emissions during the production and consumption of oil and gas. In order to meet the world's growing energy demand, it’s important to develop zero-emission technologies and combinations of different types of technologies that can reduce the GHG emission and other hazardous gases from the petroleum industry, such as offshore wind turbines or power from shore that can electrify petroleum platforms and reduce the CO_2 emissions significantly.

Lundin Energy AB (LUNE) is one of Europe's leading petroleum companies and has its main focus on Norway. Their wholly owned subsidiary Lundin Energy Norway AS (LENO) has their activity within exploration and production of oil and gas on the NCS. LENO has made several discoveries, the largest being Johan Sverdrup and Edvard Grieg, which makes LENO one of the most successful exploration company on the NCS in the last decade [4]. The Edvard Grieg discovery is LENO´s first field put into operation and their first built platform.

LENO has a strong ambition to produce oil and gas resources in the most efficient way and are constantly implementing new emission reducing technology and techniques to produce petroleum in a sustainable way. They have a strategic commitment in reducing greenhouse gas emissions and other types of emissions like NO_x-gases. They have managed to cut emissions by reducing flaring on Edvard Grieg, which is one of the main sources for emission on the platform, and they have initiated plans for how to connect the platform to onshore power to make a significant reduction in emission going forward.

In this assignment we will look at energy management and other measures to reduce emissions of GHG and NO_x from offshore rigs in operation on the NCS. We will use LENO and their leased semi-submersible drilling rig West Bollsta as a study case. West Bollsta will be the first drilling rig used in Norway with a Selective Catalytic Reduction (SCR) system that reduces NO_x-emission and a closed bus tie-system (CBT) that reduces CO_2 emissions. We will look at various technologies and methods implemented on West Bollsta to reduce NO_x and GHG and as well as additional technologies that may be parts of future solutions. We will also look at international agreements such as the Paris Agreement to reduce greenhouse gas emissions and what LENO could do and have done to achieve their own climate targets as well as the climate targets set by the Norwegian authorities, which is to reduce the greenhouse gas emission by 55% by 2030 and for Norway to be a low carbon society by 2050.

2. Theory

The petroleum industry contributes to various emissions of greenhouse gases (GHG), and other emissions like nitrogen oxides (NO_x-gases), non-methane Volatile Organic Compounds (nmVOC) and Sulphur oxides (SO_x). These emissions will influence the environment, either the greenhouse effect, ozone formation/degrading or being a health hazard affecting ecosystems or respiratory damage in animals. Therefore, different sets of regulations towards these emissions has been signed both internationally, through the Paris Agreement and the Gothenburg Protocol, and domestic with basis in Norway, the Carbon tax, GHG emission trading act and the Petroleum Safety Authority Regulations (HSE regulations).

To reduce the emissions from the industry, research and development into emission reducing technologies has evolved. The Norwegian Oil and Gas Association (NOROG) has published roadmaps with further documentation on the progress towards the petroleum industry emission reducing goals.

To guide the industry towards implementation of technologies reducing emissions, the Norwegian authorities introduced the NO_x-tax where the money raised later would be put in the NO_x-fund, providing financial support to NO_x-emission reducing technologies. Furthermore, ENOVA support other technologies that contribute to Norway becoming a low carbon society by 2050.

To comply with the regulations and goals set from the industry, operators like Lundin Energy AB (LUNE) have made environmental policies and decarbonization strategies. These documents state the company’s plan for future investments and implementation, where Lundin Energy Norway AS contributes amongst other with the field Edvard Grieg and drilling unit West Bollsta.

2.1 Greenhouse gases

Greenhouse gases (GHG) allow direct sunlight to reach Earth's surface and absorb some of the heat radiation emitted from Earth and scatter radiation further, some into to space, others towards the Earth. Greenhouse gases are divided into natural and human-made/industrial emission-gases. Of the natural GHG we have Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Ozone (O_3) and water vapor (H_2O). Some of the greenhouse gases that are exclusively human-made/industrial are e.g. Chloro– and fluorinated gases (CFC's) and HFC's (Hydrofluorocarbons) but these are not focused on in this report [5].

2.1.1 Carbon dioxide, the major waste gas from combustion

Carbon dioxide (CO_2) is the most common waste product from combustion engines and is a colourless-, acidic-gas. Emissions of CO2 have been heavily regulated by national and international bodies, and stricter regulations are being demanded by non-governmental organisations regularly. The reason CO_2 is so hard to regulate is because of its longevity in the atmosphere. Carbon dioxide can live in the atmosphere for around 300-1000 years, because of the slow carbon cycle, compared to the water cycle [6].

CO_2 is also widely considered to be the most important GHG, although maintaining a percentage of only 0.04%, 400 ppm, of the atmosphere it amounted to 84% of GHG emissions in Norway in 2018 [1]. After the industrial revolution, the concentration of carbon dioxide in the atmosphere has increased significantly, from 280 parts per million concentration in the atmosphere (ppm[1]) in the mid-1700s to 407.4 ppm in 2018 [6].

2.1.2 Incomplete combustion, methane emissions

Methane, CH_4, is the second most important greenhouse gas after CO_2. Methane emissions are mostly found in the agricultural industry, contributing to 54.8% of emissions to air within the Norwegian sector in 2018 [7]. Methane is also emitted through incomplete combustion, like flaring, and contributed to 10.2% of the Norwegian sectors emissions to air in 2018. From "CO_2-emissions from Norwegian oil and gas extraction" published by Statistics Norway, methane is found to "constitute around 15% of total GHG emissions globally (from oil and gas extraction) but only 5% in Norway". It is further stated that "this is partly due to strict restrictions on flaring in Norway", mainly limited to a safety mechanism at production start-up/shutdown of an platform [8].

1 ppm: parts per million. The same as mg/L per month.

2.1.3 N_2O, the third most important greenhouse gas

Nitrous oxide (N_2O), or nitrous, is not toxic for humans, but gives out a more settling effect as its medical uses are used as an anaesthetic and pain regulator. When nitrous oxide enters the troposphere, the effects are not favourable anymore, as it is a GHG and a powerful oxidizer. It is listed as the third most important greenhouse gas after carbon dioxide and methane. Nitrous is commonly found in production of fertilizer, and in 2018 73.8% of emissions came from agriculture, compared to 0.422% from oil and gas production in Norway [9].

2.1.4 Historical emissions of GHG from the Norwegian sector

The Petroleum industry accounts for 27% of the total GHG emissions in Norway [10]. From 1990-2018 the emissions have increased by 73%, shown in Figure 1, where in the period between 1990-2000 the increase was a result of further increasing/expanding field development, and oil production. The stabilization after year 2000 is a result of technology improvement, like electrification and other emission reducing measures. The large increase in greenhouse gas emissions are related to a higher demand for energy due to an increased activity on the continental shelf, the technological development and the solutions of production of electricity that is on the existing fields. Emissions also occur during production, storage, loading and transport of oil [1].

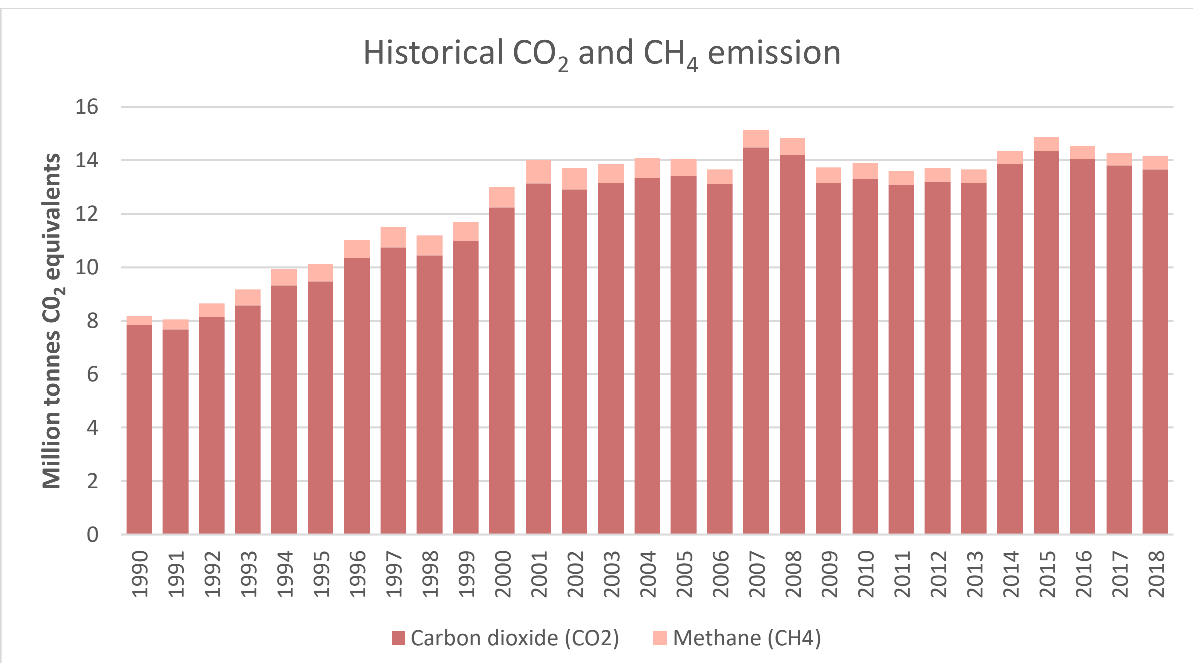

Figure 1 *Emissions of greenhouse gases from petroleum extraction on the NCS, in million tonnes of* CO_2 *equivalents. Adapted from Statistics Norway (SSB) and Norwegian Environment Agency [10].*

In 2018, the petroleum industry in Norway emitted 14.2 million tonnes of CO_2 equivalents. The largest contribution to the emission came from gas turbines on offshore platforms which alone emitted 9.47 million tonnes of CO_2 equivalents, further explained in Chapter 2.3 Greenhouse effect, emissions and impact of different GHG, section two. Furthermore, emissions in CO_2-eqvivalents from various sources in the petroleum extraction chain is shown in Figure 2 [10].

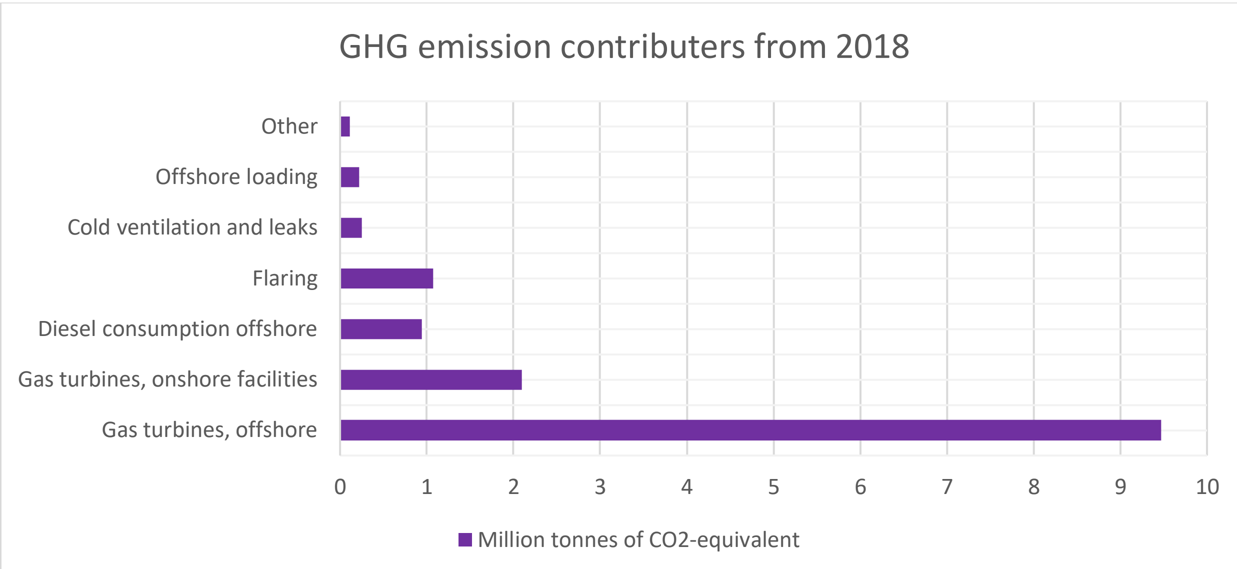

Figure 2 *Greenhouse gas emissions from oil and gas extraction broken down to source in 2018. Adapted from SSB and Norwegian Environment Agency [10].*

2.2 Other emissions from the industry

In addition to GHG, other major emissions from the petroleum industry are NO_x-gases, Non-Methane Volatile Organic Compounds (nmVOC) and Sulphur oxide (SO_x). Although these gases are not GHG, they can indirectly or directly affect the environment in various ways.

2.2.1 The composition and effect of NO_x-gases

The NO_x-gases consist of chemical compounds of Nitrogen and Oxygen and are common in combustion processes in air at high temperatures. NO_x -gases are harmful for humans even in low concentrations and is the most important source for acid rain. In the lower part of the troposphere, you can see the effects of the NO_x-gases shown in brown/yellow clouds, which in turn will release acid rain into the ecosystem. Research from the Intergovernmental Panel on Climate Change (IPCC) on page 259 of "Atmospheric Chemistry and Greenhouse Gases" [11] has found that NO_x-emissions catalyse ground level, tropospheric, O_3 as shown in Table 1. Emissions in remote areas will rise further into the upper part of the troposphere, where the effect of ozone is that of an GHG.

Table 1 *Nitrogen oxides ($NO_x = NO + NO_2$) do not directly affect Earth's radiative balance, but they catalyse tropospheric O_3 formation through a sequence of reactions, e.g. [11]. M is a non-reactive species that take up energy released in the reaction to stabilize O_3.*

$$OH + CO + O_2 \rightarrow CO_2 + HO_2 \quad (1)$$

$$HO_2 + NO \rightarrow NO_2 + OH \quad (2)$$

$$NO_2 + hv \rightarrow NO + O(^3P) \quad (3)$$

$$O(^3P) + O_2 + M \rightarrow O_3 + M \quad (4)$$

net:

$$CO + 2O_2 + hv \rightarrow CO_2 + O_3 \quad (5)$$

The challenges related to NO_x-gases derive from the regulations towards emissions and its linking with CO_2 emissions. Combustion engines driven with diesel operate with higher pressure and temperature, compared to petrol-engines, which results in higher NO_x -emissions, but will in turn emit less CO_2. In Figure 3, we can see the effect of NO_x-taxes, further explained in Chapter 2.8 Funding for emission reducing technologies, where the NO_x emissions from the NCS are shown to have decreased over the last years and projected to follow this trend for future years.

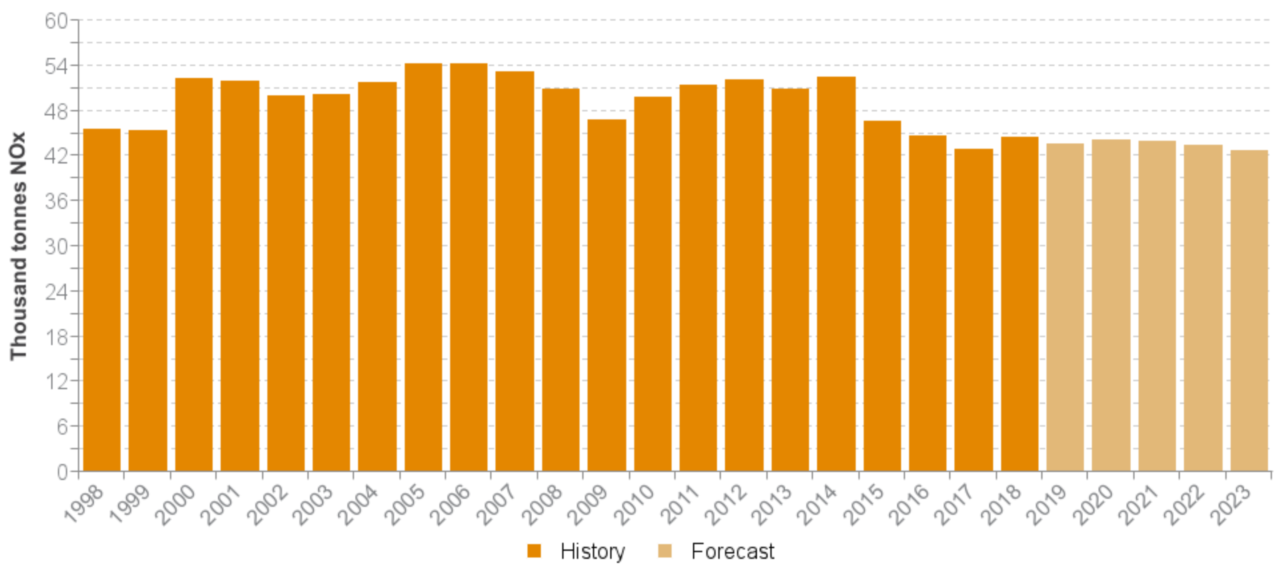

Figure 3 *Historical NO_x emissions for 1998-2018 and projections for 2019-2023. Reprinted from the Norwegian Petroleum Directorate [12].*

2.2.2 Non-Methane Volatile Organic Compounds emissions

The contributions of nmVOC come from storage and loading of crude oil through vaporization. Emissions trace to formation of ground level ozone, respiratory damage through direct contact and indirectly greenhouse effect by reaction with air to form CO_2 and ozone. Through constantly improving technology to reduce emissions and recovery of oil vapor the industry has constantly cut nmVOC emissions as shown in Figure 4 [12].

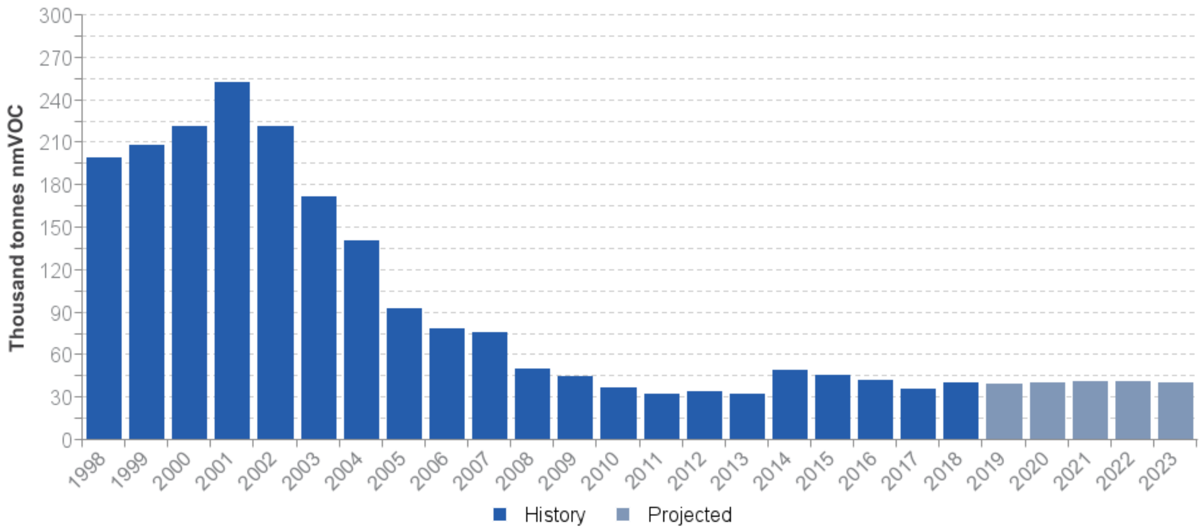

Figure 4 *Historical and projected emissions of nmVOC from the petroleum industry in Norway 1998-2023. Reprinted from the Norwegian Petroleum Directorate [12].*

2.2.3 Sulphur Oxide emissions

The emission factor from combustion of diesel in SO_x-emissions are directly linked with the concentration of sulphur in the diesel, as shown in Equation 6, adapted from NOROG 044 on page 56 [13].

$$\boldsymbol{f}_{SOx} = \frac{k_s}{100} * 2\ tonnes/tonnes \qquad (6)$$

Table 2 *Explanation on the components in the equation for calculation of SO_x-emission factors given the amount of H_2S in the diesel, measured in %. Equation 6, adapted from NOROG 044 on page 56 [13].*

Component	Unit	Explanation
$\mathbf{f}_{SO_X}$	tonnes/tonnes	Emission factor for SO_x. Multiplied with burned diesel or heating oil to find SO_x-emissions
k_s	Percentage	Amount sulphur in diesel or heating oil
2	Tonnes/tonnes	Conversion factor to calculate the emission factor for SO_x-gases from the sulphur-concentration in the diesel: $\frac{Molar\ mass\ SO_X}{Molar\ mass\ S} = \frac{64,06}{32,06} \approx 2$

SO_x-gas emissions have been cut through fuel oil limitations to vessels. MARPOL (marine pollution) regulations from January 1st, 2020 states that sulphur mass by mass in crude oil onboard ships operating outside designated emission control areas is reduced to 0.50% from 3.50% which was the previous limit. From International Maritime Organization (IMO) numbers this reduction will result in a 77% drop in overall SO_x -emissions from ships, annual reduction of approximately 8.5 million tonnes of SO_x [14]. In NOROG 044, it is further stated that new regulations towards sulphur content in diesel has been made and the new limit is 0.05 weight percentage Sulphur in diesel, lowering emissions further [13].

2.3 Greenhouse effect, emissions and impact of different GHG

The greenhouse effect is natural and keeps the average temperature on Earth to approximately 15 degrees Celsius globally. “Transparent” particles, like snow and clouds, (2-4-5), reflect suns radiation and will result in a cooling effect, as shown in Figure 5. The difference between how much heat radiation the Earth emits into outer space and the amount of radiation from the Sun reaching the Earth’s surface is called radiative forcing and is directly affected by the amount of GHG in the atmosphere [5]. With a zero radiative forcing index the heat radiation emitted from Earth and the radiation from the Sun reaching Earth’s surface would equal. With positive radiative forcing, the mean temperature on Earth would increase, and with negative radiative forcing it would decrease.

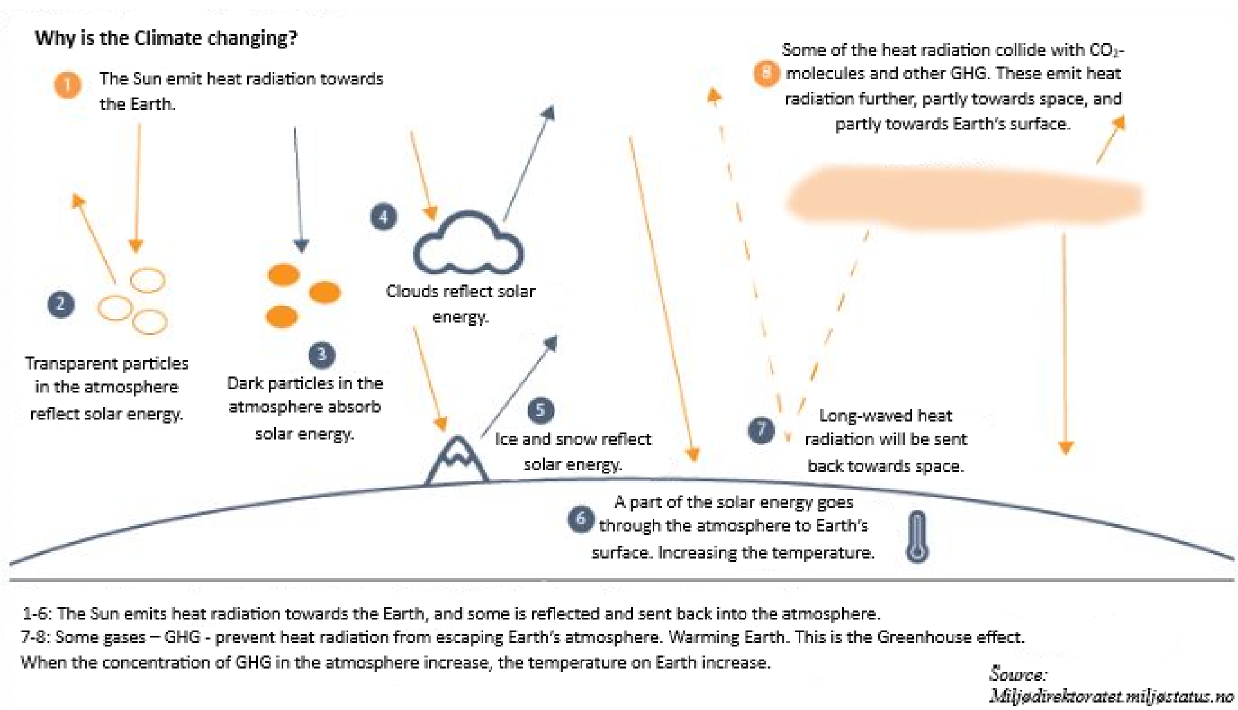

Figure 5 *Greenhouse effect, benefiters and counters to global warming. Adapted from Miljøstatus/Drivhuseffekten [5].*

The Global Warming Potential (GWP) indicates the radiative forcing of GHG compared to CO_2 in a specified time period. The most common potential period used in the United Nations Framework Convention on Climate Change (UNFCC) is the GWP-100, set to a 100-year period. Some numbers of our focused GHG in GWP-100 format is listed in Table 3 [5].

Table 3 *Global Warming Potential and CO_2-equivalents for CO_2, CH_4 and N_2O. Adapted from Miljøstatus/Drivhuseffekten [5].*

Gas	Lifetime in (years), atmosphere	GWP-100	CO_2- equivalents (per mass unit)
Carbon dioxide (CO_2)	300-1000 [6]	1	1
Methane (CH_4)	12.4	28	1:28
Nitrous (N_2O)	120	265	1:265

CO_2 equivalent (CO_2-eq) is the heating effect the specific gas has in the atmosphere compared to CO_2 in the GWP-100 metric of UNFCC. Standardizing the effect these emissions would have as if they were CO_2-emissions, example comparison CH_4: CO_2 (1:28), one pound of methane has the same GWP-100 value, as 28 pounds of CO_2.

Data from Norwegian Petroleum Directorate, shown in Figure 6, gives an estimated outcome of all emissions in CO_2-equivalents from the Norwegian sector in the following years. With higher production of oil in the Norwegian sector in the following years the emission total will increase, but emission per produced oil and gas will decrease through improvement of technology.

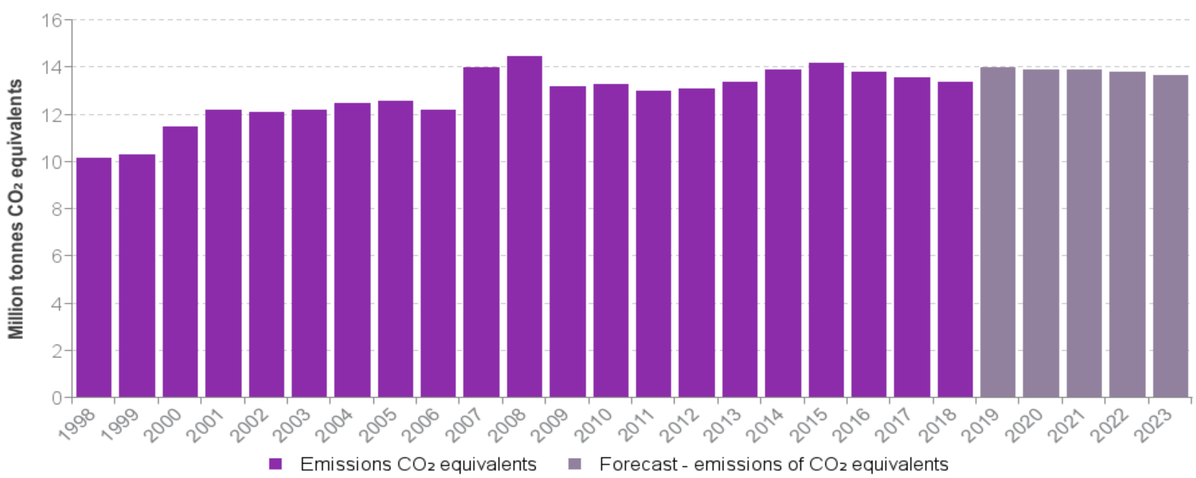

Figure 6 *CO_2 equivalents for 1998-2018 and projections for 2019-2023. Reprinted from the Norwegian Petroleum Directorate [12].*

2.4 International regulations of emissions and incentives to reduce emissions

As the emission of GHG and NO_x continue to increase, international climate agreements containing climate commitments have been introduced to reduce these gases. This thesis focuses on the Paris Agreement and the Gothenburg Protocol, which are two international agreements to reduce GHG and other harmful gases.

2.4.1 The Paris Agreement

Global emissions have increased exponentially since the industrial revolution. Technological developments have led to an increase in the need for energy. This made fossil fuels much more widely used which led to increased greenhouse gas emission. In the case of GHG emissions, global warming is an issue that will have major consequences for both humans and ecosystems. There are prominent signs of global warming today, like rise of the oceans levels and increased frequency of extreme weather conditions (heat wave, heavy rain, hurricanes etc.), which can cause health problems for both humans, animals and ecosystems [15].

In order to cut emissions, many countries in the world have come together to conclude an agreement to reduce the total emissions. The Paris Agreement is one of several agreements involving every country in the world. The Paris Agreement was signed on December 12, 2015. The Agreement stipulates that all countries must impose obligations in their own country to meet the requirements agreed upon. Beginning in 2020, the targets will be renewed every five years, where the goals will be more ambitious from 2023 onwards, and all countries shall report the emission cuts every five years [16].

There are three main objectives in the Paris Agreement (from Article 2 in Paris Agreement) [17]:

1. Limiting global warming to "well below" 2° C, but preferably to 1.5° C, compared to pre-industrial times.
2. Choosing the countries capacity to adapt to climate change and at the same time achieve a development like simpler climate robustness and low emissions.
3. Global financial flows should be made compatible with low greenhouse gas emissions and climate-robust development.

The purpose of the Paris Agreement is that the amount of emissions shall regularly decline, and sometime between 2050 and 2100 all countries in the world should be "Carbon neutral" [18].
Norway has an agreement with countries in the EU in accordance with the Paris Agreement that 55% of greenhouse gas emissions will be reduced by 2030, and by 2050 Norway will be a low carbon society.

Norway have increased its climate target from 40% to 55% to strengthen their targets under the Paris Agreement. To achieve these goals by 2050, it is necessary to have a road map that illustrates possible solutions to reduce emissions [19].

2.4.2 Gothenburg Protocol

The Gothenburg Protocol, is an international environmental agreement to cut down the emissions of nitrogen oxides (NO_x), sulphur dioxide (SO_2), ammonia (NH_3) and volatile organic compounds (nmVOC) which are gases that fertilize the environment and produce Ground-level Ozone [20]. The Gothenburg Protocol was signed in 1999 and introduced in 2005. All countries that signed the protocol are committed to the emission figures from 2010. New emission commitments for 2020 were adopted in May 2012 [21] (see Table 4). Note that Ammonia (NH_3) and $PM_{2.5}$ are not relevant for this thesis as there are minor emissions of these form the oil industry.

Norway has fully committed to fulfil this agreement and introduced a tax in 2007 to reduce NO_x emissions. With this measure, Norway aim to reduce annual NO_x emissions by 23% from 2005 to 2020. For companies that use environmental support funds such as the NO_x Fund to reduce emissions, tax exemptions are granted, further explained in subsection 2.8.1 NO_x Agreement and funding. Norway has also set a target of reducing nmVOC gases by 40% from 2005-2020. The petroleum sector accounts for almost quarter of emissions of nmVOC gas [10].

Table 4 *Norway´s commitment to the Gothenburg Protocol for 2020 (in tonnes). Adapted from Norwegian Environment Agency [22].*

Gas or particles	Emissions from year 2005	Emission reduction commitment for 2020 (%)	Emission commitment for 2020
SO_2	24 000	10	22 000
NO_x	196 000	23	151 000
NH_3	28 000	8	25 000
nmVOC	218 000	40	131 000
$PM_{2.5}$	39 000	30	27 000

2.4.3 IMO regulations, diesel engines and NO_x-emissions

Depending on the construction date of the ship, different Tiers/levels of NO_x-reduction is required. These requirements apply only when operating in Emission Control Areas (ECA), like the North Sea, where NO_x-limitations are made. Operations outside of ECA the Tier II controls apply. The IMO MARPOL regulations take effect 01.01.2021 in the North Sea involving Tier III and shown Figure 7 requires 80% less NO_x-emissions compared with Tier I [23].

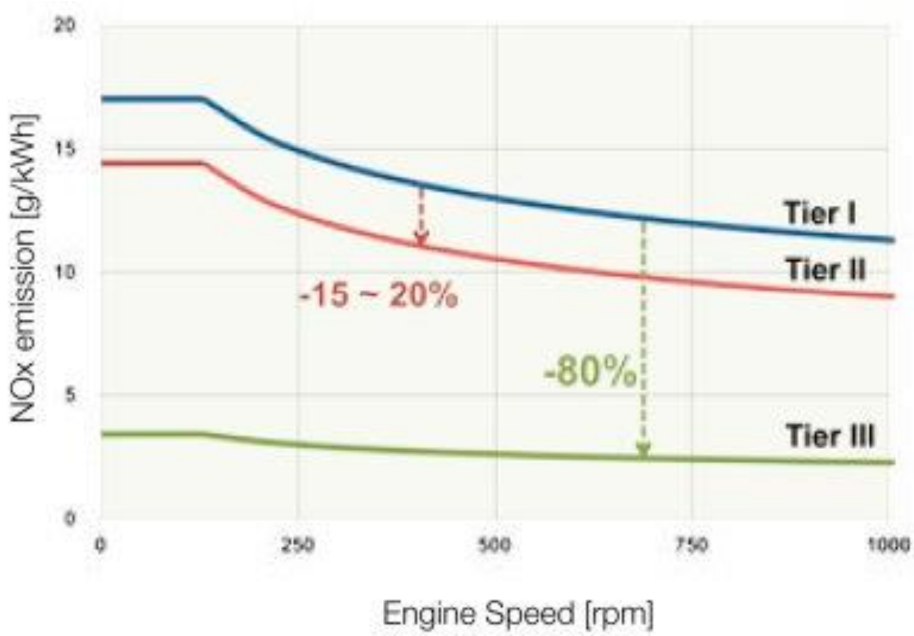

Figure 7 *Tier III ramifications towards NO_x emission cut. Reprinted from Hyundai NoNO$_x$ SCR system [24].*

2.5 Environmental requirements from Norwegian authorities

Compared with other petroleum producing companies in other parts of the world, the petroleum industry on the NCS has very high environmental and climate standards [12].The high standard is due to strict demands from the Norwegian authorities as well as the expertise Norway holds due to cooperation and competition in the industry with a desire to always do the best. This results in making the NCS world leading in terms of high recovery rate and low GHG emissions as seen in Figure 8 [25].

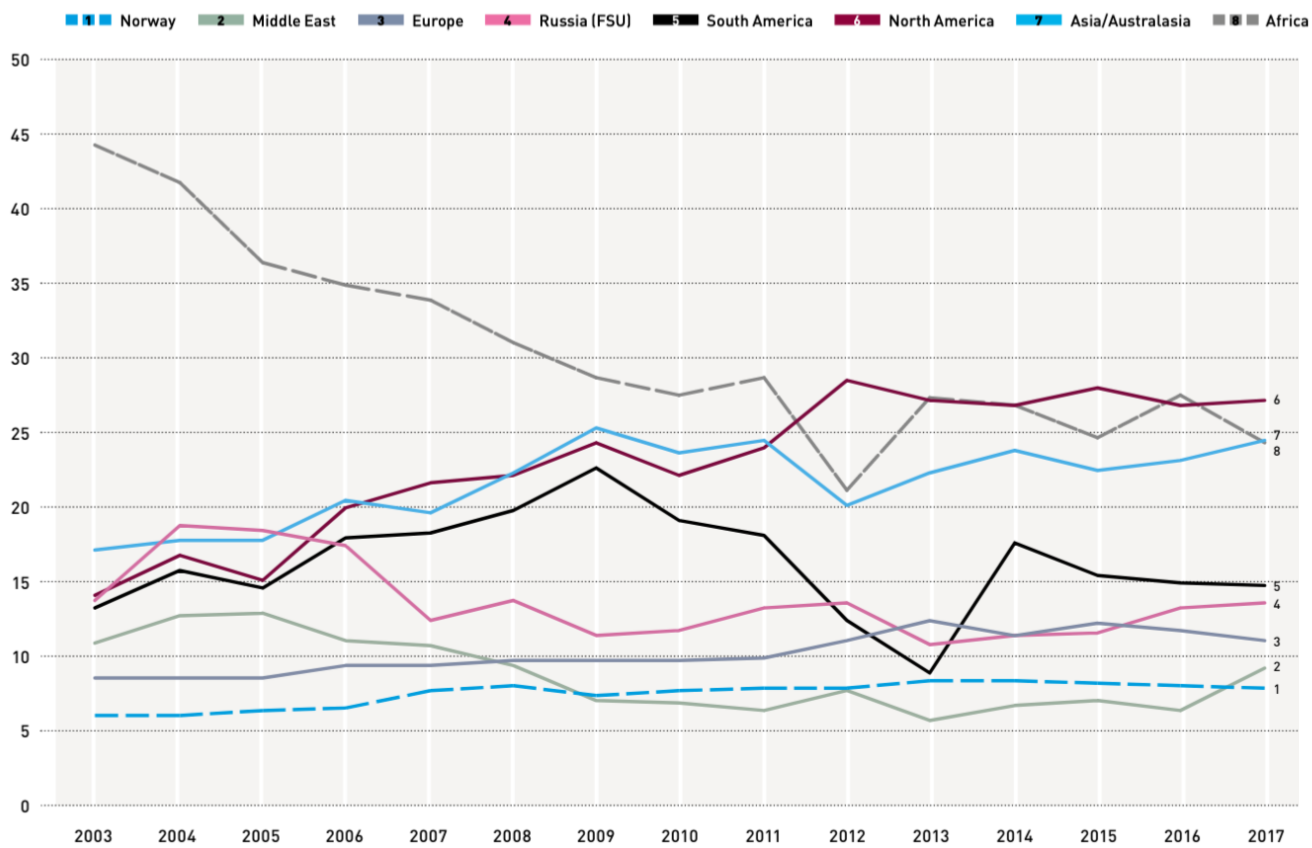

Figure 8 *GHG emissions per produced unit from various petroleum producing regions 2003-2017, (kg of CO_2 equivalents/boe per barrel of OE produced).*
Reprinted from figure 23 in NOROG´s Environmental Report 2019 [26].

Figure 9 shows the industry average of carbon intensity per kg CO_2/boe in the world compared to the industry average in Norway. The international average is around 18 kg CO_2/boe while the average on the NCS is around 8 kg CO_2/boe [27].

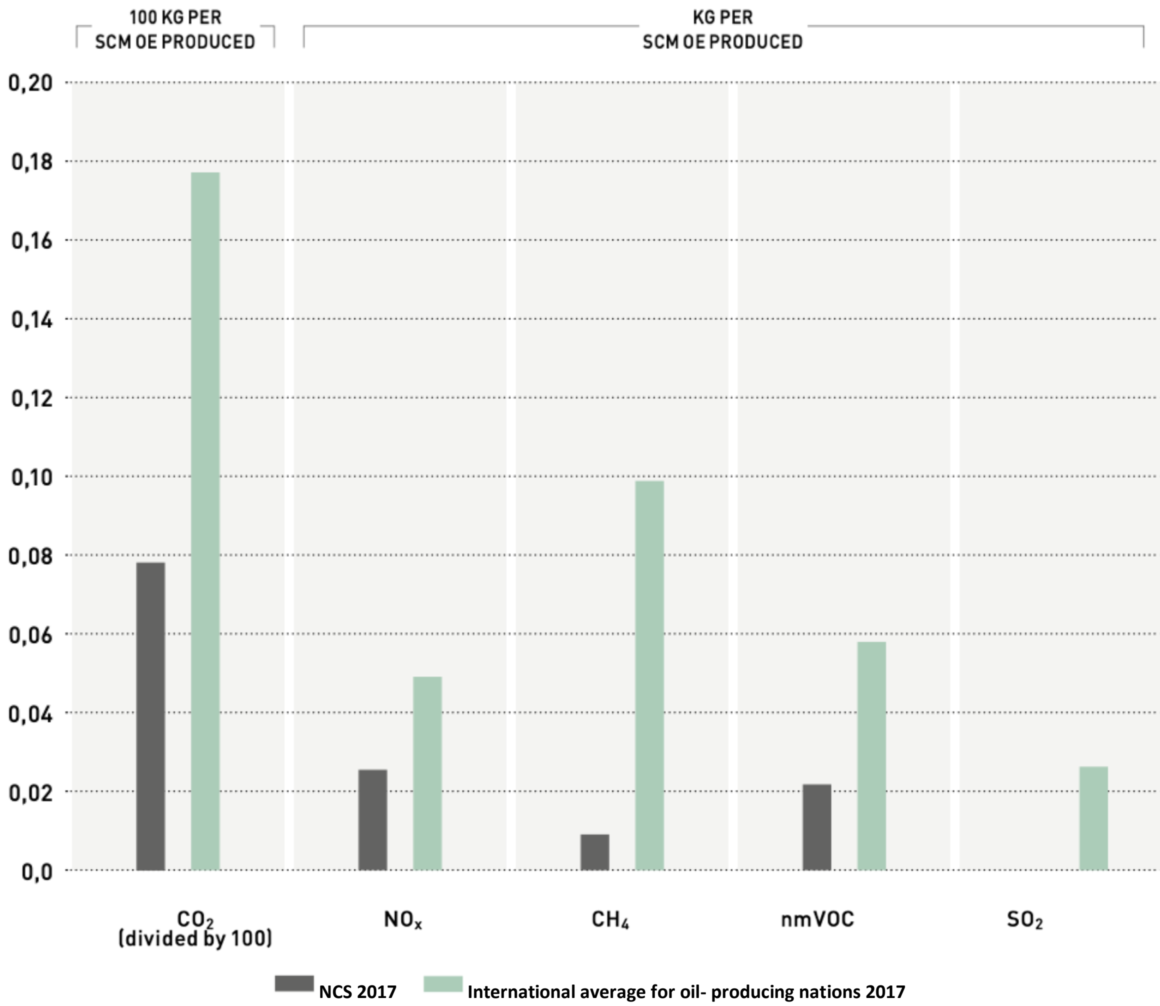

Figure 9 *Emission to air on the NCS compared with the international average in 2017. Reprinted from figure 19 in NOROG´s Environmental Report 2019 [26] and from figure 20 in NOROG´s Environmental Report 2018 [28].*

All emissions from the petroleum industry in Norway, both from offshore facilities on the NCS and the onshore facilities such as Kollsnes, Kårstø, Nyhamna, Melkøya, Sture and Tjeldbergodden, falls within the scope of the petroleum legislation and are regulated through several common laws. The Norwegian Petroleum Directorate has on their website listed the most important laws such as the Petroleum Act, the Carbon Tax, the CO_2 Tax Act on Petroleum Activities, the Sales Tax Act, the Greenhouse Gas Emissions Trading Act and the Pollution Act [12].

The two most important climate measures initiated by the Norwegian authorities for effective cuts in greenhouse gas emissions is the Carbon tax and the Greenhouse Gas Emissions Trading Act [12].

2.5.1 The Carbon Tax

In 1991, Norway became one of the first countries in the world to introduce a carbon tax. In accordance with the CO_2 Tax Act on Petroleum Activities, the Carbon Tax stipulates a tax on all combustion of oil, gas, diesel and emissions of CO_2 and natural gas from petroleum activities on the NCS. In 2020, all petroleum producing companies on the NCS have to pay a tax rate of 1.15 NOK per standard cubic meter of gas or per litre of oil or condensate. This equivalents to 491 NOK per tonne of CO_2 for combustion of natural gas. The tax rate for natural gas emissions is 7.93 NOK per standard cubic meter [12].

2.5.2 Greenhouse Gas Emissions Trading Act

The Greenhouse Gas Emissions Trading Act came into effect in 2005, and three years later Norway joined the EU Emissions Trading System (EU-ETS) [12]. By joining the system, all installations in the petroleum industry in Norway are subjected to the same emissions trading rules as other emitters within the EU. The EU-ETS acts as a "cap and trade" system, which means there is a "cap" or limitation on total GHG emission from the system. This "cap" will be reduced year by year so that the emission target of 43% cut in emission from 2005-2030 is reached. Allowances for emissions are accessible by auction or given out free of charge. One allowance gives the right to emit one tonne of CO_2. Emissions from power generation on offshore installations are not allowed free of charge [12].

If a company exceeds their allocation for emissions, they must purchase additional allowances from other companies in the EU-ETS. In this way, companies that are able to reduce their emissions can sell some of their surplus allowances. In recent years, the EU-ETS price has increased significantly. From 2018 to 2019, the average cost of an emission allowance increased from approximately 15.9 to 24.8 Euros, corresponding to an increase from 153 to 242 NOK [12]. In total, the stock price of one allowance has since May 2017 to May 5th, 2020 increased by over 400%, illustrated in Figure 10 [29].

Figure 10 *The graph shows the historical trend of the EU-ETC price in Euros for one quota. Reprinted from Markets Insider - CO_2 European Emission Allowances [29].*

Due to the combination of The Carbon Tax and The Emission Trading System companies operating on the NCS, such as LENO, have to pay approximately 700-800 NOK per tonne of CO_2 emissions. These fees are significantly higher than in other countries with petroleum activities [12].

2.5.3 The Petroleum Safety Authority Regulations (HSE regulations)

The Petroleum Safety Authority Norway (PSA) is a government supervisory and administrative agency with regulatory responsibility for safety, the working environment, emergency preparedness and security in the petroleum sector.

Their supervisory responsibility embraces oil and gas activities on the whole Norwegian Continental Shelf in addition to eight petroleum facilities on land and associated pipeline systems. They establish detailed regulations for the whole petroleum industry [30].

All companies on the NCS are required by the Environment Directorate through the Emission Permit to have energy management in accordance to ISO 50001. Regulations on energy management and energy efficiency are subject to Chapter XI - *Emissions and discharges to external environment* in the activity regulations [31], which states that:

§ 61a Energy management

> The operator shall have an energy management system for continuous, systematic and targeted assessment of measures that can be implemented to achieve the most energy-efficient production and operation.
> The energy management system shall comply with the principles and methods specified in the Norwegian standard for energy management, NS-EN ISO 50001:2018. The energy management system shall include a flaring strategy.

§ 61b Energy efficiency

> The operator shall assess and, if technically feasible and not incurring unreasonable costs, take measure to reduce energy consumption by reducing energy demand, optimizing own energy production and increasing utilization of surplus energy.

Flaring on the NCS takes place in accordance with the Petroleum Act §4-4 and is restricted to be permitted only when it is necessary for safety reasons [32]. This results in Norway having much lower emission due to flaring compared to the global average as seen in Figure 11.

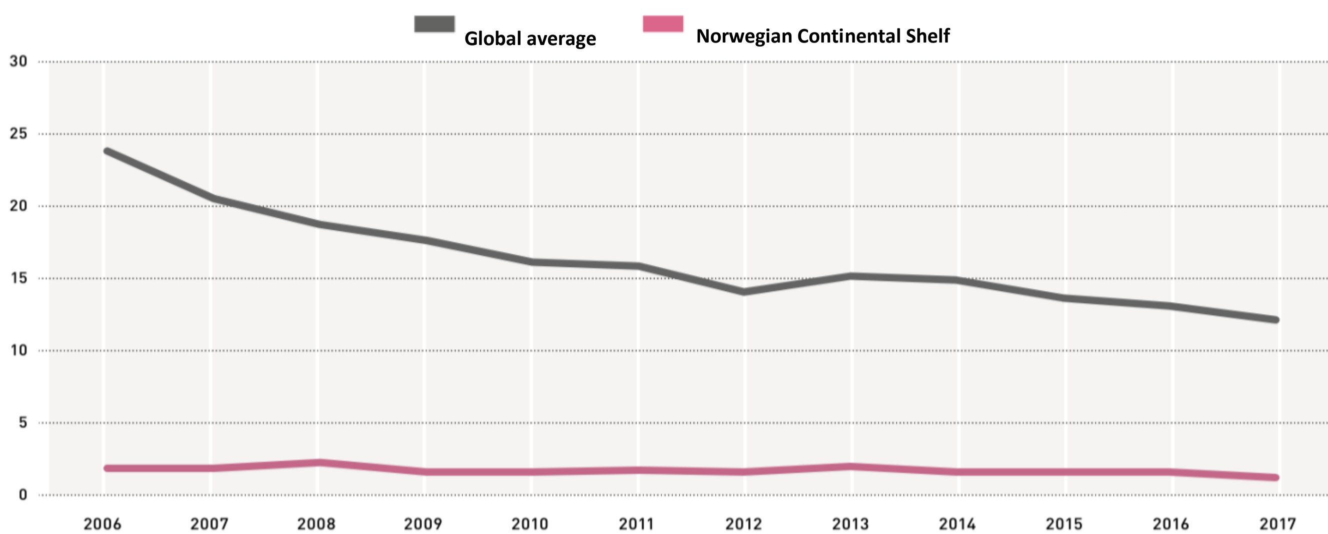

Figure 11 *The amount of gas (kg) spent on flaring per tonne produced oil equivalent on the NCS compared to the international average. Reprinted from figure 25 from NOROG´s Environmental Report 2019.*

2.6 Emission measures and technologies

The petroleum industry in Norway work continuously with implementing the best available technique (BAT) while working to create new solutions to further reduce emissions. Electrification of the NCS, heat recovery from gas turbines and CO_2 capture on the Sleipner field as well as reinjection of CO_2 at the Utsira Formation are examples on technologies used today to reduce emissions.

Emission reducing technologies focus on optimization of techniques or implementing new technology making the system operate with lower emission. These measures contribute to cleaner production of oil, and hopefully increasing income for the operators in future years with more strict regulations towards emission and technology usage.

Some other emission reducing-technologies that will be important contributors to the future oil industry are carbon capture and storage (CCS), CBT and electrification reducing CO_2-emissions likewise using SCR with urea to reduce NO_x-emissions and will be addressed in the subsections below.

2.6.1 Energy Management

Energy management includes all procedures, work processes, measures, equipment and technologies that reduce energy consumption to a minimum and thus reduce emission of CO_2 and NO_x to a minimum. Implementation of energy efficiency measures, including energy management systems are important contributes to reducing emissions. By obtaining an overview of total energy requirement and energy consumers, equipment and operation can be optimized and therefore less energy will be used [33].

2.6.2 Carbon Capture and Storage (CCS) technology

CCS is the technology of gathering carbon dioxide emissions and storing the gas in locations where it will not emit into the atmosphere. The technology has been in use by Equinor on the oil fields Sleipner and Snøhvit since 1996 and 2008, respectively. Through the "Northern lights" project [34], Equinor, Total and Shell plan to move liquified CO_2 emissions from various onshore industries to storage out in the seabed from the Mongstad-facility (TCM- Technical Centre Mongstad) [35] [36].

From the "EL001 Northern Lights – Mottak og permanent lagring av CO_2, 2019, del 2 - konsekvensutredning" document, page 17 [34], Equinor and the International Energy Agency (IEA) states that to keep global warming to 2 degrees Celsius within 2050, 6 billion tonnes of CO_2 must be captured and stored annually.

In the document on the same page, Equinor also opens about the possibility of a hydrogen marked in the future, accompanying CCS technology advancements. Furthermore, KonKraft[2] has stated that CCS can capture and store 90-95 % of the CO_2 content in the gas [37].

2.6.3 Electrification of oilfields

Electrification of the NCS is going to be a crucial measure in order to reduce emissions and reach the climate targets set by the industry in the KonKraft roadmaps. By providing electrification possibilities offshore, the running hours from gas turbines producing electricity can be cut, further reducing emissions. Full electrification from land-based industry is possible through cables on the seabed reaching out to the oilfield. Another possibility is partly electrification, e.g. the “Hywind Tampen” -project which will be an offshore wind park powering the Tampen field [35].

Hywind Tampen can cut emissions on the Tampen field in the NCS, becoming the first oilfield receiving electricity directly from an offshore wind-park. The park is expected to provide 35% of the annually power consumption to the five platforms: Snorre A and B plus Gullfaks A, B and C. This electrification technique of the platforms is estimated to cut about 1 000 tonnes of NO_x-emissions and 200 000 tonnes of CO_2-emissions, equalling the annual emissions of 100 000 cars. The funding for this project from ENOVA and NO_x-fund are respectively 2.3 billion NOK and 566 million NOK [35].

The Norwegian Petroleum Directorate claim in [38] that more than 40% of the Norwegian oil and gas output will utilize power from onshore in 2023. This is an increase of 14% over the last ten years, showing the rate electrification is expanding on the NCS. Figure 12 is a reprint from this report showing the share of total NCS production powered from shore now or due to be so under current plans [38].

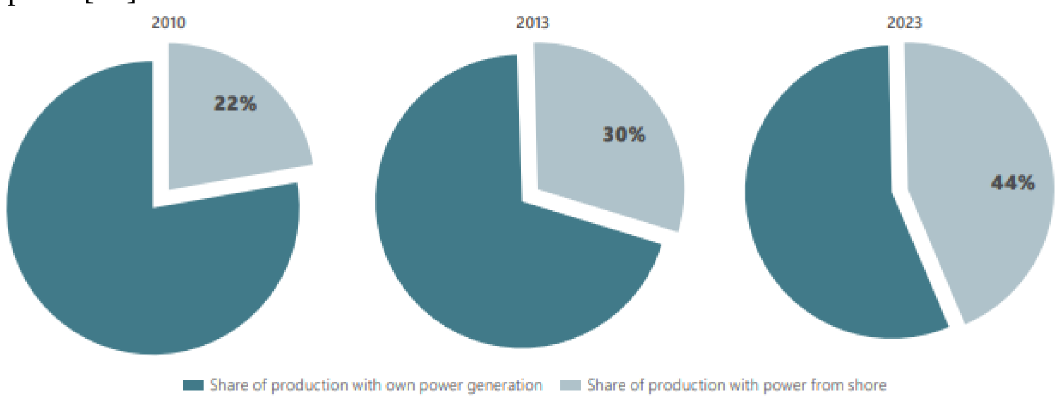

Figure 12 Share of total NCS production powered from shore now or due to be current plans. Reprinted from "Resource Report: Discoveries and Fields 2019" [38].

[2] KonKraft is a collaborative arena for Norwegian Oil and Gas Association (NOROG), the Federation of Norwegian Industry, the Norwegian Shipowners Association and the Norwegian Confederation of Trade Unions (LO), with the LO unions Fellesforbundet and Industri Energi

2.6.4 Closed bus-tie configuration (CBT)

A CBT-system is an automatic system "controlling" the dynamic positioning (DP) of the rig. Dynamic positioning being one of the more critical parts of the operation, where wellhead rotation of a couple centimetres during drilling in shallow water could result in breaking the well or the drill string leading to spills and other disasters. Therefore, redundancy has been absolute priority within this part of the machinery, where backup generators, thrusters and switchboards are set to standby start.

A closed bus-tie configuration (CBT) over the switchboards (SWB) can equally distribute load over the SWB and engines operating the dynamic positioning system (DPS). CBT can further improve engine optimization by operating in closed loop with automatic start-up, removing standby thrusters, while maintaining safety regulations from DNV-GL (Den Norske Veritas – Germanischer Lloyd). Removing redundancy in standby-thrusters will cut the total running hours of the engines, and therefore lead to lower emissions from the working engines as the rig is operating with higher load which cause a cleaner combustion of the diesel [39].

2.6.5 Selective Catalytic Reduction (SCR) of exhaust gas with Urea solution

Urea or Carbamide (CH_4N_2O) is an organic compound and the end product when proteins break down metabolically in all mammals and some fishes, eventually excreted in the urine. At normal temperatures (15-20 degrees Celsius) Urea is solid, and usual storage temperatures vary from around two to eight degrees Celsius. The melting point of Urea is 132-135 degrees Celsius and will decompose to ammonia at about 340 degrees Celsius. Urea can be produced from synthetic ammonia (NH_3) and carbon dioxide, and in 2016 more than half of the industrialized produced Urea was used as a nitrogen-release fertilizer [40].

Selective Catalytic Reduction (SCR) technology mixes urea with water in high temperature conditions of about 300-400 degrees Celsius to produce ammonia and carbon dioxide through the reaction shown in Equation 7. SCR technology has been in use in the marine industry since the 1970's. From NO_x Trap Catalysts and Technologies: Fundamentals and Industrial Applications [41], the following chemical reactions will occur.

Equation 7 Urea and water reaction to form Ammonia and small amounts of carbon dioxide [41].

$$(NH_2)_2CO + H_2O \rightarrow 2NH_3 + CO_2 \qquad 7$$
$$(Urea) + (Water) \rightarrow (Ammonia) + (Carbon\ dioxide)$$

The ammonia will then react with the engine exhaust and move to the catalyst where depending on pressure and temperature these different equations producing nitrogen and water will derive:

Table 5 NOx-reduction through the use of ammonia over catalyst layers, resulting in natural products of nitrogen and water [41].

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O \qquad 8$$

$$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O \qquad 9$$

$$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O \qquad 10$$

$$(NO_X{}'s) + (Ammonia) \rightarrow (Nitrogen) + (Water)$$

Theoretical results of NO_x-emission reduction using SCR-technology is 100%, but realistic results are closer to 80%, though not having ideal conditions 100% of the time. The fastest and preferred NO_x reduction reaction is Equation 10 and is dominant at low temperatures. A catalyst can however form NO_2 over the platinum in the SCR catalyst utilizing the following reaction:

Equation 11 Excess NO_2 produced over platinum catalyst layer [41].

$$2NO + O_2 \rightarrow 2NO_2 \qquad 11$$

The main problem with Equation 11 is that if excess NO_2 is produced over the catalyst, it can form N_2O. This is because the slowest reaction, Equation 9, becomes operative, leading to Equation 12. N_2O is not a desirable product because of its climate effects and can further become more attributed with other circumstances at hand, like incomplete ammonia oxidation.

Equation 12 the possible production of nitrous in catalyst through un-ideal temperature conditions with excess NO_x [41].

$$8NO_2 + 8NH_3 \rightarrow 4N_2 + 4N_2O + 12H_2O \qquad 12$$

$$(NO_X) + (Ammonia) \rightarrow (Nitrogen) + (Nitrous) + (Water)$$

2.7 The Norwegian Oil and Gas Association

“The Norwegian Oil and Gas Association (NOROG) is a professional body and employer´s association for oil and supplier companies” [26]. They annually publish an environmental report containing details and an overview of all emissions from the petroleum industry from the previous year. The purpose of the report is to gather information from the Norwegian petroleum industry as well as launch common national strategies, climate targets and measures and eventually publish the status and results of these targets and measures [26].

2.7.1 Roadmap 2016 – Reduce GHG emissions

In 2016, NOROG published a joint climate roadmap in collaboration with the petroleum industry in Norway through the cooperative body KonKraft. The two main purposes of the roadmap were to form ambitions for the industry´s long-term production and value creation on the NCS and to form ambitions for reduced greenhouse gas emissions towards 2030 and 2050.

The 2016 roadmap focused primarily on the ambitions to reduce GHG emissions, and contained an action plan with tree main points of measures to reduce GHG emissions on existing installations until 2030 [25]:

1. Power generation

- Use new gas turbines or in some cases improve older turbines to make them more efficient.
- Implement combined power plants to ensure best use of available energy. Examples used were heat recovery units and steam turbines.
- Implement more hybrid solutions such as offshore wind, engines combined with battery technology, fuel cells and wave power. Other interesting technologies mentioned are hydrogen, solar energy and biofuel.
- Electrifications of rigs and platforms like Johan Sverdrup, by connecting the installation to onshore power by use of a subsea power cable.

2. Drilling and operations

- Implement more efficient and automated drilling technology.
- Develop and implement overall energy optimization.
- Reduced flaring.
- More use of subsea solutions and implement more remote control.
- Focus on increased recovery with low emissions.
- Automated operations and use of robotics technology.

3. Logistics

- Optimize the use of support vessels and coordinate operations, maintenance and logistics.
- Increased focus on support vessels. Better monitoring of greenhouse gas emissions.
- Implement battery/hybrid technology onboard vessels and increase utilization of electric vessels.

For new developments planned to produce until 2050, the focus areas were:

- Focus on reduced energy consumptions throughout all phases of a field's life.
- Always using BAT for implementation of low emission power solutions.
- New technologies such as offshore hydrogen production.

The overall goal for the future of the Norwegian petroleum industry mentioned in the report are development of CCS. The goal includes developing new methods for CCS, more use of CO_2 injection to increase oil production and use empty reservoirs on the NCS as storage for CO_2 from both Norwegian and international land-based industry [25].

2.7.2 Roadmap 2020 – New emission reduction technology

In February 2020, the KonKraft collaboration published a new roadmap, called Industry of Tomorrow on the Norwegian Continental Shelf [37], with further climate targets and strategies for the Norwegian petroleum industry. In this roadmap the industry stands together on climate targets of 40 % greenhouse gas emission reduction by 2030 compared with 2005, and approximately zero greenhouse gas emissions in 2050.

A 40 % reduction of GHG emissions in 2030 corresponds to an absolute reduction of 5.4 million tonnes of CO_2-equivalents compared to year 2005 [37] as seen in Figure 13. In 2018, Norway released a total of 52 million tonnes of CO_2-equivalents, and the 40 % emission cut corresponds to more than 10 % of Norway´s total emission this year [42].

Figure 13 *The Norwegian Oil and Gas industry`s target for emission reductions by 2030. Reprinted from Figure 1 in KonKraft´s Industry of Tomorrow on the Norwegian Continental Shelf [37].*

A target of absolute emission reductions is a different tone than from the main ambitions in the KonKraft´s roadmap from 2016. To achieve these necessary emissions reductions within the next ten years, a major change in the industry and through a close cooperation between the operators, suppliers, shipping companies, research institutes and the Norwegian authorities are crucial to success [37].

Another important focus area in the roadmap is how the Norwegian petroleum industry shall work as an driving force together with shipping companies and rig owners to ensure that vessels used in offshore maritime activities contributes actively to the government's goal of a 50% cut in emission by 2030 from domestic maritime transport and fishing. This work will important into the coming years, and the industries will during 2020 collaborate to establish specific targets to ensure that they will meet the emission reduction target by 2030 [37].

The roadmap mentions new and more forward-looking technologies as one of the key factors for the industry to be able to meet their targets. This includes offshore wind power, hydrogen and CCS which will aid large emissions reductions both from industry in Norway and international.

Some of the ambitions mentioned in the roadmap [37]:

- Hydrogen demonstrated as fuel in offshore shipping by 2025.
- By 2030, have at least five European industrial companies use the NCS as storage for their CO_2 emissions.
- Further development of Norway´s strong position in renewable energy from offshore wind power.

Electrification of the NCS will be a crucial measure for reducing emissions and achieving the ambitious climate targets set by the industry for 2030 and 2050. At the same time, it will be important to ensure sufficient electricity grid capacity to meet higher demands given the requirements for national security of supply [37].

Other technical and operational measures that may contribute to further emission reductions is low- and zero-emission fuels. The most relevant alternatives to existing fuels are hydrogen, ammonia and biofuels. By converting gas turbines or by using fuel cells, the industry can use hydrogen or ammonia as fuel instead of the most traditional used fuel, diesel. Hydrogen and ammonia do not emit any GHG, as long as they are produced with clean electricity or used with CCS solutions [37].

2.8 Funding for emission reducing technologies

In Norway, there are several support schemes that companies can apply for financial support for implementation of new technology that will reduce their emissions. These schemes are important contributions for Norway to become a low carbon society. Through these schemes, the Norwegian authorities actively contribute to the change in the petroleum industry to a low- and zero-emission industry.

In this assignment we will focus on two of the most important support schemes, the NO_x Fund and ENOVA. The NO_x Fund supports projects aimed at reducing NO_x emission, and ENOVA support innovation of technology that will help Norway become a low carbon society.

2.8.1 NO_x Agreement and funding

In 2007, the Norwegian authorities introduced a tax to reduce NO_x emissions. The fee was 15 NOK per kilo of NO_x emissions. The high fee allowed the Ministry of Climate and Environment and 15 business organizations (e.g. NOROG) to enter into an agreement for the periods 2008-2010 and 2011-2017 where the NO_x tax would go to a support fund that later became the NO_x-fund. The fund was founded to reduce emissions of NO_x gas by providing financial support for innovation and new greener technology. The NO_x Fund is an important contribution to meeting Norway´s obligations under the Gothenburg Protocol. May 24, 2017 new targets were set between the Ministry of Climate and Environment and the 15 business organizations for 2018-2025 of emissions per tonne of NO_x as seen in Table 6 [43, 44].

In the NO_x Agreement for the period 2018-2025, there is an obligation to reduce NO_x emissions in Norway. There are 4 main points to this agreement (NO_x Agreement 2018-2025):

1. The NO_x Fund was founded and owned by 15 non-profit organizations to reduce NO_x emissions in Norway.
2. Companies that register with the NO_x Fund pay a deposit rate to the fund instead of a tax to the Norwegian authorities.
3. The Fund pays back to the industry. Affiliated companies can apply to the NO_x Fund for financial support for NO_x reducing measures.
4. Investing in NO_x reducing measures through greener technology that will reduce NO_x emissions (and GHG emissions) in Norway.

In the renewed agreement for 2018-2025, the business organizations exempt from the fees if they stay below the emission ceiling shown in Table 6. If their total emission exceeds 3% from the emission celling of NO_x per year, it is compulsory for them to pay a fee [45].

***Table 6** Emission ceiling of NO_x according to the NO_x Agreement, Adapted from NO_x Agreement [43].*

Year	Emission ceiling of NO_x in tonnes
2018 + 2019	202 510
2020 + 2021	192 510
2022 + 2023	182 510
2024 + 2025	172 510

2.8.2 Enova

Enova is a scheme that supports the development of new technology and innovation. The purpose of this support scheme is for Norway to become a low carbon society by 2050. Enova supports projects financial to an appropriate degree. The new technology must not only be sustainable, but also economically viable [46].

Enova and the Ministry of Petroleum and Energy (OED) entered into a collaboration where they achieved three main objectives for a four-year period from 2017-2020. They will manage the funds from a common energy fund where they will prepare a letter of assignment. Enova base their goals, assignments and reporting requirements from the letter assignment. From May 1, 2018, the Climate and Environment Ministry took over the agreement from Enova [47].

Enova and OED´s three main goals (agreement between Enova and OED 2017-2020) [48]:

1. Reduce the greenhouse gas emissions that contribute to Norway´s climate commitments for 2030.
2. Increase innovation in energy- and climate technology adapted to Norway´s transition to a low carbon society.
3. Strengthen the security of supply through flexible and efficient power and energy consumption.

2.9 Lundin Energy AB Environmental Policy and Strategy

Lundin Energy AB (LUNE) is one of Europe´s leading petroleum exploration and production companies with a main focus in Norway, where their wholly owned subsidiary Lundin Energy Norway AS (LENO) is located. LENO has operation on the NCS with their petroleum fields, e.g. Edvard Grieg and Johan Sverdrup. Through LENO´s activities on the NCS, LUNE aims to operate and develop oil and gas resources efficiently and with the highest environmental standards and for a sustainable low carbon energy future [27].

2.9.1 Environmental Policy

LUNE´s environmental policy, which is published yearly in Lundin Energy AB Sustainability Report, consists of four main targets; Climate change, Biodiversity, Water- and Waste management.

Climate change

As a result of an increasing focus on climate change, climate is at the frontline of the international agenda. LUNE´s goal is to be a leader in the industry when it comes to both exploring and production of oil and gas with a minimal carbon footprint and to contribute through its high energy efficiency strategy to the transition towards a low carbon society. Other energy efficient measures LUNE is implementing are shown through their Decarbonization Strategy [27].

The most effective measures introduced in Norway to reach a low carbon society are the carbon pricing and tax [49]. Despite operating in Norway with one of the highest carbon tax effective, LUNE is able to achieve low operating costs together with strong safety and environmental performance compared to other petroleum companies in other countries [49]. Norwegian petroleum companies have managed to reduce their operating costs because of the high fees on the different taxes, ref Chapter 2.5 Environmental requirements from Norwegian authorities.

Biodiversity

LUNE is fully committed to the conservation of biological diversity, safeguarding ecosystems, species and genetic diversity [49]. LUNE actively acquire information and increase their understanding of ecosystems in areas where they operate, including the potential of the activities. When LUNE determines the location and time of the operation, they conduct various tests like environmental mapping, risk analyses and impact assessments [27].

In 2019, LUNE also contributed through funding to the start-up of SINTEF´s LowEmission Research Centre and is currently represented on the board of the Research Centre. The main task for the Centre is to do research on how we can get a low emission petroleum industry on the NCS.

The Centre will provide help to develop new technology for offshore energy systems as well as find ways to integrate use of renewable power production in order to accelerate the development and implementation of low emission technology [27]. The Research Centre is mainly focusing on power and heat generation with less emission, reduced energy demand, energy systems and energy management [50].

Water management

The main issue with water management is operational discharges to sea. Produced water, slop and bilge water have adverse effects on the aqueous environment unless properly filtered and cleaned. LUNE´s water management therefore includes a strict monitoring of the discharges to sea. Other focus areas are reinjection of produced water into wells and prioritizing the substitution of chemicals with the most adverse properties to less hazardous substitutes.

Waste management

LUNE is committed to reducing the total amount of waste both in offices and all offshore installations. The focus is on reducing non-renewable materials and disposable cutlery. In 2019, Edvard Grieg sorted 99% of the total generated waste (see Table 7) [27].

2.9.2 Decarbonization Strategy

At the end of January 2020, LUNE announced the launch of their Decarbonization Strategy, which targets carbon neutrality by 2030. Along with the Decarbonization Strategy they also proposed a name change from Lundin Petroleum AB to Lundin Energy AB and Lundin Norway AS to Lundin Energy Norway AS, respectively.

With the Decarbonization Strategy, LUNE has formalized their ongoing commitment to reducing their carbon footprint to the lowest possible levels. Carbon reduction measures to achieve this are through an effective combination of emissions reductions, energy efficiency, targeted research and development for carbon capture mechanisms. They are also investing in renewable energy projects to replace their net electricity consumptions at the Edvard Grieg and Johan Sverdrup platforms [27]. In the Decarbonization Strategy, they also revised their long-term environmental targets from 2017, shown in Table 7, as well as presented a roadmap for their target as carbon neutral by 2030.

Table 7 Long-term environmental targets and environmental performances in past years. Reprinted from Lundin Energy´s Sustainability Report for 2018 and 2019 [27] [49].

Long-term (2030) environmental targets (Revised from 2017)		2020-2022 target	2019 performance	2018 performance
An operated portfolio of carbon intensity (kg CO_2/boe)	< 2[3]	<4	5.4	6.5
Oily water discharges (ppm)	< 15	< 15	9.9	9.2
Lifetime produced water injection regularity (%)	> 95	> 95	97.4	99
Waste sorting (%)	> 95	> 95	97.5	99.3
Non-hazardous waste recovery (%)	> 75	> 80	91	86.8
Spills to sea	0	0	0	Not reported

Roadmap for carbon neutrality by 2030

LUNE´s roadmap for carbon neutrality by 2030 is:

- To offset all business and operationally related air travel emissions through natural carbon capture, effective from 2018.
- Full electrification of Johan Sverdrup Phase 1, effective from 2019.
- From 2020 limit average operated and non-operated portfolio carbon intensity to below 4kg CO_2/boe, and from 2023 limit to below 2kg CO_2/boe.
- In 2022 fully electrify Edvard Grieg and Johan Sverdrup Phase 2, to achieve carbon intensity for these assets of less than 1kg CO_2/boe.
- From 2023 replace all net electricity usage with power from shore, through investments in renewable power generation.
- Achieve carbon neutrality across LUNE´s operations as an oil and gas producer.

LUNE has signed an agreement with the Norwegian renewable company Sognekraft AS to acquire a 50 % non-operated interest in the Leikanger hydropower project, in Midwest Norway. Once it is fully operational in 2021, Leikanger will produce around 208 GWh per annum gross from a river run off hydropower generation.

3 Revised down to < 2kg CO_2/boe in 2020 from < 10kg CO_2/boe (set in 2017)

LUNE has also acquired a 100% interest (intended to be lowered down to 50%) in the Metsälamminkangas (MLK) wind farm project, in northwest Finland. Once the wind farm is fully operational in 2022, the 200 MUSD MLK project will produce around 400 GWh per annum gross from 24 onshore wind turbines. MLK and the Leikanger projects will combined replace around 60% of LENO´s net electricity usage from 2023 shown in Figure 14, with renewable energy.

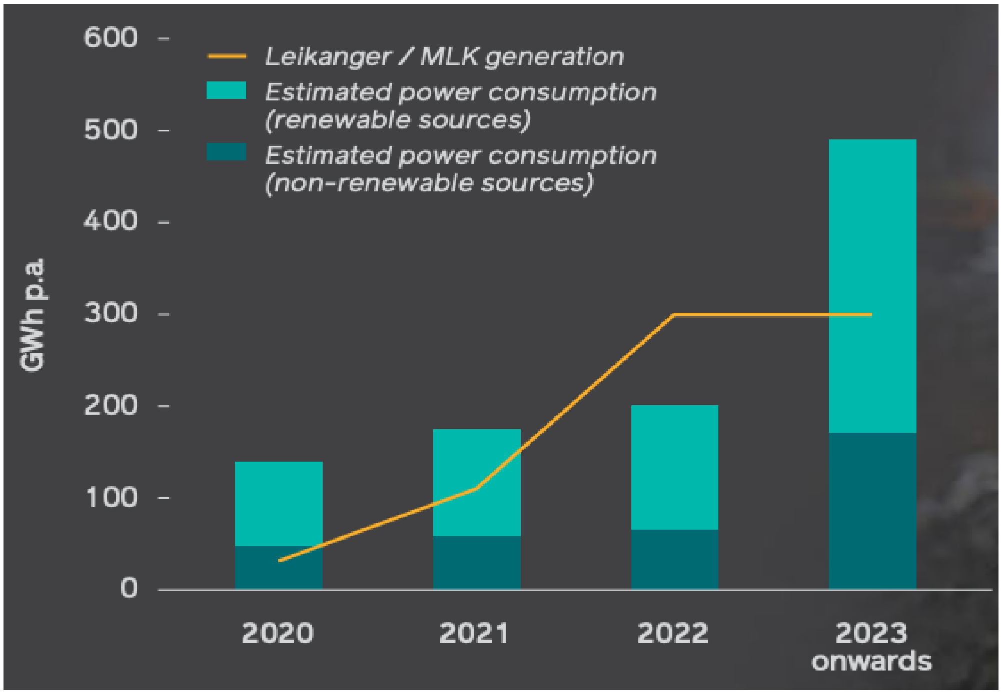

Figure 14 *Edvard Grieg & Johan Sverdrup Net Power Usage and Replacement. Reprinted from Lundin Energy Sustainability Report 2019 [27].*

2.10 Lundin Energy Norway AS Environmental Commitment and Strategy

In accordance with requirements of the Norwegian authorities, corporate policies and joint industry goals, LENO published in 2018 the following environmental commitment and strategy for all operations on the NCS [51]. The environmental commitment and strategy were revised in 2020.

2.10.1 Environmental commitment

- Minimize impact on the natural environment.
- Zero non-compliances with permit conditions.
- Deliver superior environmental performance.
- Prepare for future challenges and opportunities through industry collaborations and leadership

2.10.2 Environmental strategy

LENO environmental strategy and policy complements LUNE´s strategy with a main focus on optimization of production and continuous improvement within energy management.
The strategy is to plan and conduct all of their activities with minimal harmful exposure to the environment in accordance with ISO 14001 on environmental standards [51]. ISO 14001 is an international and recognized standard that defines the requirements for an environmental management system [52].

The focus areas in their environmental strategy are minimizing current and potential risk for environmental hazards, protect both ecosystems and genetic diversity, promote energy efficiency, reduce their carbon footprint and emissions of greenhouse gases, less use of disposal items and focus on water management [51]. Another main focus area in their environmental strategy is research, development and innovation on new emission reducing solutions and techniques.

2.10.3 Lundin Energy Norway AS´s emissions

LENO´s total emissions are divided into emissions from contracted supply vessels, exploration activities from mobile drilling units and emissions from fixed installations. They annually publish reports from each of these. The reports cover emission to air, consumption and release of chemicals at sea, discharges of oil-containing water, waste management and any accidental discharges [53]. LENO are not obliged to report to the authorities on discharges from contracted supply vessels and emission from these are therefore not included in the annually reports.

From late 2020, the semi-submersible drilling rig West Bollsta will be on contract with LENO.

The Edvard Grieg platform

The Edvard Grieg platform started production in late November 2015. Best available technologies were used when choosing technical solutions for the platform such as low-NO_x turbines, heat recovery and reinjection of produced water. In 2018, LENO also implemented an online energy monitoring system to reduce emissions [53].

The sources of emissions to air from the combustion processes on the Edvard Grieg platform during the latest reporting period, 2019, includes [53]:

- Two turbines
- Flare
- Diesel engines

In 2018, together with their license partners (OMV Norge AS and Wintershall Dea Norge AS) LENO approved a technical solution and corresponding costs associated with a full electrification of the Edvard Grieg platform.

West Bollsta

The Bollsta Dolphin rig was originally designed and constructed for Dolphin Drilling, a wholly owned subsidiary of Fred. Olsen Energy [54], at the Hyundai Heavy Industries CO Ltd (HHI) yard in South Korea [55]. Due to delays in the delivery date, Dolphin Drilling cancelled the contract in 2015 [56]. In 2017, Northern Ocean purchased the rig from HHI, and changed the rig's name to West Bollsta. Seadrill Norway Operations Ltd (hereafter called Seadrill) is the rig manager on West Bollsta and has a drilling contract with Lundin Energy Norway AS [57].

Today West Bollsta is considered to be the world´s largest semi-submersible drilling rig and amongst one of the worlds most sophisticated drilling rigs [58]. West Bollsta is a harsh environment rig and approved for ultradeep water drilling on DP (drilling at more than 3000 meters of water depth). To withstand harsh and cold environment, the rig is winterized with heated decks and partially built-in drilling tower, e.g. for year-round drilling in the Barents Sea [59].

West Bollsta is also a dual/twin-derrick rig, with an Auxiliary-derrick (AUX-derrick) in addition to the main derrick. This configuration allows West Bollsta to operate more efficiently where the AUX-derrick can ready casings, while the main derrick is operating in the mouse-hole, and the switch to case-driving is quicker [60].

West Bollsta was awarded the contract based on tender evaluation concluding the rig to provide overall best value to LENO, which was a combination of technical, HSEQ and commercial aspects. On the technical and HSEQ side, the rig scored very high because it is an efficient rig with a lot of high-technology equipment and solutions, also within the environmental area, and it is certified for drilling in the Barents Sea [33]. LENO aims to operate with the highest environmental standards and therefore their rig, West Bollsta, will become the first rig in Norway with a Selective Catalytic Reduction (SCR) system. West Bollsta will be used to drill ten wells in the Solveig field, Rolvsnes field and wells in the Barents Sea [27].

From our own citations gathered at interview with Nils Skuncke, Drilling engineer in LENO [60], West Bollsta can have a 10-15% reduction in operational time compared to a normal single-derrick rig like Leiv Eiriksson, formerly used by LENO. From a fully configurated dual/twin-derrick rig, like the ones Odfjell has, the efficiency bonus would double compare to a single-derrick rig, 15% additional to West Bollsta. The catch is diesel consumption, where a conventional drilling unit would consume around 35 m^3 diesel/day and West Bollsta is estimated to consume 50 m^3 diesel/day.

West Bollsta has an energy monitoring system in that is set up in collaboration with Kongsberg. It is a secure system where it monitors all activities and control how the rig is operated. A monitoring system ensures that the rig is in optimal operation and to have a high degree of redundancy. The number of operational hours and maintenance time can be cut down which results savings of the amount fuel used [61].

3. Method

The collection of data in this thesis has been conducted through studying literature and interviews through visits at Lundin Energy Norway AS and the West Bollsta rig. The basis data is a result of the following most important sources:

- Interviews and document gathering through a visit to Lundin Energy Norway AS office at Lysaker (January 30-31, 2020)
- Interview with Benedicte Solaas, Advisor to the CEO in NOROG at the time (January 30th, 2020)
- Interviews and documentation through a visit to West Bollsta stationed at Hanøytangen (3-6 March 2020)
- Annual reports from Lundin's website, lundin-energy.com
- Other reports from the industry as well as national and international standards
- Business sensitive data and documents

In interviews, documents and references to literature correlated to the thesis surfaced, with the purpose of gaining more in-depth knowledge. Furthermore, annual reports from the company as well as business sensitive data that will not be added as sources, only approved information from our supervisors has been added. The key contributors to quotations and other documents as well as their position within their respected companies are listed below:

Name	Company	Title within company
Axel Kelley	Lundin Energy Norway AS	Environmental Manager
Astrid Pedersen	Lundin Energy Norway AS	Environmental Advisor
Tone Rølland	Lundin Energy Norway AS	Contracts Manager for Supply Chain team, Drilling & Well and Exploration
Paul Lembourn	Lundin Energy Norway AS	Drilling Superintendent - Drilling Operations
Stig Pettersen	Lundin Energy Norway AS	Principal Engineer
Guro Tveit	Lundin Energy Norway AS	Environmental Advisor
Nils Skuncke	Lundin Energy Norway AS	Drilling Engineer
Morten Grini	Lundin Energy Norway AS	Drilling & Well Director
Arve Kallum	Lundin Energy Norway AS	Senior Rig Engineer
Sigmund Hertzberg	Lundin Energy Norway AS	Senior Marine Supervisor
Christer Savio	Lundin Energy Norway AS	Senior Logistics Advisor
Arne Fjeldsaa	Lundin Energy Norway AS	Senior Drilling Supervisor
Atle Mikkelsen	Lundin Energy Norway AS	Drilling Supervisor
Geir Håkon Gotteberg	VesselAdmin AS	CEO

Robert Bakker	Seadrill Norway Operations Ltd.	Technical Leader, West Bollsta
Petter Synnes	Seadrill Norway Operations Ltd.	Technical Section Leader, West Bollsta
Jan Oscar Wiklund	Seadrill Norway Operations Ltd.	Offshore Installation Manager, West Bollsta
Jøran Høgseth	Seadrill Norway Operations Ltd.	Senior Electrician, West Bollsta
Control room operator	Seadrill Norway Operations Ltd.	West Bollsta
Machine room operators	Seadrill Norway Operations Ltd.	West Bollsta
Drill operators	Seadrill Norway Operations Ltd.	West Bollsta
Jan Kjetil Gjerde	Seadrill Europe Management AS	Manager Safety
Benedicte Solaas	NOROG	At the time, advisor to the CEO of NOROG

Estimates and quotations from expert individuals have been gathered in the interviews, written consecutively. The most depending estimates or quotations has been investigated through having several interview subjects validating the estimate. These estimates are assumptions based on expertise from the industry. Some of the more used assumptions is listed below:

- Diesel consumption of 50 m_3 daily with CBT-technology, compared to without
- Diesel consumption of 35 m_3 daily on conventional drilling rig, basis Leiv Eiriksson
- 10-15% time reduction per activity on West Bollsta compared to a standard single derrick rig, we chose 12.5%

4. Results

The following results are adaptations and illustrations of data collected. Quantification of rig and operational performance based on interviews will always be associated with a larger uncertainty than technical or analytical results. Therefore, the future calculations based on quotes are rounded off to quantify the uncertainty.

We will illustrate how LENO's environmental strategies and climate goals affected the conclusion to hire West Bollsta. With operation of West Bollsta, the implemented emission reducing technologies onboard and their effect will be both illustrated and calculated. Furthermore, the emission contributions on the Edvard Grieg platform and the effect the electrification will have to reduce these emissions will be illustrated. At the end, calculations of cost savings from various taxes/regulations using the two systems on West Bollsta, CBT and $NoNO_x$.

4.1 Measures in accordance with LENO´s environmental policy

In accordance with their environmental policy, LENO had through 2019 a focus on identifying measures to reduce emission from their entire value chain. Therefore, LENO has implemented a number of measures to limit the hazardousness atmospheric emissions, ensure biodiversity and the marine environment [27].

By implementing an energy management system at the Edvard Grieg platform, LENO has gained an overview of the energy consumption and through optimization of the platforms operations been able to cut the energy consumption, thus reducing emissions. LENO work actively to reduce their own emissions and to influence their entire value chain to implement low-emission technology. This is achieved through both incentives in contracts, environmental budgets and involvement in research on low-emission technology.

According to their focus areas on biodiversity and climate, LENO works continuously to avoid any potential damage to the marine environment. This entails extensive environmental assessments as well as risk analyses for new projects, strict water management and waste management.

4.1.1 Measures to reduce energy consumption and emission of GHGs

In 2018, LENO´s operation team developed an online energy monitoring system which displays real-time energy consumption at the Edvard Grieg platform. This system interfaces energy measurement sensors and analytical tools to understand the energy management and potential for process optimization. The system is used to monitor energy performance of individual process equipment, as well as the entire platform [27].

With constant supervision they can see components/machine parts that does not operate to standards. These numbers come out in percentage of efficiency, and they separate between two types of losses; design losses and operation losses [62].

The design loss is on the discrepancies involving the design and fit of the machine part, this loss is only fixable by the part with a newer or a better fitted one. The operational loss is on how the machine part is driven, if the valve is properly opened, or the turbine is driven under ideal conditions, etc. The operational loss can then be cut by opening the valve to transport more fluids or heating the temperature in the turbine for higher pressure through the system [62].

By implementing this energy monitoring system, LENO will after their plans lower the operational losses on components, example a specific pump, from 25% to around 15%. After the next planned phase of implementation of the system (sometime in 2020), the system will also be able to monitor and compare emissions during start-up of production after a shutdown. When this is implemented, procedures can be optimized with regards to energy efficiency and emissions [63]. Continuously monitoring of all energy consumers on the platform are also used to optimize maintenance, and thus saving operating hours. As of today, LENO has lowered their operational energy loss with over 5 %, which corresponding to e.g. around 5 140 tonnes CO_2 equivalents/year or emissions from over 11 000 airplane passengers Oslo-New York every year and a 10 MNOK saving every year [62].

In order to further reduce their carbon footprint and emissions from GHG, environmental budgets and emission reduction targets will be established for all new projects including offshore drilling activity. Within their value chain, other incentives are being evaluated in relation to construction sites, factories, logistic supplies, etc. In 2019, they developed increased requirements for their contracted supply vessels in regard to emissions to air [64]. This includes a requirement of SCR technology for reduction of NO_x emission and use of economic speed. The supply vessel itself has to be registered in Norway [33].

To ensure new technology development and innovation, LENO contribute heavily in research on how to further reduce emissions. LENO spend 30% of the annual total budget for research and development on environmental research, specifically within development of new low emission solutions. Research on sustainable transformation of the whole petroleum industry to a low carbon society is a major focus for LENO in the years to come [65].

LENO Energy has also decided to offset their annual business and operationally related air travel emissions through natural carbon capture. The company initiated this effort through a reforestation project in Spain with the Land Life Company. The project entails planting over 26 000 trees on 24 hectares of degraded land offsetting their combined 2018 and 2019 travel emissions. They also have an aim to reduce business and operationally related air travel in the future [27].

4.1.2 Ensure biological diversity in operated areas

LENO has several environmental management processes, which contains specifications for when and how they can conduct environmental assessments to operate within their exploration- and production licences. Areas that is related to exploration activities are assessed through risk and impact analyses, with a particular attention to areas in near sensitive coastal habitats, fish pawning, seabird nesting or feeding sites, fishing areas and coral reefs. Typical risks that are emphasized include e.g. potential harm to the ocean and its biological life due to an oil spill [27].

Due to environmental assessments such as seabed mapping and risk analyses, it was decided that several planned wells in the southern Barents Sea had to be relocated from their initially planned location to avoid excessive interference with the ecosystem. Anchor lines are also positioned to minimize damage to coral and other marine life on the seabed [49].

The Barents Sea Exploration Collaboration (BaSEC) was established by Statoil (now Equinor), Eni Norge, Engie (GDF Suez, OMV and LENO in April 2015. One focus area of this collaboration has been to initiate an agreement on a joint operator approach of performing environmental risk assessments and establish an oil spill response for operations in the Barents Sea [66]. Another main focus area of the collaboration has been to identify and share valuable insights regarding biological diversity in the Barents Sea and important measures to preserve it [27].

This has resulted in an extensive mapping of fish and bird species in the area as well as an increased understanding of the seasonal dynamics and ecological significance of the polar fronts [27].

4.1.3 Protect the marine environment through Water- and Waste-management

Their water management includes a strict monitoring of the discharges to sea. The main issue with water management is operational discharges to sea. Produced water, slop and bilge water have adverse effects on the aqueous environment unless properly filtered and cleaned. LENO is prioritizing the substitution of chemicals with the most adverse properties to less hazardous substitutes [27].

LENO have implemented internal water targets of monthly averages of less than 15 ppm of oil in water and more than 95% of produced water to be reinjected into their wells [27]. Norwegian regulations state that no discharges of water shall have monthly averages above 30 ppm oil in water. From Table 7 we can see that both targets were met in 2018 and 2019. In 2018 with a 9.2 ppm oil in water content and 99% of produced water reinjected, and in 2019 with a 9.9 ppm oil in water content and 97.4% of produced water reinjected.

In 2018, LENO introduced a waste reduction campaign for all fixed offshore installations. The campaign focused on reducing the use of non-renewable materials and disposable cutlery.
The campaign has since been expanded from all fixed offshore installations to also include all of their assets including the office at Lysaker [27]. As shown in Table 7, LENO has achieved their waste sorting and recovery targets, but waste reduction is still an on-going focus and other incentives and measures are being identified to reduce their total waste.

Through the focus areas, LENO actively works to avoid any potential damage to the marine environment in the oceans.

4.1.4 LENO´s contract requirements for West Bollsta

In the contract with Seadrill for the West Bollsta rig (LENO Document 000841 Appendix F [67]), LENO requires that the rig manager shall have an energy management system in place that must be approved as part of the rig acceptance test. The system must be in accordance with NS-EN ISO 50001:2011, ref § 61. This is both a contractual requirement from LENO and a requirement from the Norwegian authorities.

Through the contract with Seadrill, LENO has a strong focus on creating accountability for the emissions from the rig. Two major points has been implemented for this work:

- Incentives for reduction of NO_x emissions.
  The contractual requirement is that if West Bollsta is IMO MARPOL Annex IV Tier III compliant (equivalent of BAT compliant), LENO will pay for all NO_x-fees and related expenses (purchase of urea etc.). If on the other hand the rig does not comply to with MARPOL Tier III, Seadrill shall reimburse LENO all NO_x-fee expenses. This gives the rig manager a clear incentive to maintain the SCR system to operate within the referred Tier III NO_x emission level, and by this a significant NO_x-fee cost saving. LENO will, on the other side, achieve its objective to execute drilling activity with as low NO_x emissions as possible.

- Incentives for reduction in fuel consumption.
  The contractual requirement is that West Bollsta shall, after a short trial period, integrate the expected daily fuel cost into the daily rig rate (payment for the rig operation). Thus, the cost of diesel, normally an operator cost, is transferred to be a potential cost benefit for the rig manager. By implementing systems or equipment to reduce the rig´s fuel consumption, the rig manager keeps the whole fuel cost saving and LENO achieve its objective to execute drilling activity with as low CO_2 emissions as possible.

The contract further states that the contractor (Seadrill) shall carry out systematic environmental surveys and assessments of the rig and the equipment and chemicals onboard and identify activities and equipment that may cause operational and accidental discharges at to sea. Areas with inadequate barriers to acute discharges shall be identified and properly managed.

They also require that West Bollsta has a clear designation of hazardous and non-hazardous drainage deck areas. The rig must have sufficient capacity to handle water contaminated with oil or other chemicals for further treatment.
For water to be discharged, the rig must have an operational bilge water treatment system. Seadrill is expected to have a waste management system with a high focus on waste sorting and minimize the use of disposable items.

LENO encourages Seadrill to actively pursue solutions, techniques and technologies which, within the existing scope of work, contribute to more efficient operations and reduced emissions from their activities.

In the event of an accident involving any discharge of hydraulic fluid from the pipes by the moonpool, Seadrill has chosen to use non-hazardous hydraulic fluid in the pipes that are exposed around the moonpool to avoid any discharges of heavy chemicals into the sea. The hydraulic fluid is both more expensive and more difficult to obtain, but Seadrill has chosen to implement this cost to prevent damage on the marine environment in the event of an accident with discharges.

4.2 LENO´s historical development in emissions

The gas turbines on Edvard Grieg are the platforms primary source for power generation. Due to stabilization of operation and high uptime on the platform, the yearly diesel consumption has since 2017 been reduced from around 5 400 tonnes/year to under 2 000 tonnes/year. This corresponds to a 60% reduction of the total yearly diesel consumption on the platform. They also managed to reduce the amount of flaring, which was reduced from 10.0 MSm_3 in 2018 to 8.1 MSm_3 in 2019 [53].

The sources of annual emission to air from the exploration activities at LENO depend on which drilling rig/rigs are hired for the drilling operations, and how many wells are planned. Different rigs have different emission factors as well as different equipment. Some leased rigs have boilers while others have electrically generated heat.

Historical development in emission of CO_2 and NO_x from the combustion processes on LENO´s exploration activities and on the Edvard Grieg platform are shown in Figure 15 and Figure 16.

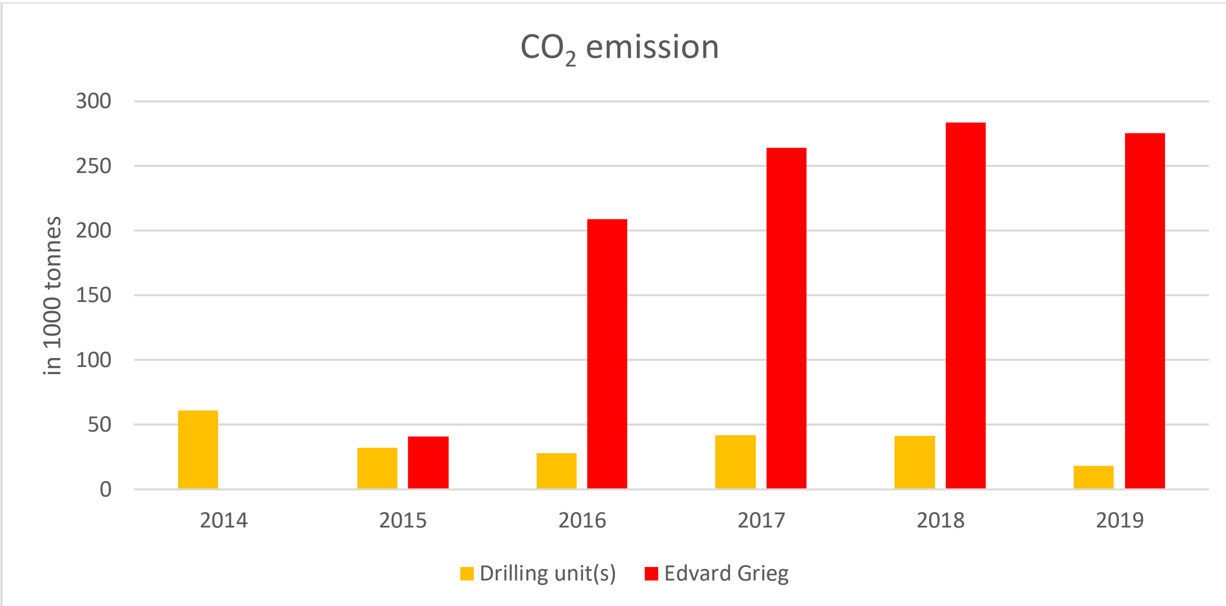

Figure 15 *Historical development in emissions of CO_2 from diesel consumption on LENO´s mobile drilling rigs and the Edvard Grieg field. Adapted from LENO´s Annual Report 2014-2019 on emissions from exploration activities [68], and from figure 7-3 in LENO´s Annual Report 2019 for Edvard Grieg [53].*

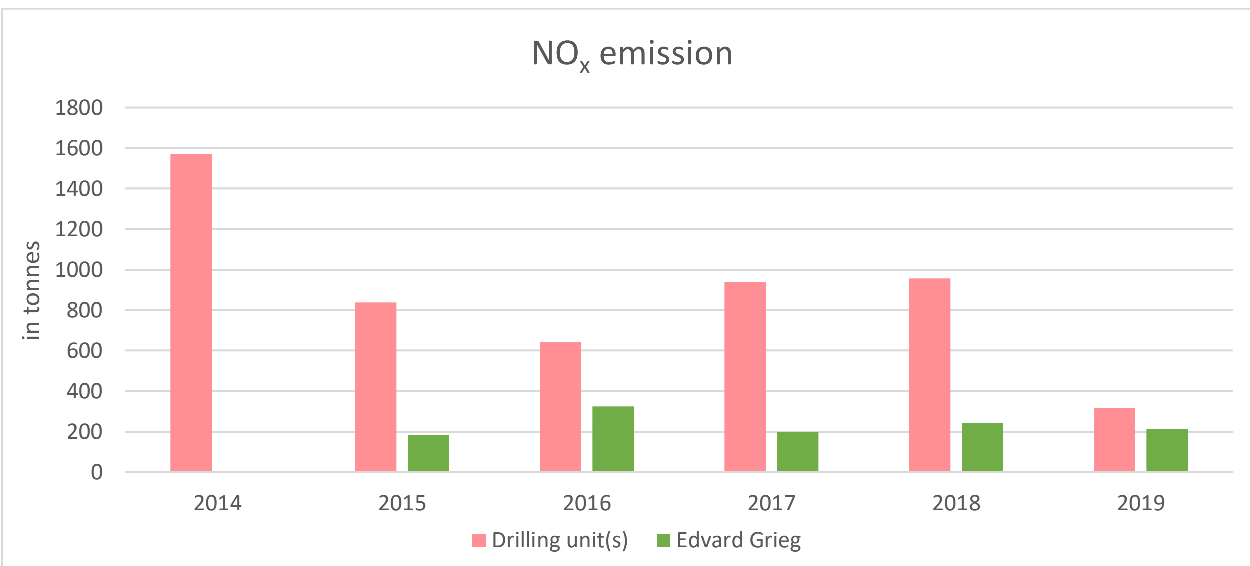

Figure 16 *Historical development in emissions of NO_x from diesel consumption on LENO´s mobile drilling rigs and the Edvard Grieg field. Adapted from LENO´s Annual Report 2014-2019 on emissions from exploration activities [68], and from figure 7-4 in LENO´s Annual Report 2019 for Edvard Grieg [53].*

The historical emissions from LENO´s drilling activities the last six years come from leased drilling rigs that did not have emission-reducing technology. Emissions in 2014 and large parts of 2015 come from drilling activities including both exploration and production drilling on the Edvard Grieg field. Production from the platform started in late 2015.

4.3 Forecast for future CO_2 and NO_x emission from the Edvard Grieg field

In our forecast for future emissions, we have used data from LENO´s annual report for Edvard Grieg as well as handout documents from LENO´s with LENO´s own forecast for future total CO_2 and NO_x emissions from Edvard Grieg for 2020-2030.

From Q4 in 2022 Edvard Grieg will be fully electrified, and there will no longer be any emissions from the gas turbines, as shown in Figure 17 and Figure 18. There will still be some emission from the diesel engines and from flaring as this is a safety mechanism. Flaring is used today to combust discharged gas during a pressure build up during the production or pressure relief during a production start-up and shut down of the platform.

The bars in the darker colours show the historical emission of CO_2 and NO_x, and the bars in the lighter colours illustrate our estimates for future emissions by source.

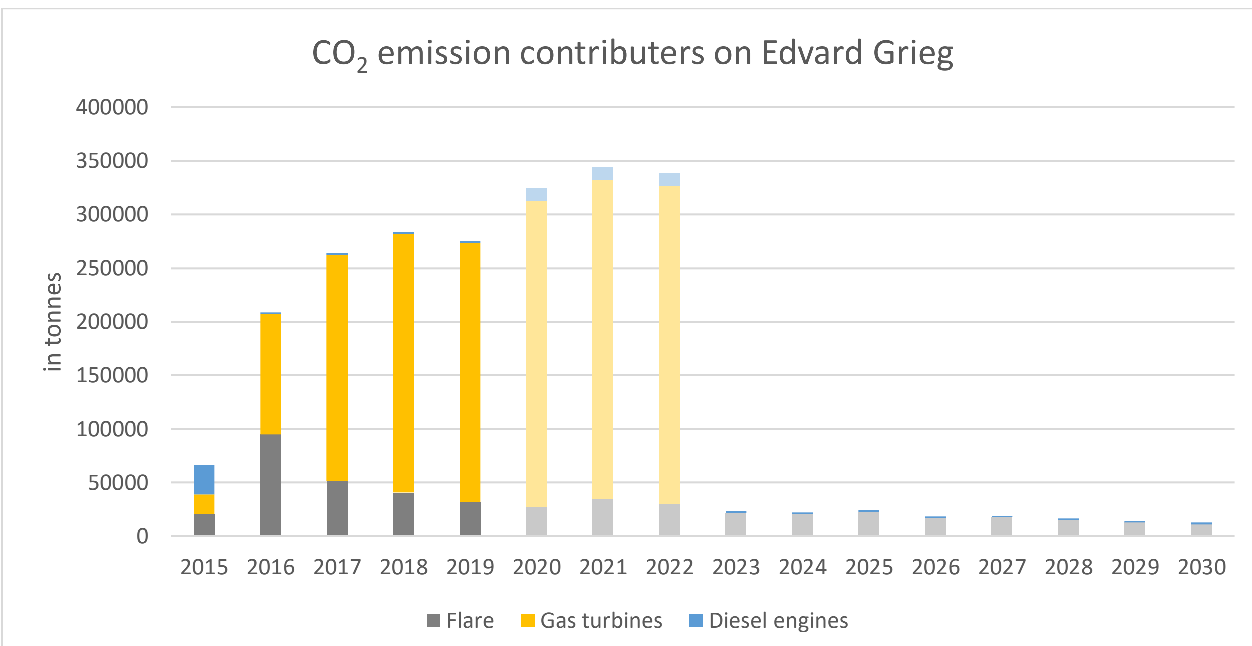

Figure 17 *Previous and future estimates of CO_2 emission by source at the Edvard Grieg field. Adapted from LENO´s Annual Report 2014-2019 for Edvard Grieg [69] and handout documentation with LENO´s own forecast for CO_2 emission [70].*

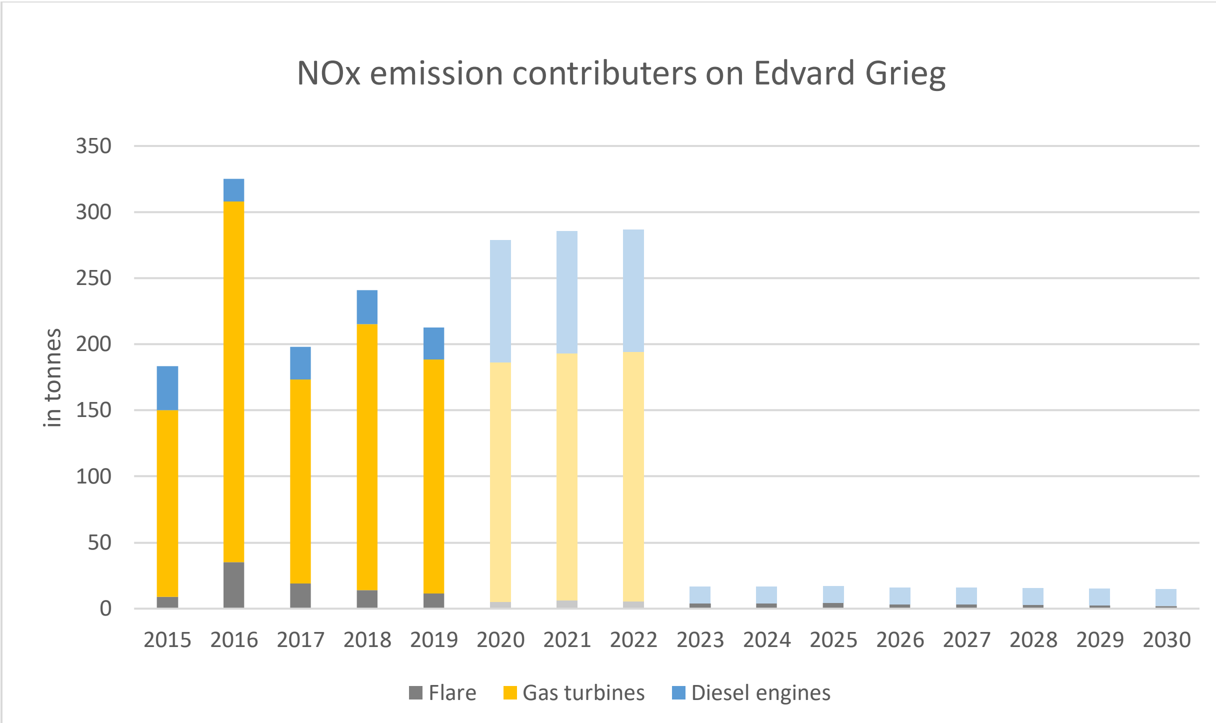

Figure 18 *Previous and future estimates of NO_x emission by source at the Edvard Grieg field. Adapted from LENO´s Annual Report 2014-2019 for Edvard Grieg [69] and handout documentation with LENO´s own forecast for NO_x emission [70]*

4.4 West Bollsta, emission and technology implementation

West Bollsta has through its construction and "re-building" in Korea implemented various technologies to reduce emissions and improve efficiency while operating the rig, compensating for diesel consumption and CO_2 emissions from this size of rig. The CBT and SCR technologies has been proved through tests to reduce emissions. West Bollsta also has an Auxiliary-derrick (AUX-derrick), which makes the rig being able to clarify and drive casing while drilling, resulting in an estimated time saving of 10-15% compared with use of a single derrick rig like that of Leiv Eriksson.

4.4.1 CBT system configuration on West Bollsta

From a normal open-bus tie configuration with thrusters in the dynamic positioning system (DPS), the tear on engines and fuel consumption has been "unnecessarily high" to maintain the obligations for redundancy. In cooperation with ABB and Siemens, Seadrill, who operates the rig through Northern Ocean, has implemented a Closed-Bus Tie system (CBT) so that the rig can position dynamically with fewer engines running on higher loads. West Bollsta is configured with four switchboards (SWB), connected with two "of both/sets of" generators and thrusters (ER).

This CBT system functions as a ring where the switchboards are connected, distributing the load equally (droop/isochronous – mode). Master- and Slave-ties between SWB's make it possible to operate the DPS in multiple configurations. This CBT-system will comply the ramifications of the DNV-GL DYNPOS-AUTRO, DP-3 classifications from IMO, safety regulations [39] [71].

The engine load and specifications can both be operated from the bridge and a separate control-room, but the system is automatic where new generators will start when the load percentage exceed a specified amount. From engine performance data in Figure 19 comparing engine load and fuel oil consumption, to save fuel the engine must be run as close to 100% as possible, but the load on the engine will result in more frequent maintenance. Satisfying both demands as well as possible, Seadrill has set a target towards 70-80% engine load, but this cannot be certain until the rig is in operation, before the next generator is set to standby start [39].

Fuel consumption and monitoring

Engine Performance Data

		Rated Power : 510 kW/cyl. at 720 rpm					
Performance Data - 750 rpm		**Engine Load (%)**					
		110	**100**	90	75	50	25
FUEL OIL CONSUMPTION 3)							
Specific Fuel Oil Consumption	g/kWh	186.7	**183.6**	183.8	185.8	195.6	225.4

3) These values are based on the 12H32/40V.
These values can be slightly different between cylinder numbers due to the charge air cooler specification

Figure 19 *Engine performance data on West Bollsta.*
Reprinted from Seadrill – Environment Management – West Bollsta [71].

In Figure 20 a failure has occurred in SWB B, and the Master- and Slave- ties are disconnected/opened towards both A and C to isolate the problem and maintenance can commence quickly. The (n-1)-principle operates as a safety stating that in case of a hidden failure, the redundancy must be met by assuming the hidden failure to be imminent and the SWB to be "breached". When failure occurs between generators and thrusters, the set that is connected to the SWB is considered unreliable. Furthermore, two generators are put in standby start, and all the other thrusters are operating.

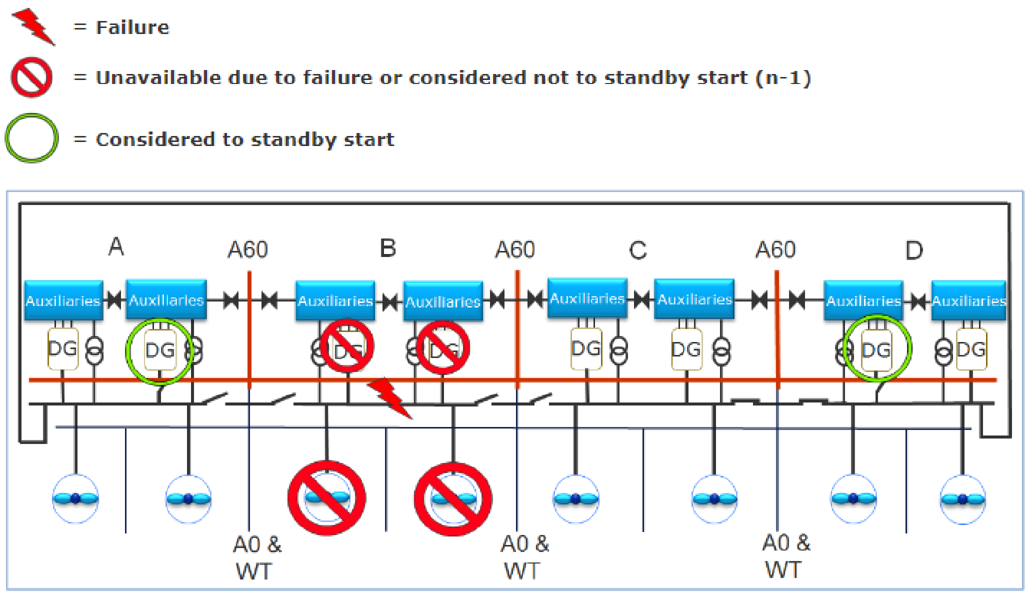

Figure 20 *CBT-system with failure on SWB B, dismantled for maintenance.*
Reprinted from: Offshore Technical Guidance: DP-classed vessels with closed bus-tie(s) [39].

Figure 21 shows theoretical results collected from Seadrill for West Bollsta that shows a massive reduction in running hours of diesel engines, further improving reduction in emissions of both CO_2 and NO_x when operating with two engines running CBT, rather than four engines/generators in open split. Theoretical results for West Bollsta with the CBT-system can reduce 11% CO_2 emissions annually, this is a result of running the diesel engines 16,500 less hours, optimizing the engine load and tie-connection between switchboards. Seadrill has estimated that West Bollsta will have a larger diesel consumption than LENO has, therefore, the reduction of 8 300 tonnes CO_2 will not comply with our results.

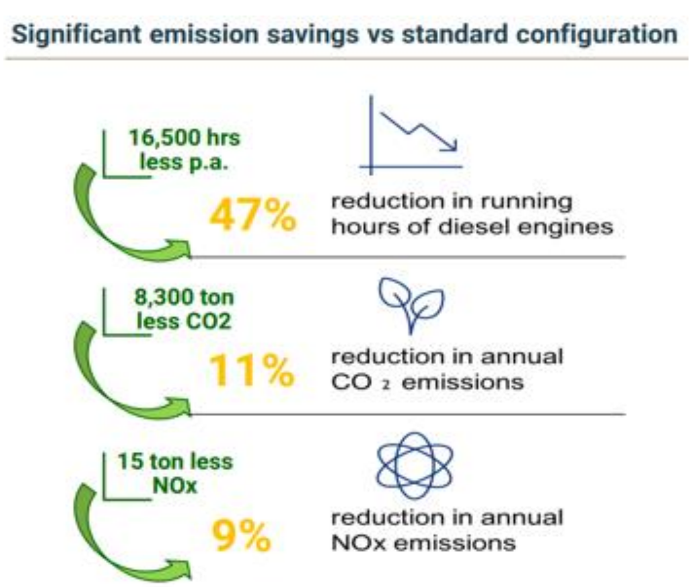

Figure *21 Hand out documentation given from Petter Synnes. Technical Section Leader on West Bollsta.*

4.4.2 Hyundai's NoNO$_x$/SCR system

West Bollsta, will become the first rig to reach Tier III goals utilizing Hyundai's NoNO$_x$ SCR system, shown in Figure 22. Seadrill is contractually obliged to meet the limitations regarding Tier III and is expected by LENO to pay the NO$_x$-fee/tax if exceeded [24].

Hyundai's NoNO$_x$ SCR system consists of seven parts of machinery that cleans the gas before it is emitted through the exhaust. Gas flow limitations is set to a max irregularity of exhaust gas flow velocity at the catalyst to prevent damage and ensure time for reaction.

The first part of the system is the "urea supply unit" supplying urea to the "dosing unit" sending the proper amount of urea solution through to the "mixing unit" in the "SCR Chamber" where water and urea will react to form ammonia and carbon dioxide, shown in Equation 7. Within the SCR chamber, two "honeycomb type PILC" catalyst layers are stationed. One problem affiliated with the use of catalyst layers is the potential creation of nitrous.

For the SCR-chamber to operate ideally, high temperatures of around 350 degrees Celsius must be upheld to decompose the urea solution into ammonia (NH_3). Then the temperature over the catalyst is crucial, because the favourable/fastest reaction (Equation 10 within Table 5) is dominant at lower temperatures. However, at too low temperatures the ammonia will pass through the system without reacting with the exhaust gas, and excess NO_2 can form in accordance with Equation 11. Excess ammonia or NO_2 in the system will cause the slowest reaction (Equation 12) to take effect which is the result of reaction 9 in Table 5 with excess NO$_x$ in the Equation, leading to nitrous emissions.

To commentate the nitrous production if excess ammonia or NO_2 is produced, the "Soot blowing unit" detects pressure irregularities. The unit then supplies compressed air to keep the pressure at a constant seven bar to catalyst surfaces. This reduces the potential of nitrous emissions and will contribute to optimization for reaction 10 within Table 5.

The last reaction (8 in Table 5) will become operative through different sets of gas flow, pressure and temperature, but is not a contributor towards any nitrous or ammonia emission, but not favourable because of slower reaction time.

The final part of the system is the "control unit", where you can monitor the process, with a fully automatic system. This closed loop urea dosing control system, makes the system easy to operate, but will take up storage and weigh heavy on the rig.

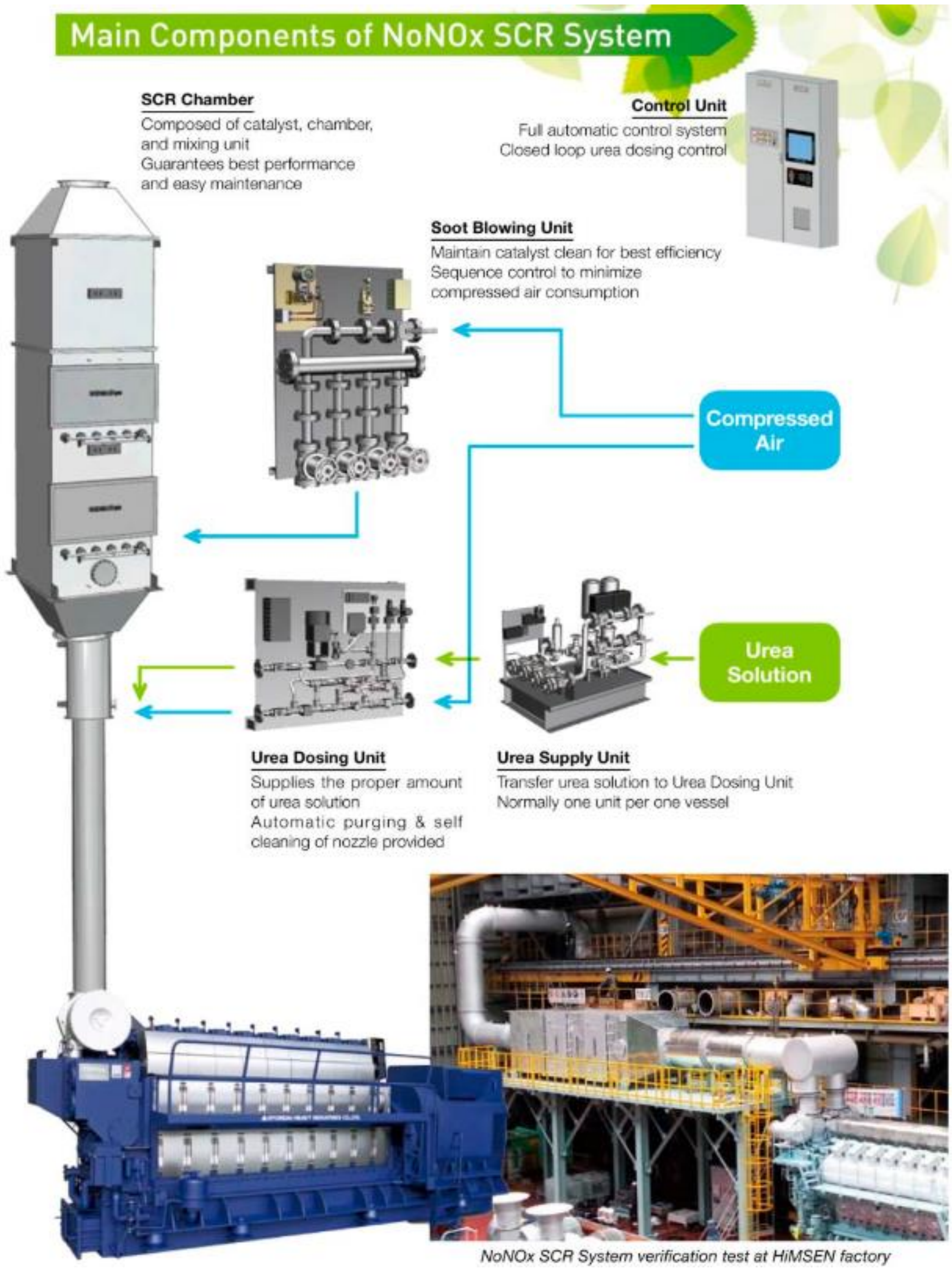

Figure 22 *Main components of Hyundai's No-NO$_x$ SCR system. Reprinted from pdf.directindustryn.com [24].*

Test results done with the No-NO_x system in 2013, when the rig was named Bollsta Dolphin, documented a result of 67-77% reduction effect compared to Tier II. This test was done simply to test if the system was working properly, and further improvements is possible through optimization of variables in the process [72].

4.4.3 Forecast for future CO_2 emissions from West Bollsta

With the CBT system, LENO have estimated 50 m^3 diesel/day based on figures from similar rig. It is not yet known how big the daily diesel consumption on West Bollsta will be, and therefore the actual daily diesel consumption is not certain until West Bollsta start operation and the operation is optimized. We estimate that West Bollsta will drill year-round.

In our forecast for future CO_2 emissions from LENO´s drilling rigs, we have used the estimated daily diesel consumption, the Norwegian Environment Agency´s national standard for diesel density [73] as well as NOROG's recommended CO_2 emission factor as a basis [13]. The Environment Agency´s national standard for diesel density is 0.855 tonnes of oil/m^3 and NOROG´s CO_2 emission factor is: 3.17 (tonnes CO_2/tonnes of oil).

In order to estimate a daily emission of CO_2, we have multiplied the daily diesel consumption with the diesel density and the CO_2 emission factor. Which gives:

$$50\ m^3/\text{day} * 0.855\ \text{tonnes of oil}/m^3 * 3.17\ \text{tonnes } CO_2/\text{tonnes of oil} \approx 136\ \text{tonnes } CO_2/\text{day}$$

Furthermore, we estimate that West Bollsta or a similar rig will drill year-round. By multiplying the daily emission of $CO_2$with 365 days we get an estimate of the annual CO_2 emissions in tonnes.

$$136\ \text{tonnes } CO_2/\text{day} * 365\ \text{days/year} \approx 49\ 500\ \text{tonnes } CO_2/\text{year}$$

Without the CBT-system the estimated daily diesel consumption would increase by 11%, resulting in 55.5 m^3/day. The annual emission of CO_2 without the CBT system would then become:

$$55.5\ m^3/\text{day} * 0.855\ \text{tonnes of oil}/m^3 * 3.17\ \text{tonnes } CO_2/\text{tonnes of oil} * 365\ \text{days/year}$$
$$\approx 54\ 900\ \text{tonnes } CO_2/\text{year}$$

Figure 23 shows our forecast of LENO´s future CO_2 emissions by using West Bollsta or a similar rig (shown with the darker yellow bars) as well as the effect the CBT system has on West Bollsta´s CO_2 emissions (shown with the lighter yellow bars).

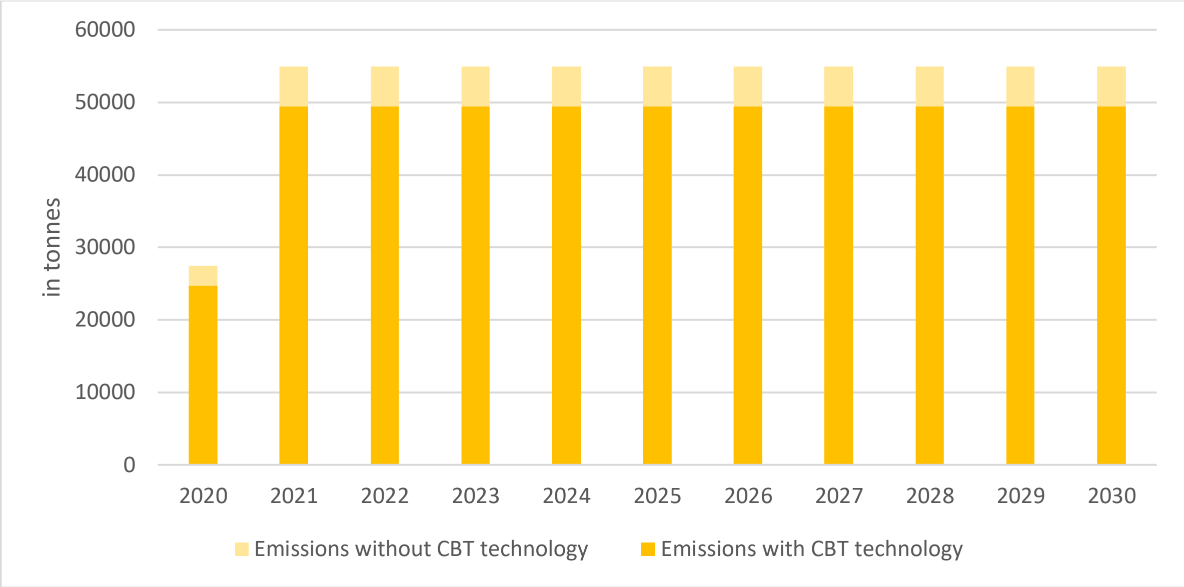

Figure 23 *Forecast of CO_2 emission from West Bollsta or a similar rig in the next ten years.*

4.4.4 Forecast for future NO_x emissions from West Bollsta

In our forecast for future CO_2 emissions from LENO´s drilling rigs, we have used the estimated daily diesel consumption and the Environment Agency´s national standard for diesel density which is 0.855 tonnes of oil/m^3 [73]. Because West Bollsta will be a Tier III rig, ref subsection 3.1.3 Hyundai's NoNO$_x$/SCR system, we have in our estimates used a NO_x emission factor according to the Tier III requirement. The NO_x emission factor used is of 0.0105 tonnes NO_x/tonnes of oil [74].

To find the daily emission of NO_x we have multiplied the following:

$$\text{Diesel consumption/day} * \text{diesel density} * \text{Tier III } NO_x \text{ emission factor}$$

$$50\ m^3/\text{day} * 0.855 \text{ tonnes of oil}/m^3 * 0.0105 \text{ tonnes } NO_x/\text{tonnes of oil} \approx 0.450 \text{ tonnes } NO_x/\text{day}$$

To find the estimate of annual NO_x emission in tonnes, we multiply the daily estimated emission of NO_x with 365 days.

$$0.450 \text{ tonnes } NO_x\ /\text{year} * 365 \text{ days/year} \approx 164 \text{ tonnes } NO_x/\text{year}$$

In order to calculate the total yearly emission of NO_x without the CBT- or the $NoNO_x$ system we used NOROG's recommended NO_x emission factor as a basis [13], which equivalents to a Tier II compliant drilling rig. NOROG´s NO_x emission factor: 0.053 (tonnes / tonnes of oil). With NOROG´s emission factor we get:

$$55.5 \text{ m}^3\text{/day} * 0.855 \text{ tonnes of oil/m}^3 * 0.053 \text{ tonnes } NO_x\text{/tonnes of oil} * 365 \text{ days/year} \approx 920 \text{ tonnes } NO_x\text{/year}$$

Figure 24 shows our forecast of LENO´s future NO_x emission as well as the effect of the CBT- and $NoNO_x$ system has on the NO_x emission from West Bollsta (shown by the darker orange bars). By comparing West Bollsta and a theoretical rig without emission reducing technology like CBT and NoNOx systems (therefore calculated with NOROG´s standard emission factors, shown with the lighter orange bars), Figure 24 shows that the technology implemented on West Bollsta contributes with over 80% reduction in NO_x emissions annually.

The CBT system contributes with nine per cent in reduction of NO_x emission, ref Figure 21, and the $NoNO_x$ system contributes with over 70% of the total yearly reduction in NO_x emission on West Bollsta.

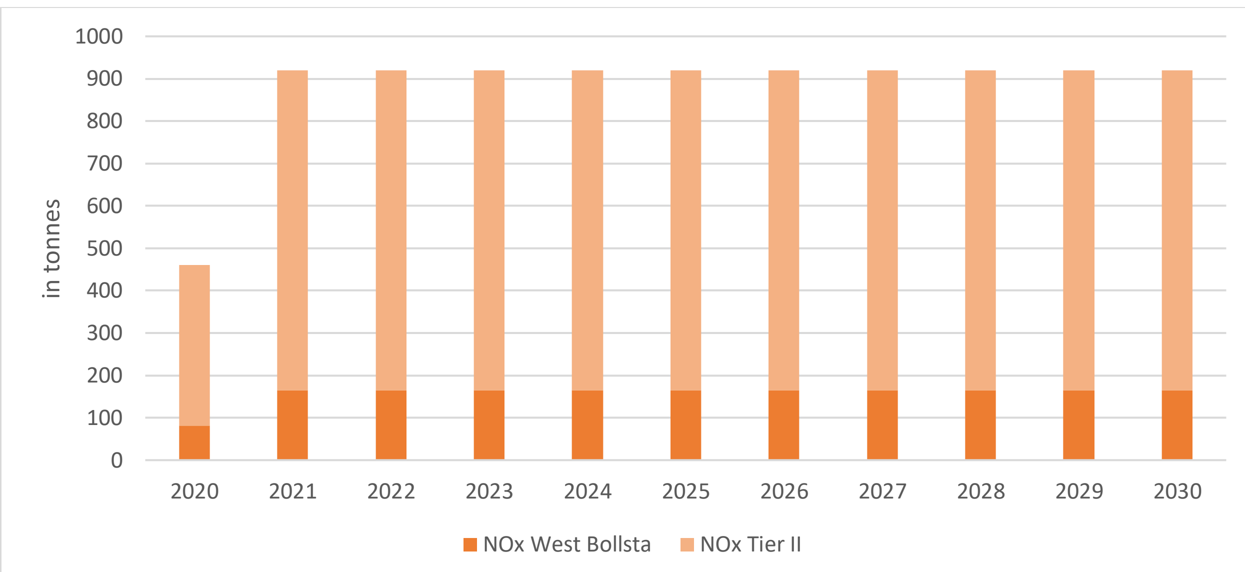

Figure 24 *Forecast for NO_x emissions from West Bollsta versus theoretical emissions from a rig without emission reducing technology like CBT and $NoNO_x$, e.g. a Tier II rig.*

4.5 Forecast for LENO´s future total emissions

Emissions from the gas turbines at Edvard Grieg will be eliminated after 2022, as a result of the electrification, but some emissions from flaring and the diesel engines will remain as shown in Figure 25 and Figure 26 show. The emissions from the drilling rigs have previously been the minor contributor, but from 2022 onwards these emissions will make up a significant portion of LENO´s total emissions.

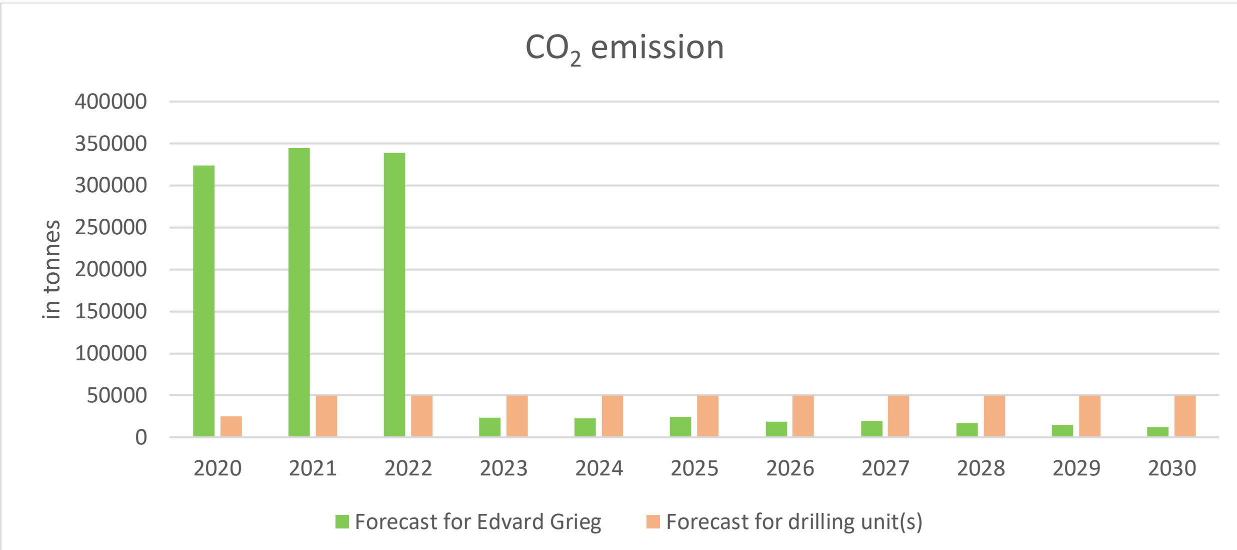

Figure 25 *Forecast of CO_2 emission both from Edvard Grieg and drilling units in contract with LENO. Data from LENO´s own forecast [70].*

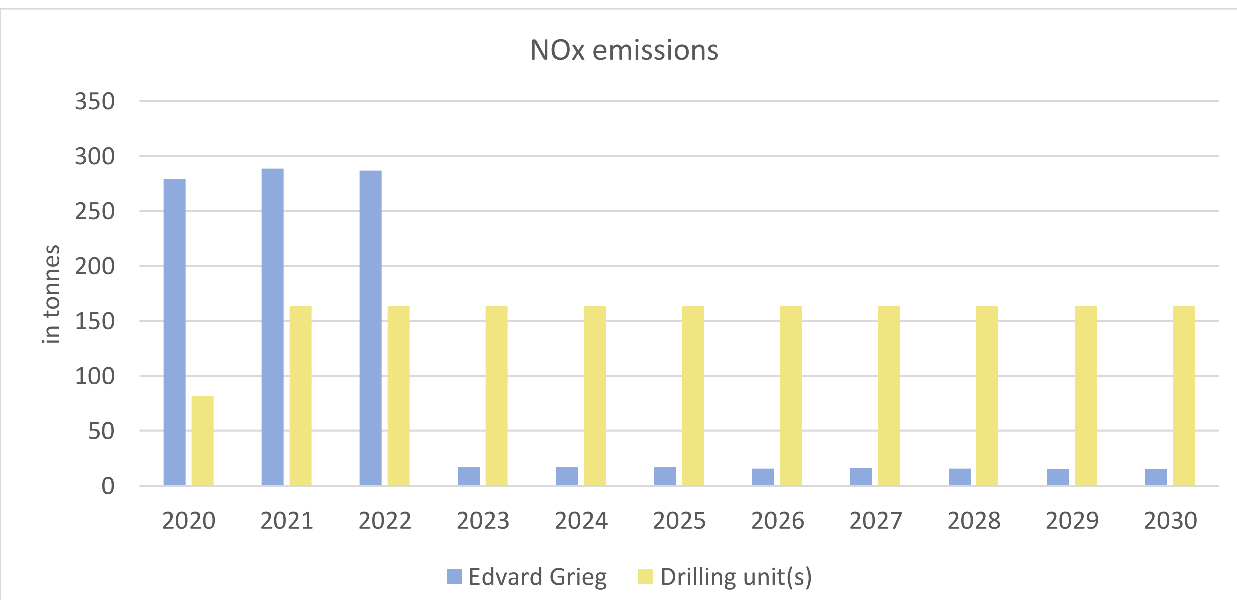

Figure 26 *Forecast of NO_x emission both from Edvard Grieg and drilling units in contract with LENO. Data from LENO´s own forecast [70].*

4.6 Cost savings with the CBT and $NoNO_x$ system

Various cost savings calculations for diesel consumption, CO_2 taxes and quotas as well as NO_x fees are shown in the subsections below.

4.6.1 Reduced diesel consumption

Direct linking with diesel consumption has multiple variables, and the estimate of 55.5 m^3 diesel/day without CBT in Figure 23 was confirmed as an expert opinion from LENO´s Drilling Superintendent, Paul Lembourn, estimating a 5-10% reduction in fuel consumption, where 11% was chosen due to notes from different mechanical meetings operating with this specific percentage reduction.

Cost savings contributed to the CBT-system, reducing diesel consumption:

(Volume with CBT– Volume without CBT) * Diesel price *1000 litre/m^3 = Future cost savings

$$(55.5\text{-}50)\ m^3/\text{day} * 4.87\ \text{NOK/litre} * 1000\ \text{litre}/m^3 \approx 26\ 800\ \text{NOK/day}$$

Yearly savings = future cost savings/day * 365 days/year *10^{-6} MNOK/NOK

$$26\ 800\ \text{NOK/day} * 365\ \text{days/year} * 10^{-6}\ \text{MNOK/NOK} \approx 9.8\ \text{MNOK/year}$$

LENO´s annual savings will be around 9.8 MNOK and the savings for a ten-year period will be around 98 MNOK.

It is also of interest to compare the rig West Bollsta to a conventional single derrick rig. It is estimated that the West Bollsta will consume 50 m^3 diesel/day, and from Nils Skuncke, drilling engineer, the rig is "presumed/estimated" to be 10-15% more time-efficient than conventional drilling rigs with single derricks.

The previous drilling rig on contract for LENO, Leiv Eiriksson, had a daily diesel consumption daily of approximately 35 m^3, while the expected time-increase using a conventional single derrick rig is according to the same source estimated to be 10-15%. For further referencing regarding single derrick conventional drilling rig, the basis is Leiv Eiriksson and its 35 m^3/day diesel consumption.

A conventional (single derrick) drilling campaign´s daily diesel consumption (adjusted with time loss per activity) is calculated to be:

$$35\ m^3/day * (100\% + 12.5\%) \approx 39.4\ m^3/day$$

Compared to West Bollsta with CBT the net added diesel consumption/day amount to additional cost of:

$$\text{Diesel consumption daily (West Bollsta – single derrick rig) * cost of diesel * 1000 litre/}m^3$$
$$= \text{Additional money spent dual/twin derrick rig}$$

$$(50\text{-}39.4)\ diesel/day * 4.87\ NOK/litre * 1000\ litre/m^3 \approx 51\ 600\ NOK/day$$

Yearly and in a 10-year period, cost savings with use of a single derrick rig in diesel cost compared to West Bollsta with CBT would then amount to 18.8 MNOK and 188 MNOK, respectively.
The diesel used is Ultra-Low Sulfur Fuel Oil, which is standard diesel throughout the North Sea. The diesel contains, as the name implies, ultra-low concentrations of Sulphur (<0.05% Sulphur) [13].

4.6.2 CO_2 tax cost

To find the future cost savings with the CBT system, the CO_2 tax from 2019 is used to obtain the most realistic figures. To find the cost savings, we have taken the difference in the volume of emissions with and without effective rig and multiplied it with the Norwegian CO_2 tax. At the time the calculations, the CO_2 tax price is 1.35 NOK/litre [70].

$$\text{(Volume with CBT effective rig – without CBT effective rig) * } CO_2 \text{ fee for 2019 *1000 litre/}m^3$$
$$= \text{Future cost savings}$$

$$(55.5\text{-}50\ m^3/day) * 1.35\ NOK/litre * 1000\ litre/m^3 \approx 7\ 400\ NOK/day$$

Furthermore, the cost-efficient capabilities of the CBT system theoretical drop of 11% tonnes CO_2-emissions annually, reduced the yearly CO_2-fee from 27.4 MNOK to 25.5 MNOK, with the forecast of a 10-year period saving LENO amounting to a total of 27 MNOK.

4.6.3 CO_2 quotas cost

All production must pay CO_2 quotas. To find the savings by having a CBT system, we look at the difference between the daily emissions of CO_2 with and without the CBT system. With this difference we find the future cost savings by multiplying it with cost of an emission allowance, ref subsection 2.5.2 Greenhouse Gas Emissions Trading Act.

$$(\text{Daily emission of } CO_2 \text{ without CBT - with CBT}) * \text{Price of emission allowance} = \text{Future cost savings}$$

$$(150\text{-}136 \text{ tonnes } CO_2/\text{day}) * 24.9 \text{ Euro/tonnes } CO_2 * 11 \text{ NOK/Euro} \approx 3\,800 \text{ NOK/day}$$

Given a conversion rate of one Euro equalling 11 NOK, the savings will be ≈ 3 800 NOK/day. This will result in an annual savings of 1.4 MNOK and is over a 10-year period estimated to be around 14 MNOK.

4.6.4 NO_x fees and urea costs

To find future cost savings for West Bollsta with the SCR system, we look at the estimated figures with and without the SCR system and the NO_x payment rate. Daily average emission of NO_x of 10-year period (2020-2030) is converted to kg in order to multiply it with the NO_x tax. The NO_x payment rate is NOK 16.5 per kg NO_x, which is the high rate that includes the petroleum activities on the NCS [75]. These payment rates apply from 2020.

$$(\text{Daily } NO_x \text{ emission without SCR – with SCR}) * NO_x \text{ tax} = \text{Future saving cost}$$

$$(2\,600 – 550) \text{ kg } NO_x/\text{day} * (16.5 \text{ NOK/kg } NO_x) \approx 34\,000 \text{ NOK/day}$$

Estimating that the NO_x-fee/tax to stays equal, the Hyundai NoNO$_x$ system will result in cost savings of approximately 12.4 MNOK annually and for a 10-year period 124 MNOK.

To find the cost of urea, it is assumed that the consumption of urea is 6 m^3/day. And from quotations of Axel Kelley and Astrid Pedersen, the price of the Urea solution will be 4 NOK/litre. Given a refund of up to 60% of the urea cost from the NOx-fund, the cost of the Urea supply will amount to the following:

Urea consumption * cost of urea * 1000 litre/m^3 = future cost

$$6 \text{ m}^3/\text{day} * 4 \text{ NOK/litre} * 1000 \text{ litre/m}^3 = 24\,000 \text{ NOK/day cost without refund}$$

Refund of 60% up to 2.5 NOK/litre:

$$6 \text{ m}^3/\text{day} * 2.5 \text{ NOK/litre} * 1000 \text{ litre/m}^3 = 15\,000 \text{ NOK/day}$$

$$24\,000 \text{ NOK/day} * (60/100) = 14\,400 \text{ NOK/day}$$

NOx-fund gives refund of 60%, up to 2.5 NOK/litre. Because the 60% cost did not override the 2.5 NOK/day mark, 14 400 NOK/day refund is the correct value.
Cost of daily Urea consumption – Refund from NOx-fund = total daily cost of Urea solution

24 000 NOK/day - 14 400 NOK/day = 9 600 NOK/day

Yearly cost of Urea will then amount to 3,5 MNOK, and in a 10-year period assuming the cost and refund will stay equal the cost will result to 35 MNOK.

4.7 Total cost savings and cost of operation

Table showing the cost savings of the technologies onboard West Bollsta, in emission-regulations and cost of diesel:

Table 8 *Cost savings of technology improvements, in a 10-year period on West Bollsta.*

Measure	West Bollsta savings with CBT and SCR (MNOK)
Diesel consumption	98
CO_2 tax	27
CO_2 quotas	14
NO_x	124
Total	263

Additional savings made from the time efficiency of West Bollsta of 12.5%, rig spread typical 6 MNOK/day for drilling units:

6 MNOK/day * 0.125 * (365 * 10) days/10-year period ≈ 2 740 MNOK

Showing the economically favourable effects of choosing West Bollsta with its time efficient capabilities and reduced emission technologies.

Cost of diesel 10-year period West Bollsta, (365 days/year*10 years/10-year period *10^{-6} MNOK/NOK) used for future (10-year conversion):

$$50\ m^3/day * 4.87\ NOK/litre * 1000\ litre/m^3 * (365\ days/year * 10\ years / 10\text{-}year\ period * 10^{-6}\ MNOK/NOK) \approx 888\ MNOK$$

CO2-tax cost 10-year period:

$$50 \text{ m}^3\text{/day} * 1.35 \text{ NOK/litre} * 1000 \text{ litre} * (10\text{-year conversion}) \approx 246 \text{ MNOK}$$

CO_2-quotas:

$$136 \text{ tonnes } CO_2\text{/day} * 24.9 \text{ Euro/tonnes } CO2 * 11 \text{ NOK/Euro} * (10\text{-year conversion}) \approx 135 \text{ MNOK}$$

NO_x-fee cost:

$$550 \text{ kg } NO_x\text{/day} * 16.5 \text{ NOK/ kg } NO_x * (10\text{-year conversion}) \approx 33 \text{ MNOK}$$

CO2 emission conventional single derrick rig, given diesel consumption of 39,4 m^3/day with standard factors from NOROG and The Environment Agency:

$$39.4 \text{ m}^3\text{/day} * 0.855 \text{ tonnes of oil/m}^3 * 3.17 \text{ tonnes } CO_2\text{/tonnes of oil} \approx 107 \text{ tonnes } CO_2\text{/day}$$

Table comparing the cost of operation of West Bollsta to that of a conventional drilling rig, like the formerly used rig by LENO, Leiv Eiriksson. The calculations done for the conventional drilling rig is therefore the same as the calculations for West Bollsta, but with a diesel consumption of 39.4 m^3/day and emission of 107 tonnes CO_2/day:

Table 9 *Cost of operation in 10-year period, comparing West Bollsta and a conventional single derrick rig.*

Measure	Environmental cost for use of West Bollsta with CBT and SCR (MNOK)	Environmental costs using a conventional drilling rig (MNOK)
Diesel	888	700
CO_2 tax	246	194
CO_2 quotas	135	107
NO_x	33	158
Urea	35	N/a
Total	1337	1159

In total, the CBT and No-NO_x system on West Bollsta will provide LENO savings of around 250 MNOK over a ten-year period, not accounting price of Urea. It is very uncertain that the price of diesel, CO_2 tax, price on Urea-solution and the NO_x tax/fee remains stable, so LENO´s accurate savings will vary if these factors change over the years.

5. Discussion

In this section, topics of what the implemented technologies with their reduced emissions and cost at West Bollsta will account for LENO in the larger picture will be discussed. What role does LENO take to contribute to reach the Paris Agreement? How will future drilling rigs cut emissions further, and how will new technologies not yet implemented but thought to become key contributors to the future of the petroleum industry develop?

5.1 Technology improvements at West Bollsta

West Bollsta has implemented technologies to reduce emissions and hopefully result in economically and environmentally favourable rig specifications. The CBT-system and the NoNO$_x$ SCR-system has been optimized, but in comparison with a conventional single derrick drilling unit, the daily diesel consumption is almost doubled. What are the favourable effects of these technologies?

5.1.1 Cutting running hours of engines with the CBT system

In the former petroleum industry, redundancy was number one priority, where generators were run on 30-40% load with full standby. The reason the DP-system was normal to run with open-ring and full standby is because of the cruciality of the system. To earn money, the system had to be in operation, hence the efficiency of the operation was run with redundancy to prevent shutdowns. From the engine performance data in Figure 19, the engine fuel-consumption and emission are favourable operating at as close to 100% as possible. With improvement in engine-technology and control systems alongside with the focus on energy efficiency, the CBT-system has now been deemed secure.

Operating at higher load percentage will however result in more frequent maintenance but at the same time cut emissions. Performing maintenance with the CBT-system can commence quickly, as the system is optimized for isolating the problem as shown in Figure 20. With Seadrill's target towards 70-80% engine load before next generator start up, maintenance is believed to minimize, while maintaining low emission factors for the engine.

The diesel consumption and cost of operating West Bollsta with or without the CBT-system (ref Figure 23) has variables that only show when the rig is taken to use, therefore the certainty of the numbers presented of an 11% reduction in diesel consumption can't be a certainty. With mechanics believing that a 11% reduction is possible, while at the same time, Paul Lembourn estimating 5-10% reduction, the ground point of mechanics was chosen. Variables like weather and drilling load will affect the usage of engines, therefore the estimate cannot be validated.

Through the CBT-system implemented on West Bollsta, the theoretical cut in running hours of diesel engines, ref 16 500 hours, will further cut diesel consumption with about 5.5 m^3 diesel/day. Implementing CBT has therefore cut diesel cost by around 27 000 NOK/day. However, use of a conventional drilling unit would result in further diesel consumption drop of 40% (35 m^3/day), but at the cost of the time consumption per activity. The difference between using a single derrick rig and West Bollsta (dual derrick rig) would therefore result in cost savings of 97 400 NOK/day.

Because of the efficiency West Bollsta will have, with the estimate of 10-15% time saving per activity, the assumption that this will directly and only effect diesel consumption for single derrick rigs is wrong, taking account for amongst other things the rig spread. Accounting for the time savings adjustment, basis in diesel consumption, the difference between a conventional single derrick rig and West Bollsta decreases to 51 600 NOK/day, with a factor of 12.5% time saving per activity operating with West Bollsta.

5.1.2 Reducing NO_x emissions through SCR and $NoNO_x$

With the big step in NO_x-emissions reduction from IMO MARPOL regarding Tier III, Hyundai's No-NO_x system and CBT technology will cause West Bollsta to emit approximately 160 tonnes NO_x per year, shown in Figure 24 With this massive reduction of over 750 tonnes NO_x/year without the $NoNO_x$ -system, this system will cause LENO to save about 12 MNOK/year in NO_x-fee payments, assuming the fee stays equal. Seadrill is not contractually obliged to reach Tier III ramifications, but to pay the whole NO_x-fee if exceeded, hence the incentives to make this system work properly "align" to both Seadrill and LENO.

Since IMO MARPOL Tier III regulations towards NO_x-emissions of a further drop towards 80% reduction with basis in Tier I, shown in Figure 7 the industry realized engine optimization would not lead to enough cuts. The solution for West Bollsta became Hyundai's $NoNO_x$ system, and from Figure 24 we see the drop-in emissions to air in comparison with not having this technology. The test results from 2013 showed a reduction of about 70% reduction compared to Tier II, and this is enough for the regulations taking effect in 2021.

Implementation of a de-NO_x system like the one on West Bollsta is not an option for every type of drilling rig. The size and weight of the system will be too high for some of the smaller rigs out there, so this is not a feasible solution for all. By building the rig with SCR technology in mind, the effects of the system will show great reduction, and because of the Tier III regulations taking effects on the ECS in 2021, we can assume this technology will become more attractive.

The cost of the $NoNO_x$ system, without accounting for cost of implementation, comes from the price of Urea, where LENO will have to pay out 9 600 NOK/day with normal drift.

Amounting to 35 MNOK in a 10-year period, the cost savings of this system has almost halved, and this with the assumption that the cost of Urea will stay equal. With the implementation of this system showing favourable effects, we can only assume other rig-owners will implement or design their soon to be built rigs with a system like this in place to reach Tier III regulations. This will most likely result in a rise in the cost of Urea solution, and further minimize the savings to be made.

With the uncertainty of future NO_x-fee payments and Urea-cost, where we can assume savings made from NO_x-emissions to rise and with the linking of Urea-price with the oil-industry/price, these costs will most likely not have the same growth as the NOx-fee [74]. However, the favourable effects of showing greatly reduced NO_x-emissions to the ever-growing environmental conscious population can exceed these payments through stakeholders, publicity and reputation.

5.2 LENO´s transition towards carbon neutrality

With companies like Equinor investing a lot of money into technology surrounding CCS, many other operators have taken their expertise to other fields so the companies can evolve together and find new or improved solutions for emission reducing technology. LENO has therefore invested heavily into the Energy Management System at Edvard Grieg, ref subsection 4.1.1 Measures to reduce energy consumption and emission of GHGs, and is providing advice to partners on how this system works and how to implement it to perfection.

By focusing on emission reduction measures through energy management, LENO managed in 2019 to achieve a carbon intensity, ref Table 7, of 5.4 kg CO_2/boe, which is lower than the NCS industry average and are approximately one fourth of the world industry average ref Figure 9.

Through the electrification of the Edvard Grieg and Johan Sverdrup fields, the goal is to achieve a total carbon intensity of less than 1 kg CO_2/boe. The power from shore project will be implemented from late 2022, upon the completion of Johan Sverdrup's Phase 2, ref *Roadmap for carbon neutrality by 2030* in subsection 2.9.2 Decarbonization Strategy.

The Edvard Grieg has been the main contributor to LENO´s historical CO_2-emissions (Figure 15), but due to the implementation of the online energy monitoring system on the Edvard Grieg platform and electrification of the whole field in 2022, ref Figure 17 and Figure 18, LENO will be able to reduce their total emissions by a large amount. As a result of the electrification of the Edvard Grieg platform alone, LENO will reduce the annual emission with over 300 000 tonnes of CO_2 emissions per year to below 30 000 [27], ref Figure 17. This is a reduction of 83% and significantly higher than the 55% cut in GHG emissions Norway and the petroleum industry (KonKraft) has committed to by the year 2030 from the Paris Agreement.

With the last emission contributors from Edvard Grieg mainly coming from the safety solution of flaring, LENO has succeeded with these cuts with respect to Edvard Grieg.

From the year when Edvard Grieg is fully electrified and onwards, comparing West Bollsta or equivalent rigs and Edvard Grieg emissions, West Bollsta will contribute to 60% of the company's total emissions. With drilling units becoming the main source of emissions, future research and development (R&D) investments into drilling units are more likely to show effect in reducing emissions. Regarding a NO_x-reduction of 85% on West Bollsta, we can in Figure 26 see that both Edvard Grieg and West Bollsta will contribute to reducing NO_x emissions, and with a total of just above 200 tonnes annually from the year 2023 and onwards. The electrification of Edvard Grieg platform and the NO_x reducing technology on West Bollsta, will cut about 1 100 tonnes of LENO´s NO_x-emissions annually.

Figure 25 and Figure 26 also illustrates that the majority of LENO´s future emissions will come from the drilling activities in the next years to come as well as remain fairly stable. Emission from the drilling activities have therefore gone from being a minor contributor to becoming the major contributor to the LENO´s total emission. Drilling activity has been the main contributor to LENO´s historical NO_x-emissions (ref Figure 16), and still is, but these emissions have now reached a milestone where they are so low, they could be compared to nmVOC emissions, showing the industry's focus towards the low-carbon/emission future. Although the total emissions from LENO will be much lower than before, several measures still need to be implemented for the company to reach their target of becoming carbon neutral by 2030.

This is why a focus on energy management and emission reducing technology on drilling rigs should be very important for LENO in order for them to achieve their goal of becoming carbon neutral by 2030. This should also be a strong focus point for the whole petroleum industry on the NCS in order for the industry to both reach KonKraft´s climate targets of 40 % greenhouse gas emission reduction by 2030 compared with 2005, and approximately zero greenhouse gas emissions in 2050, as well as reach the government's goal of a 50% cut in emission from offshore maritime activities, ref subsection 2.7.2 Roadmap 2020 – *New emission reduction technology*.

For offshore drilling activity, LENO´s contractual specifications and energy management requirements for drilling units are in continuous development to reflect the Decarbonization Strategy, to challenge the rig contractor to invest in technology and equipment as well as operational philosophy and work processes. Coupled with the corporation´s official name changes to Lundin Energy AB and Lundin Energy Norway AS, the Decarbonization Strategy proves that they are focused on operating with the highest environmental standards. The goal of becoming carbon neutral in 2030 is a strong commitment from executive management.

With the Decarbonization Strategy, ref subsection 2.9.2 Decarbonization Strategy, LENO aims to become carbon neutral 20 years before Norway aims to become a low carbon society, also aiming to become one of the first petroleum companies to achieve such targets.

Through their environmental strategy and policy, LENO has, ref Chapter 2.9 Lundin Energy AB Environmental Policy and Strategy, created ambitious roadmaps for monitoring and managing emissions to air, discharges to sea and waste handling. Through focusing on the main environmental targets, ref subsections 4.1.1, 4.1.2, 4.1.3 in Chapter 4.1 Measures in accordance with LENO´s environmental policy, they have succeeded in meeting and exceeding their targets for 2018 and 2019 earlier than planned and therefore had to revise their targets for 2020, originally sat in 2017 [27] ref Table 7.

5.3 Climate measures made by the industry

While the ongoing debate on climate change and global warming continues, the petroleum industry is in a constant change with R&D investments to further improve the transition towards a low carbon society. Technologies like SCR, CCS and CBT improve in dimension-span, optimization and capacity.

With young people like Greta Thunberg becoming the face of the climate change debate in recent years, the industry faces a well-integrated community, with non-educated people weighing in on what scientists, and climate experts, have researched and debated for years. We will not tackle the problem about this debate, but rather focus on the impact of a well-integrated system, like the one

To reach the goals set from the Paris-Agreement, the focus on emission reducing measures and reporting of such has made the NCS an even more documented and aware province for how to produce clean, low carbon emitting oil.

We can see that the emission to air is not declining, but rather increasing, therefore, companies operating on the NCS buys climate quotas trough the EU-ETS from underdeveloped countries. Increasing oil production in years to come makes it hard to cut emissions, but emission/produced oil is the key factor. Utilization of the best available technology, and better infrastructure through transport, has put oil produced on the NCS, in 2018, around 8 kg CO_2/boe well below average as seen in Figure 9.

The NO_x-gases have been somewhat of a key focus from the government by providing a fund for technologies reducing these emissions to air. From Figure 3 we can see that in the last five-year period, the NCS has cut these emissions by approximately eight thousand tonnes, which add up to a 15% reduction.

Comparing Figure 1 about CO_2-equivalents to Figure 3, on NO_x-emission, we can see that although the total emissions are projected to increase in following years, the projected NO_x-emissions are declining. From Figure 4 we can see that future nmVOC emissions are believed to remain at an equal amount, and with future cuts and optimization regarding SO_x-gas emissions as well, the NCS shows environmental consciousness. With the emission of methane directly linking with incomplete combustion, for example in flaring, the NCS proves its place even here providing lower numbers than global average, 5% on the NCS compared to 15% globally.

Technology improvements are a constant, but intentions and implementation of higher cost technologies are not a given. Companies without concern for the future environment often reject or ignore utilizing best available emission-reducing technology, and instead choosing best performance technology. The distinction will come in form of emission, and we can see from Figure 8 that provinces like Australasia, North America and Africa tend to avoid costly and complex emission reducing measures.

This is not an option for companies operating on the NCS, where the companies have a close involvement with the government, through regulations improving incentives for reducing emissions. It is not allowed to produce oil to only make money, the companies have to take the environment into account and have ambitions towards the future to reach climate goals.

In today's society, companies do not always choose to carry out only those projects that are most economically beneficial. With an ever-increasing focus on a positive presentation in the media as well as amongst shareholders, companies often undertake projects that do not have the same financial impact, but approximate positive publicity and reputation.

Especially now that renewable technology is popularized, several petroleum companies have in the latest years jumped on the trend with green footprint investments. These companies are investing millions of dollars in renewable projects both to advertise their belief in future technology, and commitment towards the climate goals. This is especially reaching out to the younger generation who are most concerned about the transition towards a low-carbon society.

As a result of the debate on the decline of Norwegian oil production, a growing number of petroleum companies that operates on the NCS are choosing to invest in green/renewable technology. This is both to improve their own reputation and to show that the industry can adapt future to continue oil production with lower emissions, thus showing that they can continue to produce for decades to come.

5.4 Norway in relation to the Paris Agreement

In order for Norway to achieve the goals of becoming a zero-emission society in accordance with the Paris Agreement, Norway must develop climate laws and other incentives that will be means of reducing emissions. According to the UN Climate Panel on Climate Change (IPCC), it is possible to reach the goals of the Paris Agreement, ie to reach the 1.5 temperature target by reducing emissions, but this process can be demanding.

The Paris Agreement has specific objectives to be achieved but does not have concrete procedures on how to achieve these goals. It is up to each country to find climate solutions to reach the goals of the Paris Agreement. Norway has chosen to reduce GHG emissions by 40% by 2030 compared with 1990. In the period 1990-2000, the annual GHG emissions increased dramatically, but after the 2000 the emissions have been relatively stable. In 2018, Norwegian emissions were almost identical to those in 1990 [76].

In order to reduce emissions from NCS, Norway can follow a roadmap developed by KonKraft. The roadmap includes various methods and technologies that can be developed to reduce emissions in the Norwegian petroleum industry to reach a 40% reduction in emissions by 2030 and approach zero emissions of GHG in 2050.

To achieve these goals, the Norwegian petroleum industry must integrate an environment that is engaging the business to reduce carbon footprint. This applies to the entire rig operations and vessels used in the petroleum operations. By developing and implementing low-emission technologies such as zero-emission fuel, CCS and offshore wind turbines, Norway can be able to export this technology to the rest of the world [25].

Norway is known for having ambitious climate goals but has not been as successful at meeting the goals set. Norway and the EU are working together to form measures for the Paris Agreement, but the EU has said that the new measures for 2020 will not be ready until autumn. For this reason, the Environment Directorate has proposed many concrete measures to reduce GHG emissions called Klimakur2030. "Klimakur2030 mission has been to work together to identify measures that can cut non-ETS emissions by 50% by 2030, compared with 2005, and to assess barriers and possible remedies that can address those measures" (Klimakur2030, 2020, p. 1) [77] [78].

Petroleum operations account for about one third of the CO_2 emissions in Norway. And compared to the rest of Europe, Norway accounts for about 3% of the GHG emissions, shown in Figure 27. Thus, the electrification of the Norwegian Continental Shelf gives a marginal effect compared to the global climate [79].

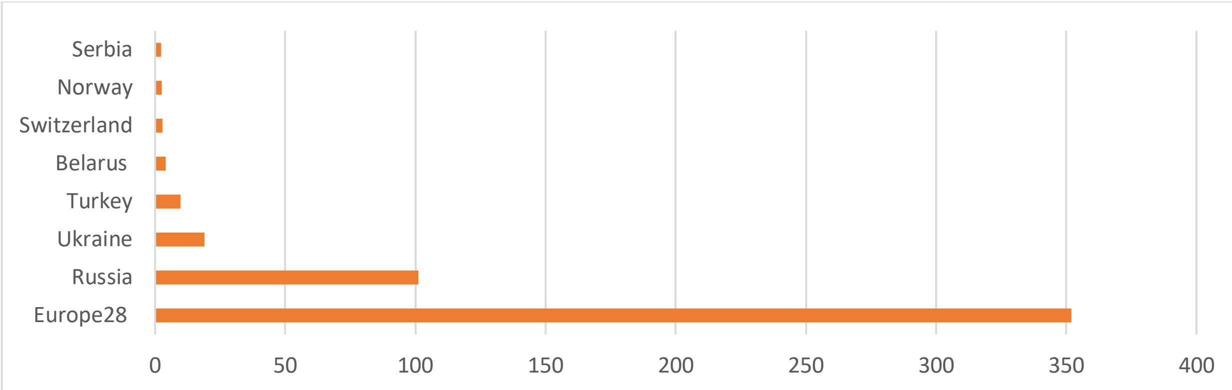

Figure 27 *Cumulative CO_2 emissions in Europe from the period 1751 to 2017 given in billion tonnes of CO_2 , adapted from Our World in Data [80].*

Norway is one of the countries in the world that is at the forefront when it comes to reducing carbon emissions. Through the development of new technology and innovation, this can help reduce emissions of natural gas. The companies with activity within the petroleum industry, can apply for various support schemes to get support to develop and implement new technologies such as ENOVA and the NO_x Fund. New innovation and new technology can disseminate to other countries in the world and help to reduce the global emissions.

CO_2 emissions represent 84% of the total emissions in Norway, which represents 43.82 millions of tonne of CO_2-equivalents in 2018 as shown in Figure 28. In order to reduce emissions in Norway, it has been introduced various GHG emission taxes. Norway has CO_2 taxes which have resulted in Norway having reduced CO_2 emissions with 0.9 % in 2018, which equivalents to 450 000 tonnes of CO_2-equivalents (data from Statistics Norway) together. At the same time, CO_2 emissions from 1990 to 2018 have increased by 24%. Most of the emissions come from the petroleum industry.

Norwegian emissions will be around 42-44 million tonnes of CO_2-equivalents in 2020, which is in line with international climate commitments. Electrification of petroleum production will have a major impact on CO_2 in the statistics in Norway (such as SSB). The Edvard Grieg electrification and Hywind project will both cut emissions by 200 000 tonnes CO_2 annually, and because Edvard Grieg will be fully electrified within the third quarter of 2022, the platform will only have some emissions from flaring and the diesel engines. Electrification of the NCS will therefore be an important measure in order for Norway to reach the goals of the Paris Agreement.

Emissions were measured to decrease in 2017 compared to the previous year, but the numbers are characterized by an uncertainty that makes it difficult to determine if the figures are real or not. This may be an uncertainty when assessing if the climate goals in the Paris Agreement has been achieved or not [81] [82].

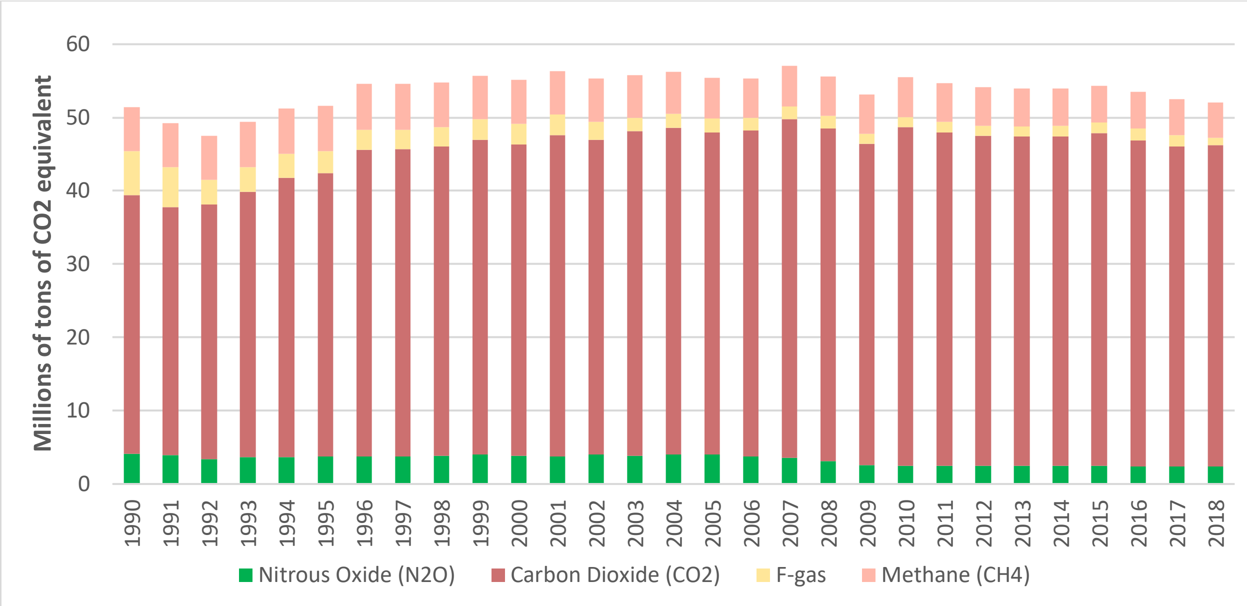

Figure 28 *Emissions of GHG gases in Norway by gas in 2018 (in millions of tons of CO_2 equivalent), adapted from Statistics Norway (SSB) and Norwegian Environment Agency [83].*

To achieve the goals of the Paris Agreement, Norway must take stricter measures. New stricter requirements such as fewer quotas and higher fees may have to be implemented in order to reduce CO_2 emissions.

5.5 New technology to reduce emissions in the future

In relation to electrification of platforms, it is currently not feasible to connect a floating drilling rig to a power grid offshore, as the rigs move according to where the drilling activities will take place. However, some rig contractors like Dolphin Drilling have initiated technology development program to implement such solution, which should be expected to have similarities to offshore floating wind turbines. For jack-up rigs, electrification is more feasible and LENO has already started to plan using such solution on their other contracted rig Rowan Viking, which is a jack-up rig, while placed besides the Edvard Grieg platform for infill drilling in 2021 [33].

Hybrid solutions will be important for the future of drilling rigs. Currently, the hybrid technology and solutions for rigs have some challenges and are not yet optimized. However, it is expected that just like the wave of electrification of passenger cars in Norway improved impressively over a number of years, a change to electrification of rigs may occur and gradually improve available technology getting new hybrid rigs better and better. Upgrading older rigs with new technology, like hybrid solutions and SCR, is challenging as the design of the construction is not prepared for this and it will therefore require excessive re-building of the rig.

The use of low- and zero-emission fuels will also be an important measure in order to reduce GHG emissions. Biofuel can more easily be used in existing gas turbines and engines with almost no modifications to existing technology. The total emission reduction one can achieve will depend on the origin of the fuel but will nevertheless provide large cuts in relation to fossil fuels [37].

As for today fuel cells are currently not optimized for use offshore. This is because that they are too bulky and heavy, which can affect the safety and stability on the offshore unit. But with further technological development, fuel cells can become an important solution for emission reductions. Fuel cells will be an important measure specially on offshore units where power from shore is not feasible [37].

Today there are only energy-dense fuels like hydrogen, ammonia and biofuel that are able to supply the amount of energy a vessel or offshore unit requires. Hydrogen can by technological development either be produced locally offshore or produced on land and transported out to the rigs. Hydrogen and ammonia produced from natural gas with CCS, or from electrolysis using renewable power, like offshore wind power, can in the future be an offshore energy supply source with low emissions. Offshore supply vessel powered by hydrogen are currently under development [37].

Production of hydrogen from natural gas with CCS can result in 90-95 % of the CO_2 content in the gas to be captured and stored. This gives hydrogen combustion a much lower carbon footprint than fossil fuels used today. Hydrogen production with CCS can also be a great way to secure provision for Norwegian natural gas resources in the future. In the long-term hydrogen can help the conversion to low-emission communities in the EU and replace the current use of fossil fuels. Converting today´s volume of export for natural gas to hydrogen produced with CCS, it would make approximately 22.5 million tonnes of hydrogen per year [37].

Ammonia is a carbon free fuel that in the future can become very important in order to fulfil IMO´s vision on reducing GHG emissions from shipping by at least 50% by 2050. Today ammonia is mainly processed from fossil sources, but it can in the future be produced with a very limited GHG footprint by using renewable power sources. Ammonia also has a number of issues. Compared to other fuel it ignites and burns poorly and is both corrosive and toxic with makes handling and storage very important. Before ammonia can be used as marine fuel, there must be a regulatory framework in place that states and require proper handling of the substance to avoid large NO_x emissions [84]. In order for low- and zero-emission fuels to be used in the coming years, it will be necessary to establish an adequate supply network at ports and bases for these fuels.

6. Conclusion

The current GHG and NO_x emission reducing technologies are not yet sufficient to reach the commitments set by the Paris Agreement and the Gothenburg Protocol, but the petroleum industry is showing improvements through research and development of technologies and innovative solutions suitable for the future. Over the coming years, different measures must be in place to reduce emissions from offshore platforms and especially drilling rigs. New stricter requirements from the authorities such as fewer quotas and higher fees may have to be implemented in order to motivate operators on the NCS to implement new emission reducing technology.

Gas turbines for energy production on platforms are the main contributor of carbon dioxide emissions on the NCS. Reducing GHG and NO_x emissions from platforms by implementing electrical power supply either from offshore wind farms or connecting the platform to onshore power shows enormous reduction potential. Equinor's Northern Lights project is also a step in the right direction, where the solution of "capturing" CO_2 emissions (CCS) from onshore as well as offshore facilities can help Norway to reach the objectives in the Paris Agreement thus becoming a carbon neutral society.

When it comes to floating semi-submersible drilling rigs, the industry must increase the effort in reducing GHG and NO_x emissions from these rigs, as it is currently not feasible to connect a floating drilling rig to a power grid onshore. Connecting jack-up rigs may be easier, as the jack-up legs are placed on the seabed, therefore the main challenges will be for large floating rigs such as West Bollsta. Consequently, it will be important to further develop and implement energy management systems on floating rigs. West Bollsta is an example of a well-integrated drilling rig with both CBT and SCR technology, where SCR technology alone shows a reduction of over 70% of the NO_x emission which can lead future rig designers to choose SCR. CBT technology reduces the diesel engine operating hours by almost 50%, and a reduction of 11% of the CO_2 emission can be enhanced by designing the rig with this technology in place from the beginning.

Switching fuel for drilling rigs and offshore vessels to low and zero emission fuel as well as using hybrid solutions or fuel cells for power supply, can further reduce emissions from the petroleum industry as well as marine activity by a large amount. In order for these changes to take place, it will be necessary to establish an adequate supply network at ports and bases for these fuels.

By electrifying both the Johan Sverdrup and the Edvard Grieg fields as well as being the first petroleum company in Norway with a Tier III compliant rig, LENO proves their commitment in becoming a carbon neutral company. Through involvement in research on emission reducing technologies and continuous improvement and development of requirements and specifications in contracts for rigs and supply vessel, LENO works actively to reduce emissions through the entire value chain.

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Appendix A: Science article

Why do we need petroleum production?

The world has a great need for energy and therefore the production of petroleum is important. Today it is difficult to picture a world without fossil fuel. It is one of the most important sources of energy and easily we have. At the same time, the world is challenged by an ongoing discussion about how to become a «green» society. This has opened up discussions about closing down the oil industry, which neither is a good idea in the short term nor really possible today. Therefore, the petroleum industry has become more focused on reducing emissions and developing different types of technologies to reduce emissions. This poses major challenges but also possibilities for the industry.

Production brings with it a number of challenges with emissions of gases

The production of petroleum has its negative sides. In the production and consumption of petroleum there are various types of gases emitted such as greenhouse gases (GHG) and other hazardous gases such as NO_x. These gases are dangerous to the planet and due to this, various types of agreements have been made and implemented by most nations world-wide to reduce these harmful gases as a joint international effort. Norway has made an agreement with countries in the EU that we, in accordance with the Paris Agreement, shall reduce greenhouse gas emissions with 55% by 2030, and that Norway will become a low carbon society by 2050. In order to achieve these targets, set by the Paris Agreement, emissions from the petroleum industry must be reduced for both for oil and gas producing platforms and offshore drilling rigs.

New solutions are needed

In order to achieve the targets, set by the Paris Agreement, it is important that the petroleum industry implements and develop new technologies that significantly reduces emissions of harmful and hazardous gases. There are many different types of technologies and measures that are in the development phase and which look promising for the future, some with best fit for platforms, other best for drilling rigs. For platforms electrification can be an effective solution. Electrification will reduce just about all emissions of CO_2. By providing offshore electrification possibilities, the running hours from gas turbines producing electricity can be significantly reduced, and considerable emission reductions achieved. Flaring will still be an emission factor, however in a small scale, as this is an important safety mechanism that cannot be completely eliminated.

Implementing hybrid solutions such as offshore wind, diesel engines combined with battery technology, fuel cells and wave power are also important measures to reduce emissions.

Other technologies such as hydrogen, low- and zero-emission fuel such as biofuel and offshore solar energy are not yet matured alternatives but may play an important role within some years. Developing low-emission technologies such as zero-emission fuel, carbon capture and storage (CCS) solutions and offshore wind turbines are already feasible and available technologies. CCS can provide a reduction of 90-95 % of the CO_2 content in the gas to be captured and stored.

The West Bollsta rig is the first rig in Norway equipped with a Selective Catalytic Reduction (SCR) system that reduces NO_x emissions with 70% and a closed bus-tie (CBT) system that reduces CO_2 emissions with11% and NO_x emissions with 9%. These systems in combination with an implemented energy management system leads to less diesel consumption, which is a major factor for emissions.

The main challenge for the petroleum industry in the future is to reduce emissions from offshore drilling rigs.

Future solutions for marine and petroleum activity will be based on low emission fuel. Currently the fuel cells are not optimized use for offshore use. This is because that they are too bulky and heavy, which can affect the safety and stability on the offshore unit. But with further technological development, fuel cells can become an important solution for emission reductions in the future. The most relevant alternatives to existing fuels are hydrogen, ammonia and biofuels. By converting gas turbines or by using fuel cells, the industry can use hydrogen or ammonia as fuel instead of the most traditional used fuel, diesel. Hydrogen and ammonia do not emit any GHG or NO_x, as long as they are produced with clean electricity or used with CCS solutions.

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Appendix B: Risk analysis

NTNU	Kartlegging av risikofylt aktivitet	Utarbeidet av	Nummer	Dato
HMS		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av	Side	Erstatter
		Rektor		01.12.2006

Enhet: IMA **Dato:** 31.01.2020

Linjeleder: Jostein Mårdalen

Deltakere ved kartleggingen (m/ funksjon): Sverre Gullikstad Johnesn, Kristina Rølland, Shayangi Govindapillai, Vegar Øye, Axel Kelley og andre medvirkende ved Lundin Norway AS

(Ansv. veileder, student, evt. medveiledere, evt. andre m. kompetanse

Kort beskrivelse av hovedaktivitet/hovedprosess: Bacheloroppgave Kristina Rølland, Shayangi Govindapillai, Vegar Øye. Energy Management for Offshore Drilling Unit.

Er oppgaven er rent teoretisk? *(JA/NEI)* JA

Skal du motta prøver fra industri? *(JA/NEI)* *NEI*

"JA" betyr separat risikovurdering av prøvene individuelt

Er det trygt å utføre arbeidet utenfor normal arbeidstid (8-17)? (JA/NEI)

Signaturer: *Ansvarlig veileder:* Sverre Gullikstad Johnsen *Student:* K.Rølland, S.Govindapillai, V. Øye

ID nr.	Aktivitet/prosess	Ansvarlig	Eksisterende dokumentasjon	Eksisterende sikringstiltak	Lov, forskrift o.l.	Kommentar
1	Besøk West Bollsta/ Maersk Mandal	Seadrill	NEI	HMS West Bollsta	HMS Seadrill	Vi får ledsager på riggen og sikkerhetskursing og briefing for besøket.
2	Tap av data, stjelt datamaskin	n/a	NEI	OneDrive	n/a	OneDrive lagrer alt kontinuerlig.
3	COVID-19	Kina	WHO (World Health organization)	Hygiene	n/a	God hygiene, ikke smitte andre på gruppen.
4	Langvarig sykdom	Eget	NEI	Førevar	n/a	Forbeholde risiko.
5	Flyreiser	Avinor	NEI	Sikkerhetsrutiner på fly	n/a	Se på flyvertinnene under demonstrasjon av evakueringsprotokoll.
6	Tap av leveranse av arbeid, oppmøte med Lundin i Oslo, grunnet ukjente årsaker.	n/a	NEI	Skype-møter, telefonmøter	Muntlig avtale.	God gjennomføring og briefing av prosjektets gang. Tett kontakt med Lundin.

NTNU	Risikovurdering	Utarbeidet av	Nummer	Dato
HMS /KS		HMS-avd.	HMSRV2603	04.02.2011
		Godkjent av	Side	Erstatter
		Rektor		09.02.2010

Enhet: IMA **Dato:** 31.01.2020

Linjeleder: Jostein Mårdalen

Deltakere ved risikovurderingen (m/ funksjon): Sverre Gullikstad Johnesn, Kristina Rølland, Shayangi Govindapillai, Vegar Øye, Axel Kelley og andre medvirkende ved Lundin Norway AS

(Ansv. veileder, student, evt. medveiledere, evt. andre m. kompetar

Risikovurderingen gjelder hovedaktivitet: Bacheloroppgave Kristina Rølland, Shayangi Govindapillai, Vegar Øye. Energy Management for

Signaturer: *Ansvarlig veileder:* Sverre Gullikstad Johnsen *Student:* K.Rølland, S. Godvindapillai, V. Øye

ID nr.	Aktivitet/prosess fra kartleggingsskjemaet	Mulig uønsket hendelse	Vurdering av sann-synlighet (1-5)	Vurdering av konsekvens: Ytre miljø (A-E)	Vurdering av konsekvens: Øk./ materiell (A-E)	Vurdering av konsekvens: Om-dømme (A-E)	Risiko-verdi (menn-eske)	Kommentarer/ status Forslag til tiltak	Risikovurdering etter tiltak
1	Besøk West Bollsta/ Maersk Mandal	Skade	3	B	A	D	D3	Bruk hjelm, se alltid opp for fritthengende og fallende gjenstander, følg alle instrukser og respekter alle barriererer. Ikke vandre rundt på egen hånd på byggeplass.	A2
2	Tap av data, stjelt datamaskin	Tap av dokumenter, konfidensiell inforsmasjon	4	B	B	D	A4	OneDrive som kontinuerlig backup, bytter passord til mail en gang i måneden.	A1
3	COVID-19	Influensa med høg feber og sengeliggende.	3	B	B	A	A3	Influensavaksinen mulig, god hygiene.	A1
4	Langvarig sykdom	Langvarige skader eller sykdom	2	C	B	C	B2	Opprettholde god helse, føre var.	B1
5	Flyreiser	Flystyrt	1	E	E	E	E1	Meir usannsynlig enn bilkræsj, kan eventuelt ta forskjellige fly.	E1
6	Tap av leveranse av arbeid, oppmøte med Lundin i Oslo, grunnet ukjente årsaker.	Naturkatastrofer, reisetilbud svekket.	3	B	B	A	A3	Med kontinuerlige oppdateringer på fremskritt i arbeidet, vil Lundin ha troverdighet på vår gjennomførelse av prosjektet, selv om vi blir forsinket.	A2

Risikoverdi = Sannsynlighet (1, 2 ...) x konsekvens (A, B ...). Risikoverdi A1 betyr svært liten risiko. Risikoverdi E5 betyr svært stor og svært alvorlig risiko.

Sannsynlighet		Konsekvens					
Verdi	Kriterier	Gradering		Menne	Ytre miljø:	Øk/materiell	Omdømme
1	**Svært liten**:1 gang pr 50 år eller sjeldnere	E	**Svært alvorlig**	Død	Svært langvarig og	Drifts- eller aktivitetsstans >1 år.	Troverdighet og respekt betydelig og varig svekket
2	**Liten**: 1 gang pr 10 år eller sjeldnere	D	**Alvorlig**	Alvorlig pers	Langvarig skade. Lang	Driftsstans > ½ år, aktivitetsstans opptil 1 år	Troverdighet og respekt betydelig svekket
3	**Middels**: 1 gang pr år eller sjeldnere	C	**Moderat**	Alvorlig pers	Mindre skade og lang	Drifts- eller aktivitetsstans < 1 mnd	Troverdighet og respekt svekket
4	**Stor**: 1 gang pr måned eller sjeldnere	B	**Liten**	Skade som	Mindre skade og kort	Drifts- eller aktivitetsstans < 1uke	Negativ påvirkning på troverdighet og respekt
5	**Svært stor** :Skjer ukentlig	A	**Svært liten**	Skade som	Ubetydelig skade og kort	Drifts- eller aktivitetsstans < 1dag	Liten påvirkning på troverdighet og respekt

MATRISE FOR RISIKOVURDERINGER ved NTNU

KONSEKVENS						
	Svært alvorlig	E1	E2	E3	E4	E5
	Alvorlig	D1	D2	D3	D4	D5
	Moderat	C1	C2	C3	C4	C5
	Liten	B1	B2	B3	B4	B5
	Svært liten	A1	A2	A3	A4	A5
		Svært liten	Liten	Middels	Stor	Svært stor
		SANNSYNLIGHET				

Prinsipp over akseptkriterium. Forklaring av fargene som er brukt i risikomatrisen.

Farge	Beskrivelse
Rød	Uakseptabel risiko. Tiltak skal gjennomføres for å redu
Gul	Vurderingsområde. Tiltak skal vurderes.
Grønn	Akseptabel risiko. Tiltak kan vurderes ut fra andre her