Analyses of the potential role of hydrogen for Norway in the transition to a zero-emission society

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Abstract

The objective of this thesis is to analyze the potential role of hydrogen for Norway in the transition to a zero-emission society. The main sector of focus is the transport sector. Here, socioeconomic analyses are carried out to increase understanding of the best usage of hydrogen in this sector. The most relevant hydrogen production technologies are also analyzed so as to provide TiZir Titanium & Iron with more information on the long-term implications of their choice of technology solution in their transition from using coal to using hydrogen as a chemical component in their production line.

In this thesis, the implications of ITE's projections of vehicle stocks developments are analyzed socioeconomically. The net present values of investments into hydrogen passenger vehicles, cargo vans, heavy-duty trucks and buses are analyzed and compared with those of electric vehicles. It is found that the best investments regarding hydrogen is the sector of heavy-duty trucks, followed by cargo vans.

Hydrogen production with steam methane reforming (SMR) and water electrolysis are analyzed and compared with each other. SMR is found to not be socioeconomically viable, not attractive due to low CO_2-taxes and there is uncertainty as to whether the technology is good enough or not. It is concluded in this thesis that hydrogen produced with fossil fuels at best is as good as hydrogen produced with energy from renewable sources. Nonetheless, it is strongly suggested that further development of this technology is pursued in light of IPCC's claim that CCS is necessary for global warming to be limited to 2 °C.

The implication of ITE's projections of vehicle stocks developments on Norway's ability to reach its climate goals are analyzed. It is found to only amount to 13 % GHG reductions in the period 2017-2030 with respect to 1990-levels. If the transport sector is to reduce emission by 40 % or more, then annual emissions must be reduced by at least an additional 2.1 Mt CO_2-equivalents by 2030 in this sector. It is concluded that Norway's climate goals will not be met if escalated actions are not taken.

Samandrag

Føremålet med denne masteroppgåva er å analysere den potensielle rolla hydrogen kan spele for Noreg i overgongen til eit nullutsleppsamfunn. Sektoren som er lagt mest vekt på er transportsektoren. Her er samfunnsøkonomiske analyser utført for å auke forståinga for best mogleg bruk av hydrogen i denne sektoren. Dei mest relevante hydrogenproduksjonsteknologiane er også analysert for å gi TiZir Titanium & Iron meir informasjon om dei langsiktige verknadane av valget av teknologiløysing dei tek i overgangen frå bruk av kol til bruk av hydrogen som kjemiske komponent i deira produksjonslinje.

I denne masteroppgåva er verknadene av Transportøkonomisk institutt (TØI) sine framskrivingar av køyretybestanden analysert samfunnsøkonomisk. Noverdiane av investeringane i hydrogenpersonbilar, -varebilar, -lastebilar og -bussar er analysert og samanlikna med dei tilsvarande noverdiane til elektriske køyrety. Det er funne at den beste investeringa for hydrogen er i lastebilsektoren, etterfylgt av varebilsektoren.

Hydrogenproduksjon ved dampreformering av naturgass (SMR) og vasselektrolyse er analysert og samanlikna med kvarandre. SMR er ikkje samfunnsøkonomisk levedyktig, ikkje bedriftsøkonomisk attraktivt grunna låg CO_2-avgift og det er usikkert om teknologien er god nok eller ikkje. I denne masteroppgåva er det konkludert med at hydrogen produsert med fossile kjelder kun har potensiale til å vere like bra som hydrogen produsert med energi frå fornybare kjelder. På trass av dette er det sterkt anbefalt at ein held fram med utvikling av denne teknologien grunna IPCC sine konklusjonar om at karbonfangst og -lagring er naudsamt for å halde global oppvarming under 2 °C.

Verknadene køyretybestandsutviklinga framskrive av TØI vil ha på Noreg si evne til å nå klimamåla er analysert. I denne masteroppgåva er det estimert at ein i transportsektoren kun oppnår ein klimagassreduksjon på 13 % i perioden 2017-2030 samanlikna med nivået i 1990. Viss transportsektoren skal redusere sine klimagassutslepp med 40 % eller meir, må årlege utslepp reduserast med minst 2.1 Mt CO_2-ekvivalentar innan 2030 i denne sektoren. Det er konkludert med at Noreg sine klimamål ikkje vert haldne viss auka innsats ikkje vert iverksett.

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Nomenclature

GWP	Global Warming Potential [kg CO_2-equivalents]
AP	Acidification Potential [kg SO_2-equivalents]
HEV	Non-plug-in Hybrid Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
BEV	Battery Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
SMR	Steam Methane Reforming
TWh	Tera Watt hours
GHG	Greenhouse Gas
POX	Partial Oxidation
WGS	Water Gas Shift
ATR	Autothermal Reforming
PEM	Proton Exchange Membrane/Polymer Electrolyte Membrane
CHIC	Clean Hydrogen in European Cities
SCC	Social costs of carbon [NOK/kg CO_2-equivalent]
ITE	Institute of Transport Economics
IPCC	Intergovernmental Panel on Climate Change
ICCG	International Center for Climate Governance
NPV	Net Present Value
nmVOC	Non-methane Volatile Organic Compound
CCS	Carbon Capture & Storage
ETS	Emission Trading System

1 Introduction

Norway has, since the mid-1960s, heavily invested in the fossil fuel industry (1). These investments have laid the foundation for the state of welfare seen in Norway today. With the world leaders meeting in Paris reaching an agreement stating all countries are to work towards limiting global warming to 2 °C (2), and Norway taking upon itself to reduce emissions by 40 % from 1990-levels by 2030 (2), Norway faces challenging times. More than 1/3 of Norway's export income comes from the fossil fuel industry (3). Norway exports more than 2 000 TWh worth of fossil fuels to international markets (4). Emissions must be reduced by 22.7 million tons CO_2-equivalents if Norway is to hold its climate goals (5), but how are these major changes to be done? Which energy sources is Norway to rely on? What will happen to the fossil fuel industry? If the fossil fuel industry dies, how is Norway going to maintain the state of welfare it experiences today? Where can emissions be cut most cost efficiently? How fast can emissions be cut? Can emissions be cut while the fossil fuel industry simultaneously thrives?

In this report, it is analyzed how hydrogen can be utilized towards reaching the climate goals Norway has set for itself. Various alternative production methods and uses of hydrogen are compared with other solutions commercially available today to get an idea of whether hydrogen or another solution should be implemented to solve a certain issue Norway either faces today or will face in the future related to tackling climate change and reaching Norway's climate goals.

When evaluating which solution is better equipped to solve specific issues for Norway today and in the future, socioeconomic net present values are estimated.

In this report, potential usage of hydrogen in a specific case is also analyzed. This case is TiZir's planned transition from using coal as chemical component in their production line for titanium and iron to using hydrogen. Here, communication is established with TiZir to reach an understanding of their most valued factors when deciding between the alternative methods of hydrogen production. These factors are analyzed, acting as decision support for their evaluation of the available alternatives.

Political leaders in the Norwegian society have requested methods for estimating the government's budget's impact on national GHG reductions (6). Part of this request is answered in this master thesis.

2 Theory

In this chapter, various hydrogen production technologies, usage of hydrogen and distribution of hydrogen are presented. Additionally, information on carbon capture and storage, social costs of emissions and national forecast for vehicle stocks are presented.

2.1 Production of hydrogen

Globally, hydrogen production and consumption amounts to approximately 50 million tons per year (7).

Hydrogen is, as of 2016, produced mainly from natural gas steam reforming without CCS, accounting for 48 % of all hydrogen production. The remainder comes from petroleum production during the refining process accounting for 30 %, coal based hydrogen represents 18 % and the rest, 4 %, is hydrogen produced with electrolysis (8).

In the following chapter, the most common production technologies will be presented in detail.

2.1.1 Steam reforming method

The steam reforming method consists of two steps. In the first step, water vapor and the hydrocarbons react assisted by a nickel catalyst at around 800 °C (9). Meanwhile, Nikolaidis et al. claim that the temperatures are closer to 900 °C, with pressures up to 3.5 MPa and steam-to-carbon ratios of 3.5 (10). The fundamental reaction equation of the steam reforming method is

$$\mathrm{CH_4 + H_2O \rightarrow CO + 3H_2}$$

Equation 1: Chemical equation for the reformer in the steam-methane reforming process

In the next step in the process, the remaining carbon monoxide reacts with more water vapor in the "water gas shift reactor" assisted by a new catalyst, this time copper or iron, and at a temperature of approximately 500 °C (9).

$$\mathrm{CO + H_2O \rightarrow CO_2 + H_2}$$

Equation 2: Chemical equation for the WGS reactor in the steam-methane reforming process

Other gases used as raw materials are ethane, propane, butane, pentane and light and heavy naphtha (10). After the reformers, the mass flow consists mainly of hydrogen and carbon dioxide. Either, the CO_2 is removed and the remaining gas goes through a methanation process in order to recycle the remainder of the carbon monoxide. Alternatively, the mixture passes through a pressure swing adsorption unit which separates the carbon dioxide from the hydrogen. Hydrogen with a very high purity can be achieved. According to Rönsch et al (11), there are three CO_2 methanation technologies available on the market. These are namely Outotec, Etogas and MAN methanation, which are all fixed-bed reactor concepts (11). The chemical reaction occurring in the methanator is as follows

$$CO + 3H_2 \rightarrow CH_4 + H_2O$$

Equation 3: Chemical equation for the methanator in the steam-methane reforming process

2.1.2 Partial oxidation method

The partial oxidation (POX) method is similar to the steam methane reforming method. However, here also oxygen in addition to water is mixed with the hydrocarbons. This is better illustrated with the chemical equations of the reformer

$$C_nH_m + \frac{1}{2}nO_2 \rightarrow nCO + \frac{1}{2}mH_2 \text{ (catalytic)}$$

Equation 4: Chemical equation for the catalytic part of the reformer in the partial oxidation method

$$C_nH_m + nH_2O \rightarrow nCO + \left(n + \frac{1}{2}m\right)H_2 \text{ (non} - \text{catalytic)}$$

Equation 5: Chemical equation for the non-catalytic part of the reformer in the partial oxidation method

Equation 2 and Equation 3 give the chemical equations of the water gas shift (WGS) reactor and methanator, respectively. The reformation process is divided into two subparts. The first part, as shown in Equation 4, is a catalytic process occurring at about 950 °C, which can use feedstock ranging from methane to naphtha. The second part, as shown in Equation 5, is a non-catalytic process occurring at 1150-1315 °C according to Nikolaidis and Poullikkas with feedstock being hydrocarbons including methane, heavy oil and coal (10).

Nikolaidis and Poullikkas claim POX to be the most appropriate technology for production of hydrogen from heavier feedstock, such as heavy oil residues and coal. However, due to the low hydrogen content of heavy oil and coal, water supplies respectively 69 and 83 % of the hydrogen produced.

2.1.3 Autothermal reforming method

The autothermal reforming method (ATR) essentially is a combination of the steam methane reforming method and the partial oxidation method. In ATR, the heat required for the endothermic steam reformation is provided by the exothermic partial oxidation (10). This means that the reforming and oxidation reactions occur simultaneously due to steam and air being injected into the reformer at the same time. Nikolaidis et al. (10) claim the optimum operating temperature for ATR hydrogen production from methane to be 700 °C.

2.1.4 Hydrocarbon pyrolysis

Unlike the previously discussed fossil fuel methods of hydrogen production, hydrogen from hydrocarbon pyrolysis comes solely from the hydrocarbons (12). This occurs by decomposition of the hydrocarbons through heating in an inert atmosphere. The chemical reaction is given in Equation 6.

$$C_nH_m \rightarrow nC + \frac{1}{2}mH_2$$

Equation 6: Hydrocarbon pyrolysis chemical reaction

Pyrolysis of methane occurs at temperatures up to 980 °C and atmospheric pressures (10). As this process does not require carbon capture and sequestration, the hydrogen production cost for large plants is 25-30 % lower than that of the processes of steam conversion or partial oxidation.

2.1.5 Thermochemical processes based on biomass

Thermochemical processes based on biomass consist mainly of pyrolysis and gasification. Pyrolysis of biomass and hydrocarbons are rather similar. However, since biomass generally carry a significant amount of oxygen, the chemical reaction becomes somewhat different (13):

$$C_aH_bO_c \xrightarrow{\text{Heat}} dH_2 + eCO + fCO_2 + gCH_4 + hC + \text{Tar}$$

Equation 7: General chemical equation for thermochemical production of hydrogen based on biomass (13)

The production cost of hydrogen by pyrolysis is expected to be in the range of $ 1.25-2.20/kg hydrogen, depending on the facility size and biomass type (10).

Gasification of biomass usually undergoes one of the following reactions in order to produce hydrogen:

$$C_aH_bO_c + \text{Air} \xrightarrow{\text{Heat}} dH_2 + eCO + fCO_2 + gCH_4 + hH_2O + \text{Tar}$$

Equation 8: General chemical equation for gasification of biomass using water (10)

$$C_aH_bO_c + dH_2O \xrightarrow{\text{Heat}} eH_2 + fCO + gCO_2 + hCH_4 + \text{Tar}$$

Equation 9: General chemical equation for gasification of biomass using steam (10)

Operating temperatures and pressures of gasification range from 500-1 400 °C and atmospheric to 33 bar, respectively, depending on plant scale (10). The best-known reactors utilized for biomass gasification are fixed bed and fluidized bed gasifiers. Fixed bed gasifiers have a bed of solid fuel particles through which the gas moves with low velocity. Meanwhile, the fluidized bed gasifier implies that the gas entering has such a high velocity that the bed acts as a fluid, causing great mixture of the gas and the solids.

2.1.6 Biological processes based on biomass

The main biological hydrogen production processes are photolysis and fermentation. Photolysis utilizes the same principles as found in photosynthesis, but is in this case adapted to the generation of hydrogen gas as shown in Equation 10.

$$2H_2O + \text{sunlight} \rightarrow 2H_2 + O_2$$

Equation 10: Overall chemical reaction of photolysis using algae

In traditional photosynthesis, only CO_2 reduction takes place. This is due to the hydrogen-forming enzyme, hydrogenase, being absent. The green algae require anaerobic conditions and darkness in order to activate and synthesize their hydrogenase enzyme (14). When this is achieved, some hydrogen is produced. Returning the green algae to light, still under anaerobic conditions, results in increased hydrogen production.

Fermentation is an oxidation process of incomplete combustion which can be found at bacteria and mushrooms (15). It is a conversion of organic compounds, such as organic waste and biomass materials, to hydrogen in anaerobic conditions. The chemical equation of one such fermentation process is given in Equation 11 (16).

$$C_6H_{12}O_6 + 12H_2O \rightarrow 6H^+ + 6HCO_3^- + 12H_2$$

Equation 11: Chemcial equation for fermentation of glucose (16)

2.1.7 Water electrolysis

Most studies done on hydrogen production from electrolysis is done with electricity supplied from a photovoltaic system or wind farm, usually on quite a small scale. For hydrogen production facilities in Norway, where 97 percent of electricity production is based on renewable resources, the aspect of carbon capture and sequestration is unnecessary to consider. The immediately economically most viable solution in Norway is to connect one’s hydrogen production facility to a nearby hydropower facility or simply to the power grid to meet electricity demand.

Water electrolysis can be simplified to consist of the following chemical reaction.

$$2H_2O \rightarrow 2H_2 + O_2$$

Equation 12: General chemical reaction for water electrolysis

During the electrolysis, the positive ions are reduced by adopting electrons from the negative electrode, the cathode. Simultaneously, the negative ions are oxidized by giving electrons to the positive electrode, the anode.

Different electrolyzers function in slightly different ways. This is mainly due to the different types of electrolyte material involved.

Proton Exchange Membrane electrolyzer

In the proton exchange membrane (PEM) electrolyzer, also known as the polymer electrolyte membrane (PEM) electrolyzer, the electrolyte is a solid plastic material (17).

In the PEM electrolyzer, oxygen and protons are formed by the water's dissociation reaction at the anode. The protons are allowed through the membrane as the name indicates, while the electrons flow through an external circuit powered by a power supply. At the cathode, the hydrogen ions and electrons recombine, forming hydrogen gas.

The usage of PEM electrolyzers have increased of late, some of which due to the following properties (7):

- PEM electrolyzers can operate under high current densities. Especially for systems utilizing dynamic energy sources such as wind and solar energy, this can lead to reduced operating costs.
- Due to PEM's area demand being lower than alkaline's, PEM's economic viability increases as production demand of hydrogen increases. In cases where available area is constrained, PEM will be especially advantageous
- Since PEM electrolyzers usually are pressurized, further compression of the hydrogen for distribution or storage is less energy consuming and as such less cost intensive than otherwise.
- PEM electrolyzers produce hydrogen of very high purity, which is a demand for many applications.

The greatest disadvantage of the PEM electrolyzer is its cost (7). Some of this is due to the PEM technology being rather young (7), and the industry expects the cost of PEM electrolyzers to approach that of alkaline electrolyzers over a period of 5-10 years. The reason for this being mainly potential for increased stack area, reducing usage of materials and area demand which again reduces costs.

The dominating suppliers of PEM electrolyzers on the European market are Hydrogenics, ITM Power, Air Liquide and Siemens (7). For instance, ITM Power recently announced they will establish their first hydrogen station in collaboration with Shell in the United Kingdom (18).

Alkaline electrolyzer

While PEM electrolyzers transport protons between the cathode and the anode, alkaline electrolyzers transport hydroxide ions, OH^-. The formation of hydrogen gas at the cathode and oxygen gas at the anode is shown in Equation 13 and Equation 14, respectively.

$$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$$

Equation 13: Hydrogen production in an alkaline eletrolyzer

$$4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$$

Equation 14: Oxidation of the hydroxide

The alkaline technology has reached state of the art-level (13) and electrolyzers with a liquid alkaline solution of sodium or potassium hydroxide as the electrolyte have been commercially available for many years (17).

The commercially available alkaline electrolyzers today have an average energy consumption of 4.5 kWh/Nm^3 hydrogen, giving an electric efficiency of 67 % (7).

The most renowned supplier of alkaline electrolyzer hydrogen production plants today is NEL, which are well on their way of supplying the market with plug-and-play hydrogen modules (19), both for production and for fueling (20).

According to a study done by Gahleitner (21), the average nominal efficiency of the alkaline electrolyzers is 70 %. This is based on the higher heating value. Equation 15 shows the definition of the energy efficiency.

$$\eta_{\text{electrolyzer}} = \frac{\dot{V}_{H_2} \cdot \text{HHV}}{P_{\text{el}}}$$

Equation 15: Energy efficiency of electrolyzers used in the Gahleitner study (21)

Here $\dot{V}_{H_2}$ is the nominal capacity, P_{el} is the installed power of the electrolyzer and HHV is the higher heating value of hydrogen with 12.75 MJ/Nm^3 (21).

Solid Oxide Electrolyzer Cell

The Solid Oxide Electrolyzer Cell (SOEC) conducts negatively charged oxygen ions (O^{2-}) through its electrolyte, a solid ceramic material, at elevated temperatures (17).

At the cathode, water is split into hydrogen gas and oxygen ions as shown in Equation 16. As mentioned, the oxygen ions pass through the electrolyte to the anode, where the chemical reaction of Equation 17 occurs.

$$2H_2O(l) + 4e^- \rightarrow 2H_2(g) + 2O^{2-}(aq)$$

Equation 16: SOEC reaction at the cathode

$$O^{2-} \rightarrow O_2 + 4e^-$$

Equation 17: SOEC reaction at the anode

SOEC is more advantageous compared to PEM and alkaline electrolyzers due to the fast electrochemical reactions and good ion conduction at an elevated temperature (22), leading to lower electrical energy requirements. The solid oxide membrane functions properly at about 700-800 °C, setting the standard for the SOEC operating temperature (17).

2.1.8 Water thermolysis

Thermolysis of water is similar to pyrolysis of hydrocarbons. In water thermolysis, also known as single step thermal dissociation of water, water is decomposed into hydrogen and oxygen gas at very high temperatures. For example, at 3 000 K and 1 bar, the degree of dissociation is 64 % (13). Avoiding recombination of hydrogen and oxygen is a major part of this production method, and is done by separating the two gases with palladium membranes (23). Equation 18 gives the general chemical reaction equation.

$$H_2O \rightarrow x_1H_2O + x_2OH + x_3O + x_4H + x_5O_2 + x_6H_2$$

Equation 18: General chemical reaction equation for water thermolysis (23)

2.2 Usage of hydrogen

In the following chapter, various areas of use for hydrogen are explained.

2.2.1 Production of Ammonia

About 75 % of all ammonia produced globally uses the Haber-Bosch method, where nitrogen reacts with hydrogen as shown in the following chemical reaction equation (24):

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

Equation 19: Production of ammonia

This process occurs usually at temperatures of 350-600 °C and pressures of 150-300 bar. In order to achieve a sufficient reaction rate at this temperature, an iron based catalyst is utilized. The hydrogen used in this process is made from natural gas, outcompeting the previously used facilities based on coal or water electrolysis (24).

Some ammonia is also produced by the Casale or the Claude method (24), which is principally similar to the Haber-Bosch process, but uses higher pressures.

2.2.2 Refineries

In refineries, hydrogen, amongst other things, is used in hydrocracking, isomerization and hydrotreating and sulphur plants (25).

In hydrocracking, heavier hydrocarbon molecules are broken down to lighter products such as petrol and diesel. Here, hydrogen combines with the chemical bonds of the cracked hydrocarbons, creating isomers with the desired characteristics.

In isomerization, paraffins, which are straight-chained hydrocarbons, are chemically rearranged to become isoparaffins, which are branched.

In hydrotreating, hydrogen is used to remove contaminants from the desired products. Mostly, the consumption of hydrogen here goes to the removal of sulfur, forming hydrogen sulfide.

2.2.3 Production of methanol

In the process industry, hydrogen is used in the production of methanol. The relevant chemical reaction equations are (26):

$$2H_2 + CO \rightarrow CH_3OH$$

Equation 20: Carbon monoxide and hydrogen react to methanol (26)

$$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$$

Equation 21: Carbon dioxide and hydrogen react to methanol and water (26)

$$CO + H_2O \rightarrow CO_2 + H_2$$

Equation 22: Carbon monoxide and water react to carbon dioxide and hydrogen (26)

Normally, these reactions are done at pressures of 40-120 bar and temperatures of 200-300 °C in fixed-bed reactors (26).

Catalysts typically used in such systems are mixtures of copper, zinc oxide, alumina and magnesia.

2.2.4 Fuel cells

Despite the principle technology for fuel cells dating back to the British physicist W. R. Grove of 1839 who was able to develop electricity by the reaction of hydrogen and oxygen (27), it is not until today this technology looks to become commercialized.

As a fuel cell is operated in the same way as an electrolyzer, only in opposite direction, the technology will not be discussed in detail.

Passenger cars

Fuel cell electric vehicles (FCEV) are being made by numerous manufacturers at present and near future. An overview of the status as of January 2017 is shown in Table 1.

Manufacturer	Release date	Comments
Hyundai	2013	ix35 was their first model. New model due 2018
Toyota/Lexus	2015	Mirai was their first model. New models will be introdused before the Tokyo Olympics 2020
Honda	2016	Clarity Fuel Cell was their first model. Cooperation established with General Motors for new models from 2020
Mercedes	2017	GLC F-Cell plug-in, a hybrid og battery and hydrogen, coming in 2017.
Nissan	-	So far only has a prototype SOFC vehicle running on bioethanol.
Ford	-	No FCEV of their own, but co-developed Mercedes' fuel cell for the GLC model
Mazda	-	Agreement of cooperation established with Toyota.
Renault	2014	HyKangoo ZE was their first model. This was a fuel cell battery hybrid. New models available for pre-order now.
GM/Opel	2020	See Honda. 119 test vehicles have been part of GM's research program since 2007. 30 of these have been Opel's vehicles.
Kia	2020	Little information is available regarding this release. When this release will actually transpire is uncertain.
BMW	2021	Little information is available regarding this release. When this release will actually transpire is uncertain.
VW/Audi	2020	Pilots showcased in 2014. Audi A7 and Q7 hydrogen hybrid consepts shown in 2016

Table 1: Status for enrollment of fuel cell electric vehicles (28)

The list presented in Table 1 is based on a list created by the Norwegian Hydrogen Forum (28).

The oldest commercially available hydrogen vehicle being the Hyundai ix35 model, released in 2013, there has been a steep decline in sale price for hydrogen vehicles. The Hyundai ix35's cost in Norway, 2013, was 1.2 million NOK (29). Two years later the price had dropped by more than 50 %, and in 2017, through an agreement established between Hyundai, Greenstat, Hordaland County Council, Bergen City Council and CMR Prototech, more than 20 cars are being sold in the Bergen area in Norway for 400 000 NOK (30).

Public transport: buses and trains

The development of public transport fueled by hydrogen is young of nature. The Clean Hydrogen in European Cities project (CHIC) lasted from 2010-2016 and was a flagship zero-emission bus project (31). Over the course of this project, a fleet of 54 fuel cell electric buses and hydrogen fueling stations were deployed across Europe and at one site in Canada. An overview of the deployment and specifications is given in Table 2, while statistics over the project period for the individual cities are given in Table 3:

Bus manufacturer	APTS	EvoBus Mercedes-Benz	New Flyer	Van Hool	Wrightbus
City of operation and number of buses	Cologne (2)	Aargau (5) Bolzano (5) Hamburg (4) Milan (3)	Whistler (20)	Cologne (2) Oslo (5)	London (8)
Drive power [kW]	240	240	170	170	134
Fuel cell system power [kW]	150	120	150	150	75
Hydrogen storage capacity [kg (kWh)]	40 (1 333)	35 (1 167)	56 (1 866)	40/35 (1 333)	31 (1 023)
Electricity storage power [kW]	200	250	n/a	90/100	105
Electricity storage capacity [kWh]	28	26.9	47	24/17.4	20

Table 2: Deployment of hydrogen buses in the CHIC project (31)

CHIC city	Number and length of buses	Operating time [hours/day]	Accumulated km over test period	Average hydrogen consumption [kg/100 km]	Litres diesel replaced
Aargau	5 (12 m)	18-20	1230691	7,9	467663
Bolzano	5 (12 m)	0-12	481454	8,6	208277
London	8 (11,9 m)	16-18	1298565	9,7	480469
Milan	3 (12 m)	0-17	178396	10,3	100259
Oslo	5 (13,2 m)	0-17	546223	13,2	273112
Berlin	4 (12 m)	n/a	898477	22,8	377360
Cologne	2 (18,5 m)	12-16	109790	16,5	48813
Cologne	2 (13,2 m)	12-16	122656	12,5	54533
Hamburg	4 (12 m)	0-16	457712	8	171651
Whistler	20 (12,5 m)	0-22	>4005000	15,67	2202750

Table 3: Statistics over the project period in the CHIC project (31)

According to the CHIC report, more than 850 buses are in planning globally (31). During the project period, from 2010-2016, the costs of hydrogen fueled buses have decreased dramatically. At the start of the project a 12-meter bus cost well over € 1 million, with expected cost in 2017 being € 650 000. It is believed this price ultimately, with technology improvements and increased sale volumes of buses and passenger cars, will go below € 400 000 (31).

Not much information is available regarding trains fueled by hydrogen, as this area is even younger than for buses. The first fuel cell passenger train, Coradia iLint, is in 2017 being extensively tested in Germany and Czech Republic (32). The Coradia iLint will run its first passenger test runs in Germany in the beginning of 2018.

Figure 1: Alstom's hydrogen train Coradia iLint on its test track in Salzgitter, Germany (32)

Heavy-duty trucks and cargo vans

ASKO, Norway's largest wholesaler (33), aims to become climate neutral (34). As a vital step towards this goal, ASKO has placed an order for three fuel cell cargo vans fueled by hydrogen from Scania with a range of up to 500 km. ASKO plans to establish a facility for hydrogen production for fueling of these cargo vans (34). Director of ASKO, Jørn Endresen, states that the cost of these trucks amount to 7 million NOK, and that they estimate hydrogen trucks to be price competitive with traditional diesel trucks in the early 2020s (35).

Nikola Motor Company, located in Salt Lake City, have developed two models of hydrogen fueled semi-trucks (36). One with a sleeping compartment and one without. Nikola states their truck to have 1 000 horsepower, which translates to 746 kW, and a range of 800-1200 miles, which translates to roughly 1300-1900 km (37). The average hydrogen consumption is estimated to be 4.6 kg/100 km (38).

Renault have developed a hydrogen fueled truck named Renault Maxity with a range of 200 km, hydrogen fuel cell of 20 kW charging the batteries and power of the electrical motor of 47 kW (39).

E-trucks Europe deployed in 2013 their hydrogen powered garbage truck (40). This truck has a range of 360 km. The truck is reported to save 109.37 kg CO_2 each operational day, amounting to 4.83 tons per year (40). Equipped with a 30 kW fuel cell providing energy for the battery and a power output of 144 kW from the electrical motor, the truck has a hydrogen consumption of 6-9 kg/100 km (41).

Esoro Konsortium have developed a fuel cell truck with 375-400 km range, average hydrogen consumption of 7.5-8 kg/100 km, fuel cell of 100 kW and electrical motor power output of 250 kW (42).

An overview of the discussed manufacturers' products is listed in Table 4.

Manufacturer	Range [km]	Motor power [kW]	Average hydrogen consumption [kg/100 km]
Scania	<500	n/a	n/a
Nikola Motor	1300-1900	746	4.6
Renault Maxity	200	47	n/a
E-trucks Europe	360	144	6-9
Esoro Konsortium	375-400	250	7.5-8

Table 4: Oveview of hydrogen trucks (34, 38, 41-44)

2.2.5 Metal industry

In Tyssedal, Norway, TiZir Titanium & Iron (TTI) are planning to replace the use of coal in their production line and begin using hydrogen instead in order to reduce their greenhouse gas emissions by 90 % (45).

Today, TTI's process involves partial oxidation of the ilmenite ore ($FeTiO_3$) in a rotary kiln at 1 100 °C together with coal, where 70-75 % of the iron is prereduced to metal (46). The remaining ilmenite is then fed into an electric arc furnace, reducing the rest of the iron.

The simplified chemical reaction equations occurring in the process is given in Equation 23 and Equation 24.

$$\mathrm{C(s) + CO_2(g) \rightarrow 2CO(g)}$$

Equation 23: Carbon in the coal reacts to form carbon monoxide (46)

$$FeTiO_3(s) + CO(g) \rightarrow Fe(s) + TiO_2(s) + CO_2(g)$$

Equation 24: Ilmenite reacts with carbon monoxide to form iron, titanium dioxide and carbon dioxide (46)

As can be seen from Equation 23, carbon in the coal is oxidized by carbon dioxide to form carbon monoxide. It is this carbon monoxide which in turn acts as the reducing agent in Equation 24.

Lobo (46) states that hydrogen increases reaction rate compared to the present process, with the increased reaction rate being proportional to the volume percentage of hydrogen in the gas.

2.3 Distribution of hydrogen

The favorable options for distribution of hydrogen are suggested to be the utilization of heavy-duty vehicles for national transportation and shipping for international transportation (47). In the former hydrogen would be transported as compressed hydrogen gas, while in the latter hydrogen would be transported as liquid hydrogen (47).

2.3.1 Shipping

Kamiya et al. have estimated hydrogen costs for a system where hydrogen is produced by the use of brown coal in Australia, liquefied and transported by ship to Japan (48). Here, CO_2 is assumed to be stored through the CarbonNet Project, which utilizes the offshore storage sites in Gippsland (49). Kamiya et al. estimate liquefaction, transportation by ship and CO_2 storage to amount to respectively 33 %, 9 % and 10 % of the total costs of hydrogen (48). With the price of hydrogen being estimated to be \$ 3.23/kg H_2, liquefaction, transportation by ship and CO_2 storage amount to respectively \$ 1.07/kg H_2, \$ 0.29/kg H_2 and \$ 0.32/kg H_2 (48).

2.3.2 Heavy-duty vehicles

Through one of their projects, Greenstat have come to an estimate of 56 NOK/km for transportation of high pressure hydrogen (50). This estimate is used as a basis for calculations on distribution of hydrogen in this report. However, this cost of 56 NOK/km does not include capital investment in the actual containers (50). As such, the actual cost per kilometer depends on how frequently these containers are used. Greenstat consider 40 feet containers with a storage pressure of 300 bar to be most beneficial for their use, and list the following container suppliers as good alternatives:

- Hexagon: 845 kg H_2/container at 4.715 MNOK
- Wystrach: 900 kg H_2/container at 5.280 MNOK
- Umoe: 785 kg H_2/container at 2.570 MNOK

2.4 Carbon capture and storage

Storage of CO_2 today mostly happens due to injection of CO_2 into oil wells to improve recovery of oil (EOR). The majority of these projects use CO_2 from natural geologic accumulations. Some use anthropogenic CO_2, but only a few of these perform a sufficient degree of monitoring, measurement and verification (MMV) to qualify as CCS. As such, they cannot determine whether storage of CO_2 is likely to be permanent (51). Haugan argues that the research necessary to determine whether storage of CO_2 in a specific storage location is likely to be permanent or not is costly and time consuming, and that such locations should not be used for storage of CO_2 if that CO_2 may be removed by other measures (52).

Atkins Norge and Oslo Economics have carried out socioeconomic analyses of CCS alternatives in Norway (53).

They estimate that an 8-year period is required for concept studies and investment phases, before operation can begin in the ninth year of a CCS project (53). Seven potential projects have been analyzed, which are compared with each other and two additional projects. An overview of the costs per ton CO_2 for the various projects is presented in Table 5.

Project name	Abatement cost [NOK/ton CO_2]
CCS White Rose (UK gov)	1650
CCS Peterhead (UK gov)	4850
CCS Mongstad	2900
CCS three sources	1400
CCS cement and small source	1650
CCS waste	2400
CCS ammonia	1700
CCS cement	2250
CCS minimum	2900

Table 5: Abatement cost of emission reductions via CCS (53)

Atkins Norge and Oslo Economics conclude that with today's market pricing of CO_2, an investment in CCS is not socioeconomically advantageous (53).

Knoope et al. have analyzed the net present value (NPV) of investments into CCS infrastructure solutions (54). Two alternative infrastructure solutions are analyzed: transportation of CO_2 by ship and by pipeline. Overviews of the economic estimates made by Knoope et al. are presented in Table 6 and Table 7.

CCS with pipeline solution						
	1 Mt CO_2/year		2.5 Mt CO_2/year		10 Mt CO_2/year (fixed project duration of 25 years)	
	250 km	500 km	250 km	500 km	250 km	500 km
NPV whole CCS project (MNOK)	-2854	-4029	-2588	-4532	3157	-542
Overall levelized costs (NOK/ton CO_2)	711	865	474	575	298	346
Required initial CO_2 price (NOK/ton CO_2)	696	847	464	563	291	338

Table 6: Net present value estimates of CCS with pipeline solution (54)

As can be seen in Table 6, various pipeline capacities are analyzed, along with two different distances of transportation; 250 km and 500 km. The authors also analyzed a pipeline with capacity of 10 Mt CO_2/year and limited storage capacity. This is not included because many of the CO_2 storage locations on Norwegian territory have storage capacities far exceeding 250 Mt CO_2 (55-57). Of the three areas the Barents Sea, the Norwegian Sea and the Norwegian North Sea, the Barents Sea and the Norwegian Sea have at least one storage location with sufficient capacity (56, 57). The Norwegian North Sea has several locations with capacities of the gigaton class (55). From Table 6, one can see that only storage of 10 Mt CO_2/year at a distance of 250 km yields a positive net present value, and that with an initial CO_2 price of 291 NOK/ton CO_2. Note that the CO_2-price in the report of Knoope et al. is set to increase by 3 % per year (54).

CCS with ship solution						
	1 Mt CO_2/year		2.5 Mt CO_2/year		10 Mt CO_2/year (fixed project duration of 25 years)	
	250 km	500 km	250 km	500 km	250 km	500 km
NPV whole CCS project (MNOK)	-2607	-2664	-2654	-2787	-12	-881
Overall levelized costs (NOK/ton CO_2)	679	686	478	484	339	351
Required initial CO_2 price (NOK/ton CO_2)	665	672	467	474	332	347

Table 7: Net present value estimates of CCS with ship solution (62)

As can be seen in Table 7, various ship capacities are analyzed, along with two different distances of transportation; 250 km and 500 km. The authors also analyzed a ship with capacity of 10 Mt CO_2/year and limited storage capacity. This is not included because many of the CO_2 storage locations on Norwegian territory have storage capacities far exceeding 250 Mt CO_2 (55-57). None of the proposed solutions yield a positive net present value.

2.5 Environmental impact

Hydrogen is, as of 2016, produced mainly from natural gas steam reforming without CCS, accounting for 48 % of all hydrogen production. The remainder comes from petroleum production during the refining process accounting for 30 %, coal based hydrogen represents 18 % and the rest, 4 %, is hydrogen produced with electrolysis (8). The production of this hydrogen resulted in approximately 500 million tons CO_2-equivalents worth of emissions (8).

According to Dincer and Acar (13), hydrogen production by water electrolysis has a GWP of 8 kg CO_2-equivalents/kg H_2 produced. It is not stated which energy source this electrolysis is based upon. They cite their results by basing the environmental impact numbers on Ozbilen et al (58) and Bhandari et al. (59).

According to Ozbilen et al. (58), solar based electrolysis results in approximately 2.4 kg CO_2-equivalents/kg H_2 production, considerably more than wind based electrolysis of about 0.6 kg CO_2-equivalents/kg H_2 production. Steam methane reforming accounts for roughly 11.7 kg CO_2-equivalents/kg H_2 production. This report was published in 2013. However, the calculations for solar, wind and SMR hydrogen production stem from reports of respectively 2004 (60), 2004 (61) and 2001 (62).

Bhandari et al. (59) report GWP of solar based electrolysis to range from approximately 2-8 kg CO_2-equivalents/kg H_2 produced. Hydro, wind and solar thermal electrolysis are reported to have a GWP from roughly 0.6-3 kg CO_2-equivalents/kg H_2 produced. Electrolysis with electricity fed from the power grid is reported to have a GWP of 31-32 kg CO_2-equivalents/kg H_2 produced. The latter has an enormous GWP due to a high share of fossil fuel resources in the grid electricity mix. The wider spread of values from Bhandari et al. is due to their report being based on a significantly larger number of sources, ranging from being published in 2001 to 2012.

2.5.1 Social costs of carbon

The relation social costs of carbon (SCC), expressed as social costs per ton CO_2 released, is the linking of damage due to emissions of GHGs causing changing climate with CO_2 emissions (63).

In a report published by the International Panel on Climate Change, an SCC of $ 90/t CO_2 is presented as the best estimate (63). These are 2005 USD. Their range of estimates is converted to 2017 NOK and presented in Table 8 (63).

Greenhouse gas	Minimum social cost (NOK/kg)	Best guess social cost (NOK/kg)	Maximum social cost (NOK/kg)
CO_2	0,182	0,964	3,748
CH_4	-	-	-
N_2O	-	-	-
SO_2	42,834	-	107,084
NO_X	21,417	-	107,084
nmVOC	-	-	-
NH_3	-	-	-
PM2,5	107,084	-	7535,000

Table 8: Social costs of various greenhouse gases as reported by the IPCC (63)

In a report published by the climate and pollution agency both social costs of CO_2 and abatement costs were estimated (64). Their range of estimates is presented in Table 9 (64).

Greenhouse gas	Minimum abatement cost (NOK/kg)	Maximum abatement cost (NOK/kg)	Minimum social cost (NOK/kg)	Maximum social cost (NOK/kg)
CO_2	0,255	-	-	-
CH_4	5,364	-	-	-
N_2O	79,183	-	-	-
SO_2	15	23	19	166
NO_X	26	38	32	153
nmVOC	1	2	-	-
NH_3	-	-	0	8
PM10	-	-	255	7 535

Table 9: Abatement and social costs of various greenhouse gases as reported by the Norwegian climate and pollution agency (64)

2.6 National forecast

Emissions within Norwegian territory in 2015 amounted to 53.9 million tons CO_2-equivalents (5). The main contributors are oil and gas extraction with 15.1 million tons, industry and quarrying with 11.9 million tons and road traffic with 10.3 million tons. Most of the emissions from oil and gas extraction and industry and quarrying are subject to the quotas trading system (65). Accumulated emissions subject to the quotas trading system in 2015 amounted to 27.9 million tons CO_2-equivalents (5).

Norway has committed to reducing the national emissions by at least 40 % by 2030 with respect to the emission level of 1990 (66). National emissions of 1990 amounted to 51.73 million tons CO_2-equivalents (5). By this, national emissions must be reduced by 22.86 million tons CO_2-equivalents in the period 2015-2030. In order to meet national targets, the Norwegian government takes aim to achieve a set of goals, some of which are listed in the following (67):

1. By 2025, all new passenger vehicles and cargo vans shall be zero-emission vehicles.
2. By 2025, all new city buses shall be zero-emission vehicles or run on biogas.
3. By 2030, all new heavy-duty vehicles, 75 % of all new long-distance buses and 50 % of all new trucks shall be zero-emission vehicles.
4. Ensure that all vehicle ferries utilize low or zero-emission solutions and contribute to ferries on county level and express boats utilize low or zero-emission solutions.

The Institute of Transport Economics presented in December 2016 a report where two scenarios for the Norwegian emission development toward 2050 are highlighted (68). In scenario one, “Trendbanen” translating to the trend path, current developments in the national car stock are prolonged. If this scenario comes true, CO_2 emissions from road traffic will decrease by 21 % from 2015 to 2030 (68). In 2015, national emissions amounted to 10.3 million tons CO_2-equivalents (5). By 2030 this will then amount to 8.14 million tons CO_2-equivalents, which is still more than 1990-levels of 7.77 million tons CO_2-equivalents.

Scenario two, “Ultralavutslippsbanen” translating to the ultra-low emission policy scenario, is tailored towards achieving the suggested goals set by the Norwegian transport agencies (69). These goals are in essence the same as those the Norwegian government takes aim to achieve (67). However, the Norwegian transport agencies do not allow new city buses to run on biogas as listed in point 2 above.

Nonetheless, the estimates by the Institute of Transport Economics give an impression of what the development in the transport sector might look like in the long term transition to a zero-emission transport sector (68):

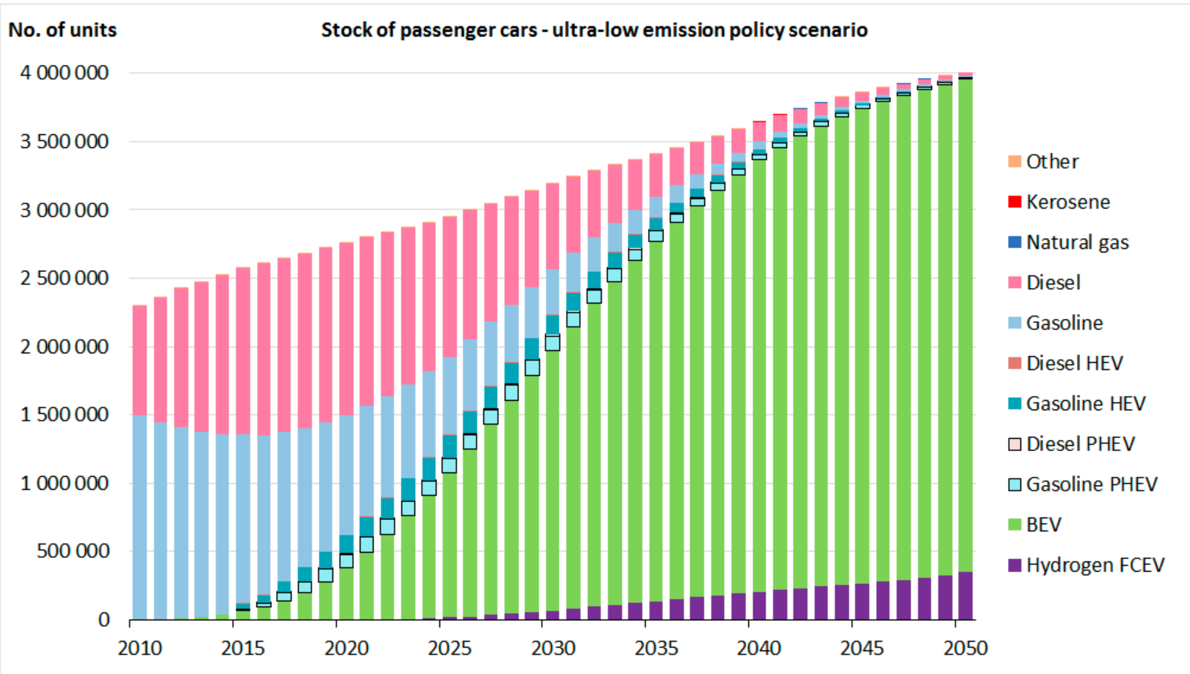

Figure 2: Composition of the Norwegian passenger vehicle stock from 2010-2050 in the ultra-low emission scenario (68). Figure reused with permission.

Figure 2 shows potential development of the Norwegian stock of passenger cars in the ultra-low emission policy scenario. In this scenario, battery electric vehicles dominate the stock of passenger cars towards 2050, taking over from diesel and gasoline.

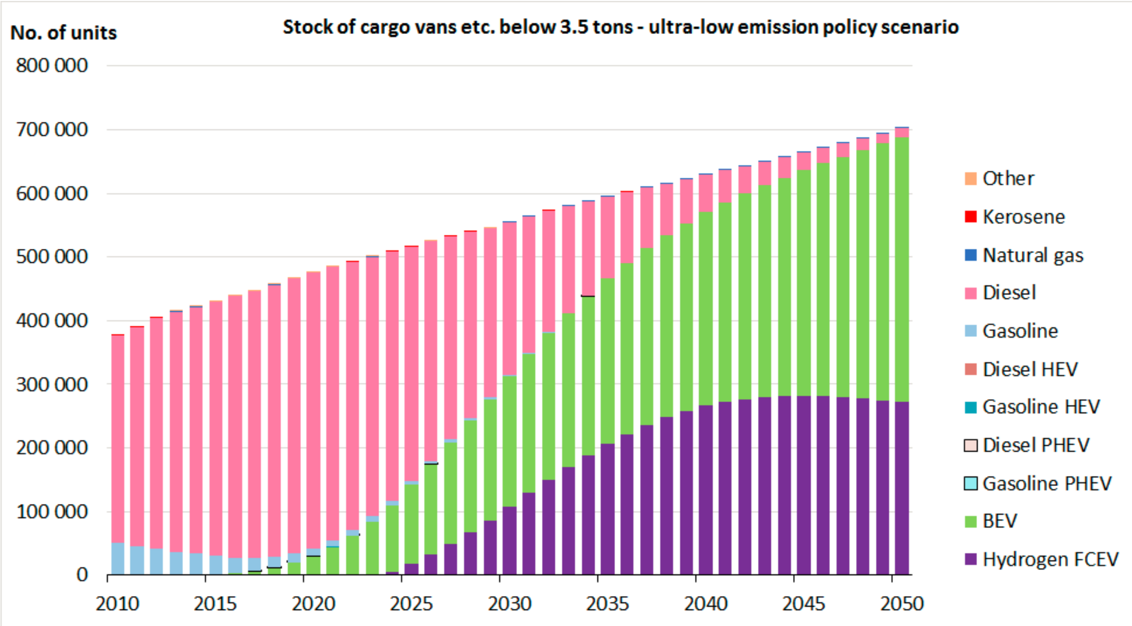

Figure 3: Composition of the Norwegian cargo van stock from 2010-2050 in the ultra-low emission scenario (68). Figure reused with permission.

Figure 3 displays potential development of the Norwegian stock of cargo vans in the ultra-low emission policy scenario. Here the stock is dominated by diesel vehicles, and is gradually substituted by battery electric vehicles and hydrogen fuel cell electric vehicles.

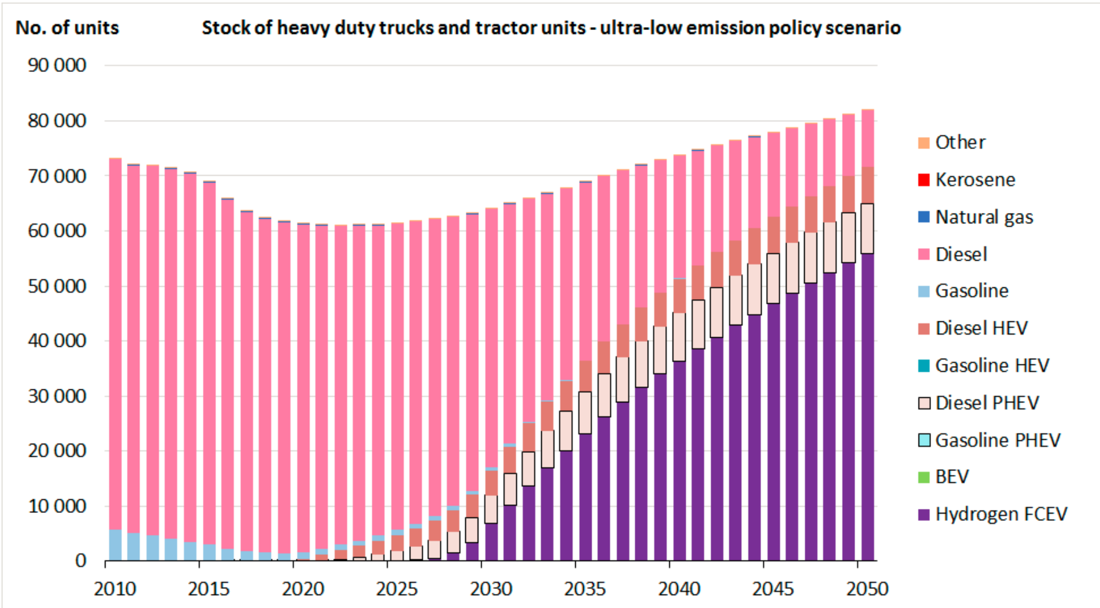

Figure 4: Composition of the Norwegian heavy-duty trucks and tractor units stock from 2010-2050 in the ultra-low emission scenario (68). Figure reused with permission.

As can be seen in Figure 4, the stock of heavy-duty trucks and tractor units in this scenario transitions mainly from diesel vehicles to hydrogen FCEVs.

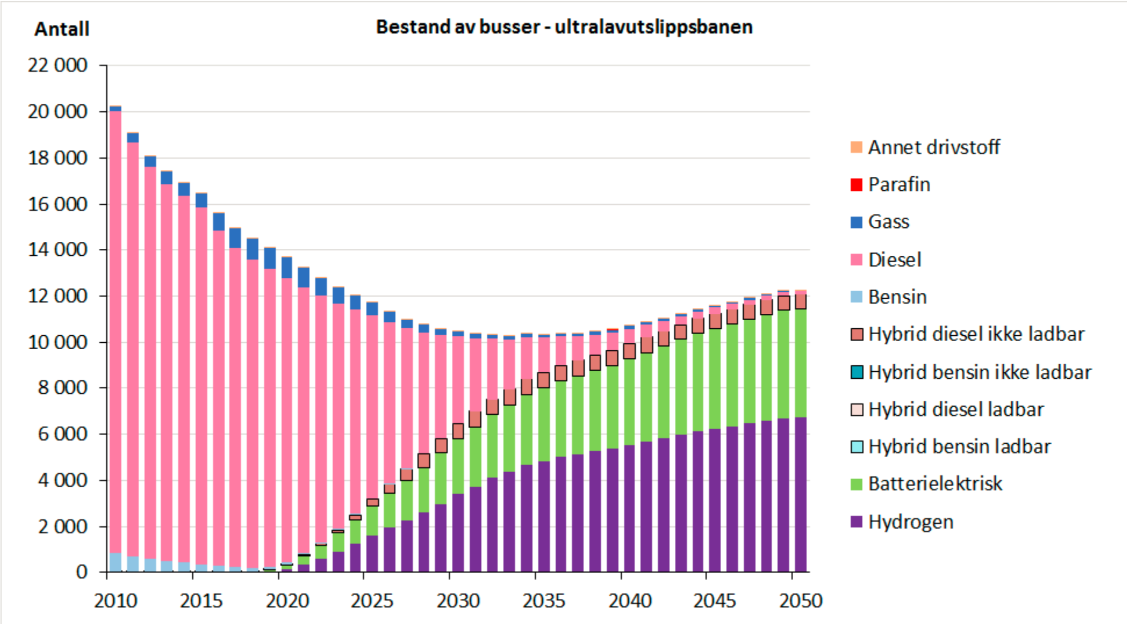

Figure 5: Composition of the Norwegian bus stock from 2010-2050 in the ultra-low emission scenario (68). Figure reused with permission.

In Figure 5, development of the Norwegian stock of buses in the ultra-low emission scenario is shown. Here, diesel vehicles presently have the majority share, while BEVs and hydrogen FCEVs gradually take over.

Based on the calculations made by the Institute of Transport Economics, it is clear that in the transition towards a zero-emission society, battery electric vehicles will be dominating in the passenger car and cargo van stocks, while hydrogen fuel cell electric vehicles will be dominating in the heavy-duty trucks and tractor units and bus stocks.

3 Economic analyses

In the following, economic analyses of hydrogen production methods and usage of hydrogen in the transport sector will be presented and the potential GHG reductions and their respective costs will be discussed in light of Norway's climate goals.

3.1 Hydrogen production methods

In this chapter, costs of hydrogen production methods discussed in chapter 2.1 are presented.

3.1.1 Steam-methane reforming method

A study performed by Bartels et al. (70) presents a hydrogen cost relationship developed by Gray and Tomlinson (71) as follows

$$C_{H_2,G\&T}\left(\frac{\$}{\text{MMBtu}}\right) = 1.27 \cdot \text{NG price}\left(\frac{\$}{\text{MMBtu}}\right) + 0.985$$

Equation 25: Relationship for cost of hydrogen (71)

Equation 25 is applicable to facilities with a production rate of around 100 million standard cubic feet per day (SCFD). This equals 236 239 kg/day. These facilities shall also have a capital cost of $ 0.65-0.8/SCFD and a thermal efficiency of 70 % or higher based on natural gas' higher heating value. With this, Bartels et al. estimated the hydrogen cost to be $ 2.48/kg in 2007 dollars. Their calculation is based on a price of natural gas of $ 10.00/MMBtu from April 2008. Adjusted to 2017 dollars this becomes

$$\begin{aligned} C_{H_2,G\&T}\left(\frac{\$}{\text{kg}}\right) &= \frac{\text{CPI in January 2017}}{\text{Annual average CPI 2007}} \cdot \text{Hydrogen cost 2007} \\ &= \frac{242.839}{207.342} \cdot 2.48\frac{\$}{\text{kg}} = \underline{2.905\frac{\$}{\text{kg}}} \end{aligned}$$

Equation 26: hydrogen cost by the Consumer Price Index inflation formula

Which in 2017 NOK becomes 24.39 NOK/kg H_2.

Consumer Price Indices (CPI) for 2007 and 2017 are collected from the Bureau of Labor Statistics (72). The 2007 average CPI is taken from the report "Annual Average Indexes 2007 (Tables 1A-23A)" in table 1A, for *all items*. The 2017 January CPI is collected from report "January 2017 (complete text and tables)" in table 1, for *all items.*

Penner (73) has given a similar hydrogen cost equation as follows

$$\mathrm{C}_{\mathrm{H_2,Penner}}\left(\frac{\$}{\mathrm{kg}}\right) = 0.286 \cdot NG\ \ price\ \frac{\$}{\mathrm{MMBtu}} + 0.15$$

Equation 27: Penner's equation for hydrogen cost (73)

According to the U.S. Energy Information Administration (74), the December 2016 natural gas price was 4.32 $/Mcf (Dollars per 1,000 cubic feet (75)). Converted to MMBtu this becomes

$$\mathrm{NG\ price}\ \frac{\$}{\mathrm{MMBtu}} = 4.32\frac{\$}{\mathrm{Mcf}} \cdot \frac{1\ \mathrm{Mcf}}{1.032\ \mathrm{MMBtu}} = \underline{4.186\frac{\$}{\mathrm{MMBtu}}}$$

Equation 28: Natural gas price conversion from $/Mcf to $/MMBtu

With this, the hydrogen cost is

$$\mathrm{C}_{\mathrm{H_2,Penner}}\left(\frac{\$}{\mathrm{kg}}\right) = 0.286 \cdot 4.186\ \frac{\$}{\mathrm{MMBtu}} + 0.15 = \underline{1.347\frac{\$}{\mathrm{kg}}}$$

Equation 29: Penner's hydrogen cost equation solved for January 2017 natural gas price

Which in 2017 NOK becomes 11.31 NOK/kg H_2.

Since the hydrogen cost from Equation 26 is based on a cost of natural gas of $ 10/MMBtu from April 2008, it is worth attempting to convert this into a price for hydrogen based on natural gas for 2017, as is done with Penner's formula.

Bartels et al. estimate a price of $ 2.48/kg H_2 when adjusted to 2007 dollars and converted from $/MMBtu to $/kg H_2. This means there are two variables to consider when using a new price for natural gas. In Penner's formula only the adjustment to 2007 dollars is performed, meaning this adjustment factor can be found by the following

$$\begin{aligned}\mathrm{Adjustment\ factor} &= \frac{3.17\frac{\$}{\mathrm{kg}}}{\left(0.286\cdot \mathrm{NG\ price}\ \frac{\$}{\mathrm{MMBtu}} + 0.15\right)\frac{\$}{\mathrm{kg}}} \\ &= \frac{3.17\frac{\$}{\mathrm{kg}}}{\left(0.286\cdot 10.00\ \frac{\$}{\mathrm{MMBtu}} + 0.15\right)\frac{\$}{\mathrm{kg}}} = \underline{1.053}\end{aligned}$$

Equation 30: Adjustment factor to 2007 dollars

Assuming the two calculations use the same adjustment factor, the conversion factor from $/MMBtu to $/kg H_2 can now be found.

$$\text{Conversion factor} = \frac{\left(1.27 \cdot \text{NG price} \frac{\$}{\text{MMBtu}} + 0.985\right)\frac{\$}{\text{kg}}}{\frac{2.48 \frac{\$}{\text{kg}}}{1.053}} = 5.811$$

Equation 31: Factor for conversion from $/MMBtu to $/kg hydrogen

As such, the January 2017 industrial natural gas price can be applied to the modified Equation 25, including the conversion factor calculated with Equation 31

$$C_{H_2,G\&T}\left(\frac{\$}{\text{kg}}\right) = \frac{1.27 \cdot \text{NG price}\left(\frac{\$}{\text{MMBtu}}\right) + 0.985}{\text{Conversion factor}}$$
$$= \frac{1.27 \cdot 4.186\left(\frac{\$}{\text{MMBtu}}\right) + 0.985}{5.811} = \underline{1.084 \frac{\$}{\text{kg}}}$$

Equation 32: Gray and Tomlinson's hydrogen cost equation solved with January 2017 natural gas price

This gives 9.1 NOK/kg H_2 in 2017 NOK.

Bartels et al. (70) also discuss two more hydrogen production plants studied by Rutkowski (76), one with carbon capture technology and one without. These plants have a production capacity of 379 387 kg H_2/day and production output of 341 448 kg H_2/day at 90 % capacity factor. Bartels et al. adjusted their estimated hydrogen costs to $ 2.55/kg H_2 and $ 2.33/kg H_2 for steam methane reforming, with and without CCS, respectively (70). This is done with the same natural gas price as previously at $ 10.00/MMBtu from April 2008 and adjustment to 2007 dollars. By adjusting for the difference in natural gas price of April 2008 and December 2016 and for inflation between 2007 and January 2017, the hydrogen cost can be estimated for January 2017 prices

$$C_{H_2,\text{Rutkowski}_{CCS}}\left(\frac{2017\,\$}{\text{kg}}\right)=2.55\frac{2007\,\$}{\text{kg}}\cdot\frac{\text{December 2016 NG price}\frac{\$}{\text{MMBtu}}}{\text{April 2008 NG price}\frac{\$}{\text{MMBtu}}}\cdot\frac{\text{CPI in January 2017}}{\text{Annual average CPI 2007}}$$
$$=2.55\frac{\$}{\text{kg}}\cdot\frac{4.186\frac{\$}{\text{MMBtu}}}{10.00\frac{\$}{\text{MMBtu}}}\cdot\frac{242.839}{207.342}=\underline{1.250\frac{2017\,\$}{\text{kg}}}$$

Equation 33: hydrogen cost with CCS based on Rutkowski (70) and adjusted to December 2016 industrial natural gas price and January 2017 Consumer Price Index

This gives 10.5 NOK/kg H_2 in 2017 NOK.

$$C_{H_2,\text{Rutkowski}_{\text{Non-CCS}}}\left(\frac{2017\,\$}{\text{kg}}\right)=2.33\frac{2007\,\$}{\text{kg}}\cdot\frac{\text{January 2017 NG price}\frac{\$}{\text{MMBtu}}}{\text{April 2008 NG price}\frac{\$}{\text{MMBtu}}}\cdot\frac{\text{CPI in January 2017}}{\text{Annual average CPI 2007}}$$
$$=2.33\frac{\$}{\text{kg}}\cdot\frac{4.186\frac{\$}{\text{MMBtu}}}{10.00\frac{\$}{\text{MMBtu}}}\cdot\frac{242.839}{207.342}=\underline{1.142\frac{2017\,\$}{\text{kg}}}$$

Equation 34: hydrogen cost without CCS based on Rutkowski (70) and adjusted to December 2016 industrial natural gas price and January 2017 Consumer Price Index

This gives 9.59 NOK/kg H_2 in 2017 NOK.

3.1.2 Biomass

Padró and Putsche (77) found hydrogen costs from biomass gasification to range from \$ 8.69/GJ H_2 produced to \$ 17.1/GJ H_2 produced using lower heating value, depending on production plant size. Based on the lower and higher heating value of hydrogen, respectively 120.0 MJ/kg and 141.8 MJ/kg (37), and accounting for inflation, the cost of hydrogen in 2017 dollars becomes

$$C_{H_2,\text{P\&P,LHV, low}}\left(\frac{\$}{\text{kg}}\right)=\frac{\text{CPI in January 2017}}{\text{Annual average CPI 1999}}\cdot C_{H_2,\text{low},1999}\cdot LHV_{H_2}$$
$$=\frac{242.839}{166.6}\cdot 8.69\frac{\$}{\text{GJ}}\cdot 0.12\frac{\text{GJ}}{\text{kg}}=\underline{1.52\frac{\$}{\text{kg}}}$$

Equation 35: Lower cost of hydrogen from Padró and Putsche (77) when accounting for inflation and lower heating value

This gives 12.76 NOK/kg H_2 in 2017 NOK.

$$C_{H_2,P\&P,LHV,high}\left(\frac{\$}{kg}\right)=\frac{\text{CPI in January 2017}}{\text{Annual average CPI 1999}}\cdot C_{H_2,high,1999}\cdot LHV_{H_2}$$
$$=\frac{242.839}{166.6}\cdot 17.1\frac{\$}{GJ}\cdot 0.12\frac{GJ}{kg}=\underline{2.99\frac{\$}{kg}}$$

Equation 36: Higher cost of hydrogen from Padró and Putsche (77) when accounting for inflation and lower heating value

This gives 25.11 NOK/kg H_2 in 2017 NOK.

$$C_{H_2,P\&P,HHV,low}\left(\frac{\$}{kg}\right)=\frac{\text{CPI in January 2017}}{\text{Annual average CPI 1999}}\cdot C_{H_2,low,1999}\cdot HHV_{H_2}$$
$$=\frac{242.839}{166.6}\cdot 8.69\frac{\$}{GJ}\cdot 0.1418\frac{GJ}{kg}=\underline{1.80\frac{\$}{kg}}$$

Equation 37: Lower cost of hydrogen from Padró and Putsche (77) when accounting for inflation and higher heating value

This gives 15.12 NOK/kg H_2 in 2017 NOK.

$$C_{H_2,P\&P,HHV,high}\left(\frac{\$}{kg}\right)=\frac{\text{CPI in January 2017}}{\text{Annual average CPI 1999}}\cdot C_{H_2,high,1999}\cdot HHV_{H_2}$$
$$=\frac{242.839}{166.6}\cdot 17.1\frac{\$}{GJ}\cdot 0.1418\frac{GJ}{kg}=\underline{3.53\frac{\$}{kg}}$$

Equation 38: Higher cost of hydrogen from Padró and Putsche (77) when accounting for inflation and higher heating value

This gives 29.64 NOK/kg H_2 in 2017 NOK.

Consumer Price Indices (CPI) for 1999 and 2017 are collected from the Bureau of Labor Statistics (72). The 1999 average CPI is taken from the report "Annual Average Indexes 2000 (Tables 1A-23A)" in table 1A, for *all items*. The 2017 January CPI is collected from report "January 2017 (complete text and tables)" in table 1, for *all items.*

3.1.3 Partial oxidation method

Using coal as a feedstock, Bartels et al. (70) have reviewed several studies done on hydrogen production facilities. The common denominator of these facilities is that they all produce electricity to one extent or another, decreasing the resulting cost of hydrogen. Assuming this electricity can be sold to utility companies or to an industrial user of hydrogen for a comparable price to what it is assumed to be sold for in Gray and Tomlinson's study (71), the relevance of the electricity produced can be neglected. Additionally, these facilities produce hydrogen in a range of 281 100-770 700 kg H_2/day. Lastly, the carbon sequestration ranges from 0-100 %, where 0 % means less costly hydrogen and vice versa. Bartels et al. report a hydrogen cost of $ 1.63/kg H_2 for a plant including CCS and a hydrogen production rate of 276 900 kg H_2/day and \$ 1.34/kg H_2 for a plant without CCS and a hydrogen production rate of 255 400 kg H_2/day. Which in NOK becomes 13.69 and 11.25 NOK/kg H_2, respectively.

3.1.4 Autothermal reforming method

Nikolaidis et al. (10) claim the optimum operating temperature for ATR hydrogen production from methane to be 700 °C. Additionally, they state the ATR investment costs to be 15-25 % lower than those of SMR. Hydrogen production from advanced large-scale ATR plants with a CO_2 capture and storage of 90 % and investment costs at about \$ 500/kW, would enable a price of \$ 1.48/kg H_2 gas produced. Which in NOK becomes 12.43 NOK/kg H_2.

3.1.5 Water electrolysis

Gray and Tomlinson have estimated costs of hydrogen from photovoltaic electrolysis varying from 0.98 to \$ 6.02/kg H_2. This is in 2007 dollars. Utilizing Equation 26 and converting to NOK, this becomes 9.64 to 59.21 NOK/kg H_2.

3.1.6 Summary

In this section, a summary of the costs of the hydrogen production technologies found in the literature is presented via Table 10 (10, 70, 71, 73, 76, 77).

Costs of hydrogen production technologies				
	Source	Scale [kg H_2/day]	CCS	Cost [NOK/kg H_2]
SMR	Gray and Tomlinson	236 239	NA	9,1
	Penner	NA	NA	11,31
	Rutkowski	379 387	Yes	10,5
	Rutkowski	341 448	No	9,59
POX	Bartels et al.	276 900	Yes	13,69
	Bartels et al.	255 400	No	11,25
ATR	Nikolaidis et al.	NA	Yes	12,43
Hydrocarbon pyrolysis	-	-	-	-
Thermochemical, biomass	Padró & Putsche	197 736	NA	12,76-15,12
	Padró & Putsche	1977	NA	25,11-29,64
Biological, biomass	-	-	-	-
Water electrolysis	Gray and Tomlinson	NA	-	9,64-59,21
Water thermolysis	-	-	-	-

Table 10: Costs of hydrogen production technologies, brief literature review

3.2 The TiZir case

In this chapter, the aim is to provide TiZir with more information on the most relevant hydrogen production technologies (78), to the end that they may decide upon a solution for their transition with a broader understanding of the long term implications of their choice.

None of the sources found on costs of hydrogen production shown in Table 10 are of the production scale relevant for the TiZir case. As such, the relevance of scaling to costs of hydrogen must be taken into account.

As hydrogen today mainly is produced by steam methane reforming and the main competitor is water electrolysis (78), these two are the technologies of focus in this study.

3.2.1 Steam-methane reforming vs electrolysis

Through talks with TiZir employee Stian Seim, a list of the most relevant information on SMR and electrolysis was developed:

SMR:

- What will the price of hydrogen be?
- When will infrastructure for CCS be available?
- How will the price of emission of CO_2 develop due to increased CO_2-tax and what consequences will that have for TiZir?
- When can a SMR facility be ready for production?

Electrolysis:

- What will the price of hydrogen be?
- When can the facility be ready for production?

The Norwegian company Reinertsen aims for the mass production of hydrogen by steam methane reforming (79). They estimate the price of hydrogen to approach 10-15 NOK/kg H_2 produced (79). The production rate accompanied with this price is not given.

In their master thesis, Jakobsen and Åtland have estimated breakeven prices of hydrogen vs. production capacity (80). Their results are presented in Figure 6.

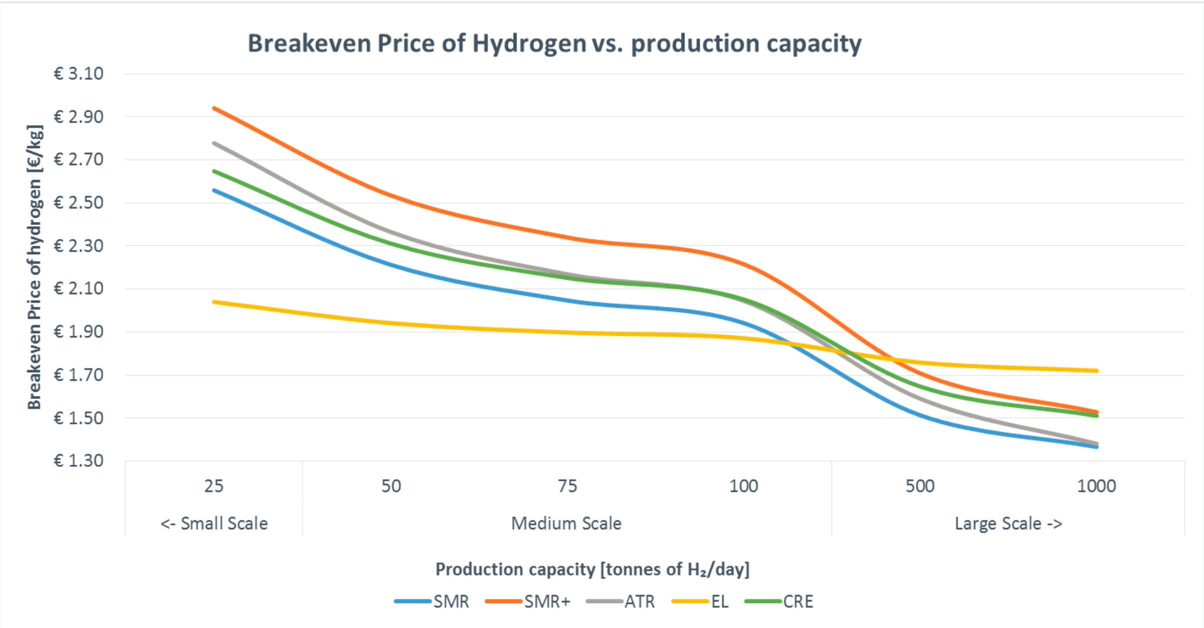

Figure 6: Breakeven price of hydrogen vs production capacity (80). Figure reused with permission.

As can be seen in Figure 6, at a production capacity of 30 tons H_2/day, which is TiZir's demand, hydrogen produced with electrolysis costs roughly € 2.1/kg H_2, which is roughly 19.7 NOK/kg H_2. This is significantly lower than all given SMR solutions. These calculations are made using an electricity price of 188.32 NOK/MWh and 1.6 NOK/Sm^3. By this, hydrogen production facilities using SMR must be of a scale 10 times greater or more than what TiZir needs. One possibility is centralized production of hydrogen with SMR and distribution.

Greenstat AS have delivered an offer to TiZir on hydrogen production of 30 tons H_2/day (81). In this offer, they propose a price of hydrogen of 22.04 NOK/kg H_2. In this calculation, a constant electricity price of 260 NOK/MWh is assumed. They also state that if governmental financial support is given to the project, the price of hydrogen decreases to 19.89 NOK/kg H_2 with the same electricity price. Greenstat estimated potential operation of the hydrogen production facility to begin 2021, but this has been offset since then (81).

According to a report on CCS by Oslo Economics and Atkins, establishment of CCS infrastructure needs 8 years from start of project to operation (53).

For TiZir to be able to go through with their expansion, the central electricity grid must be upgraded (81). Through talks with the industry, the required upgrade is estimated to take roughly 10 years (82). As the upgrade of the central grid appears to require longer time than the other factors, there should be no solution that presents a sooner start of operation than the other.

The most uncertain factor is the development of the price of hydrogen by SMR due to development of CO_2-taxes. First and foremost, for CCS to become an economically viable option on the long term, the price of CO_2 has to increase to a level of 500-600 NOK/ton CO_2 (53). The development of the ranges of CO_2-price needed to limit global warming to 2 °C have been estimated by the Intergovernmental Panel on Climate Change (IPCC) and the International Center for Climate Governance (ICCG), listed in Table 11 below (53):

Development of CO_2-prices for a limited global warming [NOK/ton CO_2]			
Source	2020	2030	2050
IPCC low	121	197	522
IPCC high	1846	3098	6789
IPCC average	452	798	2040
IPCC median	395	645	1573
ICCG average	303	575	2085
ICCG median	265	605	1692

Table 11: Development of CO_2-prices when limiting global warming to 2 °C (53)

In Table 11, the notation low and high represent minimum and maximum values for the CO_2-price needed to limit global warming to 2 °C. The average and median values are to be considered the values closest to reality.

Outlooks on the price of CO_2 based on today's prices in EU ETS are given in Table 12 (53),

Development of CO_2-prices based on status quo [NOK/ton CO_2]			
Source	2020	2030	2050
EU ETS future projections	41	60	131
Thompson Reuters linear projections	164	297	707

Table 12: Development of CO_2-prices based on status quo (53)

To find out what consequences this can have for TiZir, estimates for emissions must be made.

Businesses bound by the quota system must deliver an equal amount of quotas to the amount of tons CO_2-equivalents they have emitted (83). This means one quota equals one ton CO_2-equivalent.

TiZir have been awarded roughly 356 000 quotas each year for 2017-2020 (84). Their emissions of 2016 amounted to approximately 250 000 tons CO_2-equivalents.

Hydrogen produced by SMR with CCS has potential of zero-emissions as all carbon dioxide is stored instead of released to the atmosphere. Based on estimates stating replacement of coal with hydrogen in today's production line resulting in emissions amounting to 60 000 tons CO_2, which is down from 300 000 tons CO_2 when using coal, TiZir's emissions after expansions can be estimated.

The Norwegian Environment Agency reports that the first expansion will reduce emissions by 450 000 tons CO_2, and that the last expansion will reduce emissions by 900 000 tons CO_2 in comparison to what would have been the case with usage of coal (85). TiZir's actual emissions after these expansions are estimated assuming linear correlation in Equation 39 and Equation 40:

$$E_{\text{TiZir,exp 1}} = \left(60000 \cdot \frac{450000}{240000}\right) \frac{\text{tonnes CO}_2}{\text{year}} = \underline{112500 \frac{\text{tons CO}_2}{\text{year}}}$$

Equation 39: TiZir's emissions after the first expansion when using hydrogen

$$E_{\text{TiZir,exp 2}} = \left(60000 \cdot \frac{900000}{240000}\right) \frac{\text{tonnes CO}_2}{\text{year}} = \underline{225000 \frac{\text{tons CO}_2}{\text{year}}}$$

Equation 40: TiZir's emissions after the second expansion when using hydrogen

The total emissions connected to TiZir's production line in these scenarios are found by also estimating emissions due to production of hydrogen.

If hydrogen is produced by the use of electrolyzers and renewable electricity, Equation 39 and Equation 40 give the total emissions connected to TiZir's production line. If hydrogen is produced by the use of steam methane reforming with CCS, this is also the case assuming the CCS solution includes no leakage of CO_2 and that all CO_2 from SMR is captured.

If hydrogen is produced by the use of SMR without CCS, these emissions must also be calculated.

Chen et al. have estimated moles CO_2-emissions per mole H_2 produced from steam methane reforming to be approximately 0.45 mol CO_2/mol H_2 produced (86). Converted to kg CO_2/kg H_2 this becomes:

$$\frac{m_{CO_2}}{m_{H_2}} = \frac{n_{CO_2} \cdot M_{CO_2}}{n_{H_2} \cdot M_{H_2}} = \frac{0.45 \text{ mol CO}_2 \cdot 44.009 \frac{\text{g CO}_2}{\text{mol CO}_2}}{1 \text{ mol H}_2 \cdot 2.016 \frac{\text{g H}_2}{\text{mol H}_2}} = \underline{9.823 \frac{\text{kg CO}_2}{\text{kg H}_2}}$$

Equation 41: Emitted CO_2 related to H_2 in SMR as estimated by Chen et al. (86)

With a daily production of 30 tons H_2/day, the annual CO_2-emissions are given by

$$m_{CO_2,\text{emissions}} = 9.823 \frac{\text{kg CO}_2}{\text{kg H}_2} \cdot 30000 \frac{\text{kg H}_2}{\text{day}} \cdot 365 \frac{\text{days}}{\text{year}} = \underline{107\,560 \frac{\text{tonnes CO}_2}{\text{year}}}$$

Equation 42: Annual CO_2-emissions without CCS

Assuming 30 tons H_2/day will cover today's production line, expansions 1 and 2 will cause emissions of 201.68 Mtons CO_2/year and 403.35 Mtons CO_2/year, respectively.

Some uncertainty exists among the industry when it comes to how much of CO_2-emissions CCS solutions are able to capture. Due to a high share of nitrogen in the exhaust gases, capture of CO_2 appears to be limited to 90 % where SMR is concerned (87). In addition to this, Gassnova estimates leakage of CO_2 connected to CCS to be less than 0.0001 % of injected amount. This would increase expected costs, but it is neglected due to this amount being very small.

The potential costs due to CO_2-emissions are given in Table 13 . TiZir's 356 000 quotas are assumed to be constant.

Costs of CO_2-emissions [MNOK]							
		Today's production line		Expansion 1		Expansion 2	
		CCS	No CCS	CCS	No CCS	CCS	No CCS
IPCC low	2030	13,9	33,0	26,1	61,9	52,3	123,8
	2050	36,9	87,5	69,3	164,0	138,5	328,0
IPCC high	2030	219,2	519,1	411,0	973,3	822,0	1946,6
	2050	480,4	1137,6	900,7	2133,0	1801,4	4265,9
IPCC average	2030	56,5	133,7	105,9	250,7	211,7	501,4
	2050	144,3	341,8	270,6	640,9	541,3	1281,8
ICCG average	2030	40,7	96,3	76,3	180,7	152,6	361,3
	2050	147,5	349,4	276,6	655,1	553,2	1310,1
EU ETS future projections	2030	4,2	10,1	8,0	18,9	15,9	37,7
	2050	9,3	22,0	17,4	41,2	34,8	82,3
Thompson Reuters linear projections	2030	21,0	49,8	39,4	93,3	78,8	186,6
	2050	50,0	118,5	93,8	222,1	187,6	444,2
CCS economically viable	-	38,9	92,2	73,0	172,8	145,9	345,6

Table 13: Costs of CO_2-emissions in TiZir's production line

As can be seen, CO_2-emissions can become very costly due to increased CO_2-taxation. Depending on which development occurs, the costs with today's production line and CCS vary from 9.3 MNOK to 480.4 MNOK.

3.3 Hydrogen usage in the transport sector, socioeconomic analysis

Calculation of net present value over the period 2017-2030 of the fossil fueled vehicles is performed by utilizing the general equation below:

$$\mathrm{NPV}_{\mathrm{fossil}} = \sum_{\mathrm{i}=0}^{13} \frac{\sum \mathrm{Costs}_{\mathrm{emission\ type}}}{(1+r)^i}$$

Equation 43: General equation for the net present value of fossil fueled vehicles

Here r is the required rate of return, which in this report is assumed to be 4 % based on an expert committee's analysis of frameworks for socioeconomic analyses (88). Their estimation is based on the Government Pension Fund Global's (GPFG) real rate of return of 2.5 % from government bonds plus risk premium of 1.5 % (88). One might therefore argue that the required rate of return should be decreased to 3 %, based on the GPFG's required rate of return most likely being decreased from 4 % to 3 % (89). The net present value is evaluated over a period of 14 years to evaluate the compatibility with Norway's climate goals.

The socioeconomic importance of the most significant changes in the sector is evaluated. This means the transition from diesel and gasoline vehicles to hydrogen FCEVs and EVs is the focus.

The calculations in this chapter are based on the following assumptions and simplifications:

- A scenario for production costs for an arbitrary hydrogen or electric bus or heavy-duty truck based on the development of hydrogen buses given by FCH is evaluated (90). Due to ASKO director Jørn Endresen's estimates of cost compatibility between hydrogen and diesel heavy-duty trucks by the early 2020s (35), another scenario is added where governmental expenses due to purchase of hydrogen heavy-duty trucks converges to zero in 2030. Convergence by early 2020s is not included due to the major disparity in estimates by Endresen and FCH (35, 90).
- It is also assumed that this reduction in costs is mirrored in relative terms by public support awarded for purchase of such vehicles.
- For hydrogen FCEVs in each separate sector, it is assumed that 50 % more fueling stations than what is theoretically necessary must be established in order to supply all vehicles.
- In the calculations of the net present value of the hydrogen value chain, governmental expenses due to operation and maintenance of hydrogen fueling stations and distribution of hydrogen are neglected.
- The emissions of diesel and gasoline vehicles are assumed to decrease linearly by 32.5 % from 2017 to 2030. Over the period 2030-2050, emissions of diesel and gasoline vehicles are assumed to decrease linearly by an additional 25 %. This is loosely based on the Ministry of Finance's report of 2016, where the development of annual average CO_2-emissions from new passenger vehicles from 2001 to 2015 is presented (91). Over these 14 years, the annual average CO_2-emissions have decreased from roughly 180 to 100 g CO_2/km.
- For the reference scenario of status quo prolonged, it is assumed that 55 % and 45 % of all new vehicles in the period 2017-2050 are respectively diesel and gasoline vehicles.
- The development of vehicle stocks are set from ITE's report from 2016 (68).

Statistics of emissions from passenger vehicles, cargo vans and heavy-duty trucks are collected from the Norwegian Public Roads Administration (NPRA) and shown in Table 14 (92).

National emissions by vehicle and fuel type, 2013										
Vehicle type	Fuel type	CO_2 (1000 tonnes)	CH_4 (tonnes)	N_2O (tonnes)	SO_2 (tonnes)	NO_X (tonnes)	NMVOC (tonnes)	NH_3 (tonnes)	Particles - PM10 (tonnes)	Particles - PM2,5 (tonnes)
Passenger vehicles	Gasoline	2 571	355	40	7	4 077	6 105	997	39	39
	Diesel	2 943	16	84	14	8 732	638	19	351	333
Cargo vans	Gasoline	76	16	3	0	175	278	23	2	2
	Diesel	1 459	7	30	7	5 272	283	7	364	346
Heavy duty trucks	Gasoline	33	6	0	0	297	178	0	0	0
	Diesel	2 847	11	65	13	16 165	435	8	261	248

Table 14: National emissions by vehicle and fuel type, 2013 (92)

The emission numbers of Table 14 are combined with national numbers for kilometers driven by the various vehicle and fuel types for 2016 (93), developing specific estimates for emissions per kilometer driven. The result of this is shown in Table 15.

Emissions, by vehicle and fuel type											
Vehicle type	Fuel type	Million kilometers driven	kg CO_2/km	kg CH_4/km	kg N_2O/km	kg SO_2/km	kg NO_X/km	g NMVOC/kr	kg NH_3/km	kg PM10/km	kg PM2,5/km
Passenger vehicles	Gasoline	12110,2	0,2123	0,0000293	0,0000033	0,0000006	0,0003367	0,0005041	0,0000823	0,0000032	0,0000032
	Diesel	20420	0,1441	0,0000008	0,0000041	0,0000007	0,0004276	0,0000312	0,0000009	0,0000172	0,0000275
Cargo vans	Gasoline	268	0,2832	0,0000596	0,0000112	0,0000000	0,0006520	0,0010358	0,0000857	0,0000075	0,0000002
	Diesel	6984	0,2089	0,0000010	0,0000043	0,0000010	0,0007549	0,0000405	0,0000010	0,0000521	0,0000286
Heavy duty trucks	Gasoline	0,1	330,0000	0,0600000	0,0000000	0,0000000	2,9700000	1,7800000	0,0000000	0,0000000	0,0000000
	Diesel	1971	1,4443	0,0000056	0,0000330	0,0000066	0,0082006	0,0002207	0,0000041	0,0001324	0,0000205
Buses	Gasoline	2	0,2832	0,0000596	0,0000112	0,0000000	0,0006520	0,0010358	0,0000857	0,0000075	0,0000002
	Diesel	527	0,2089	0,0000010	0,0000043	0,0000010	0,0007549	0,0000405	0,0000010	0,0000521	0,0000286

Table 15: Emissions, by vehicle and fuel type

As the NPRA did not provide numbers for buses, these are assumed to equal those of cargo vans. Additionally, as the estimates for heavy-duty trucks running on gasoline in Table 15 do not appear realistic, the numbers for heavy-duty trucks running on diesel will be used here. It is assumed that the annual amount of kilometers driven on Norwegian roads is constant over the evaluated periods. An essential factor when calculating emissions in the transport sector is the projected amount of vehicles for the time period evaluated. The Institute of Transport Economics (ITE) in Norway have made an estimate of this, the results of which are presented in Table 17 through Table 20 (68).

Vehicle stock development, current path								
Year	2015	2020	2025	2030	2035	2040	2045	2050
Cargo vans	430170	475678	515494	542128	552762	556363	567368	590971
Heavy duty trucks	60572	51232	49183	48343	47919	48027	48556	49506
Tractor units	8506	10056	11984	13799	15495	16905	18255	19790
Buses	16484	13656	11737	10586	10427	10596	10689	10688
Passenger vehicles	2578424	2758593	2910881	3074099	3256107	3449440	3629604	3759532

Table 16: Vehicle stock development, current path (68)

Table 16 shows vehicle stock development along the current path estimated by ITE in their current path scenario (68). It is these numbers scenario status quo prolonged is based on. The calculations in this report evaluate the period 2017-2050, and interpolation and extrapolation is performed for the years not specified by ITE.

Passenger vehicles stock projection, by fuel								
Year	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	1237057	871805	571155	329243	149564	55153	20049	7287
Diesel	1220981	1263550	1020751	627367	315364	140470	59417	24032
BEV	68995	377987	1058034	1901929	2634358	3159089	3472458	3607597
Hydrogen	19	374	16591	68037	136801	206485	266656	348616

Table 17: Passenger vehicle stock projection, by fuel (68)

Table 17 shows the most significant changes projected by ITE in their ultra-low emissions scenario from 2015 to 2050 (68) in the passenger vehicle stock. BEVs are projected to take over most of the passenger vehicle stock, while diesel and gasoline consequently lose their shares. Hydrogen FCEVs are projected to take only a small share of the stock. The sum of passenger vehicles is projected to increase from roughly 2.58 million vehicles in 2015 to 4 million vehicles in 2050 (68). The calculations in this report evaluate the period 2017-2050, and interpolation and extrapolation is performed for the years not specified by ITE.

Cargo vans stock projection, by fuel								
Year	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	29141	12011	5517	2258	671	194	59	12
Diesel	398845	433172	369182	239910	127990	59124	27595	14051
BEV	1805	30231	123937	204687	259778	304169	354265	417393
Hydrogen	0	12	17756	108291	205959	265965	281772	271450

Table 18: Cargo van stock projection, by fuel (68)

Table 18 shows the most significant changes projected for the cargo van stock by ITE in their ultra-low emissions scenario from 2015 to 2050 (68). Here, both BEVs and hydrogen FCEVs are projected to take close to equal and major shares of the stock, while gasoline and diesel consequently decrease significantly. The sum of cargo vans is projected to increase from roughly 430 000 to 703 000 vehicles over the time period.

Heavy duty trucks and tractor units stock projection, by fuel								
Year	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	2982	1242	901	577	81	5	1	0
Diesel	65809	59360	55627	46883	32313	22398	15407	10382
BEV	2	1	0	0	0	0	0	0
Hydrogen	0	0	60	6757	23163	36321	46825	55895

Table 19: Heavy-duty trucks and tractor unit stock projection, by fuel (68)

Table 19 shows the most significant changes projected for the heavy-duty truck and tractor unit stock by ITE in their ultra-low emissions scenario from 2015 to 2050 (68). Here, BEVs are projected to essentially have no share. Diesel remains the dominant fuel used in this period, even though its share is halved. Hydrogen FCEVs are projected to come to the market around 2025, rapidly increasing its share after entry. This projection is conservative, as Nikola One expect to begin delivering their trucks in 2020 (43) and ASKO as soon as 2018 will have heavy-duty trucks running on hydrogen (94). The sum of heavy-duty trucks is projected to decrease from roughly 60 000 to 58 500 vehicles, while tractor units are projected to increase from roughly 8 500 to 23 500 units. Note that here both heavy-duty trucks and tractor units are accounted for; while in the calculations in this thesis heavy-duty trucks are assumed to represent the average unit in this sector.

Bus stock projection, by fuel								
Year	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	297	90	38	21	3	0	0	0
Diesel	15498	12345	7919	3769	1493	639	263	142
BEV	11	171	1281	2429	3186	3741	4350	4725
Hydrogen	5	153	1607	3390	4841	5526	6242	6721

Table 20: Bus stock projection, by fuel (68)

Table 20 shows the most significant changes projected for the bus stock by ITE in their ultra-low emissions scenario from 2015 to 2050 (68). Hydrogen FCEVs are projected to take the largest share in this sector, closely followed by BEVs. Consequently, diesel vehicles are projected to decline from roughly 15 500 to barely 100. The amount of buses is projected to decrease from roughly 16 500 to 12 000 vehicles over the period.

3.3.1 Passenger vehicles

In a report published by the Norwegian Environment Agency, governmental outcome due to purchase of EVs are 70 000 NOK for a small EV and 435 000 NOK for a big EV (95). In the following calculations, it is assumed that these expenses are valid for FCEVs as well. In addition, it is assumed that governmental expenses due to purchase of EVs and hydrogen FCEVs decrease by 0.5 % for every thousand vehicles of the respective category sold. 15 % of all EVs and FCEV are assumed to be of the category 'big', while the remaining 85 % are assumed to be of the category 'small'.

Through email correspondence with Tor Kjetil Bergsaker of Uno-X, it became clear that governmental expenses for one of their hydrogen stations, the "Car-200", is 10 MNOK (96). One such station has the capacity to cover hydrogen consumption of 486.67 hydrogen vehicles. This ratio is used as basis for calculations for all hydrogen stations. It is assumed that governmental expenses connected to establishment of hydrogen stations decrease over time. The nature of this decrease is uncertain, and a range of 1-2 % reduction per hydrogen station established is used in these calculations. As hydrogen passenger vehicles will receive financial support from the government until year 2025 or until 50 000 hydrogen passenger vehicles have been purchased (91), both these scenarios are evaluated. The results are given in Figure 7 and Figure 8.

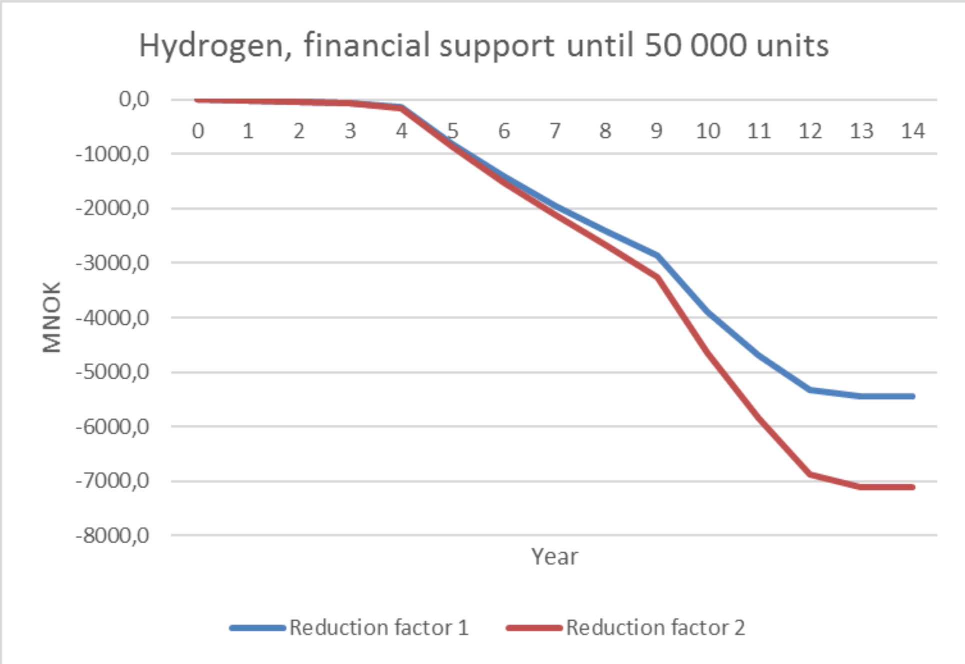

Figure 7: Net present value development for hydrogen passenger vehicles with financial support until 50 000 units and required fueling stations

Figure 7 shows the range of net present values of the costs for hydrogen passenger vehicles and required fueling stations with financial support until 50 000 units. Evaluating over the 14-year period renders net present values from -5 441 MNOK to -7 127 MNOK. The stock of hydrogen FCEVs reach 50 000 units early in year 13, meaning NPV difference from years 12 to 14 mostly comes from public financial support for fueling stations. See Appendix 1: Tables and calculations for relevant tables.

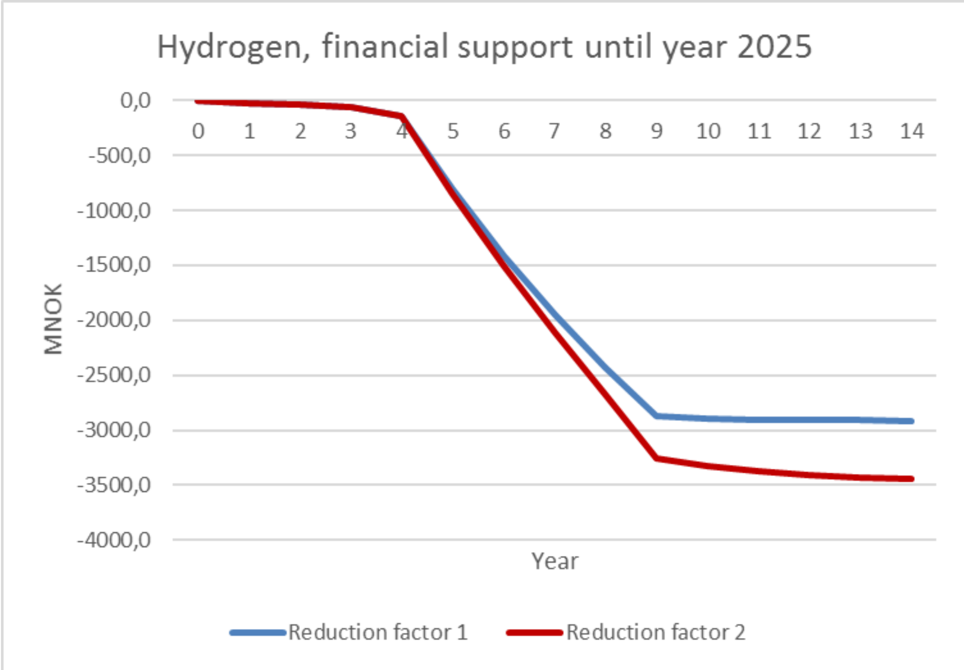

Figure 8: Net present value development for hydrogen passenger vehicles with financial support until year 2025 and required fueling stations

Figure 8 shows the range of net present values of the costs for hydrogen passenger vehicles and required fueling stations with financial support until year 2025. Evaluating over the 14-year period renders net present values from -2 913 MNOK to -3 447 MNOK. The hydrogen FCEV stock reaches 16 591 units by year 2025, which is an increase of 16 501 units from the start of 2017. The NPV difference from years 9 to 14 only comes from public financial support for fueling stations.

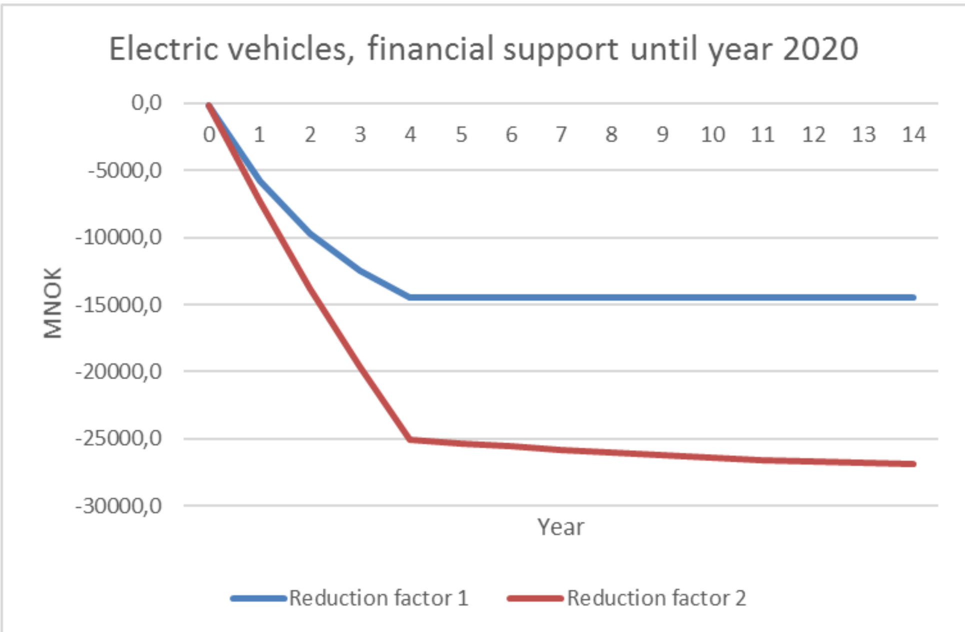

Figure 9: Net present value development for electric passenger vehicles with financial support until year 2020 and required rapid charging stations

Figure 9 shows the range of net present values of the costs for electric passenger vehicles with financial support until year 2020 and required rapid charging stations. Evaluating over the 14-year period renders NPVs from -14 499 MNOK to -26 929 MNOK. The EV stock reaches 377 987 units by 2020, which is an increase of 247 194 units from the start of 2017. The abrupt change from year 4 to 5 is due to purchases of EVs no longer being publicly financially supported and the assumption that governmental expenses to rapid charging stations decrease by 0.1 % for reduction factor 1 and 0.01 % for reduction factor 2 for each station established.

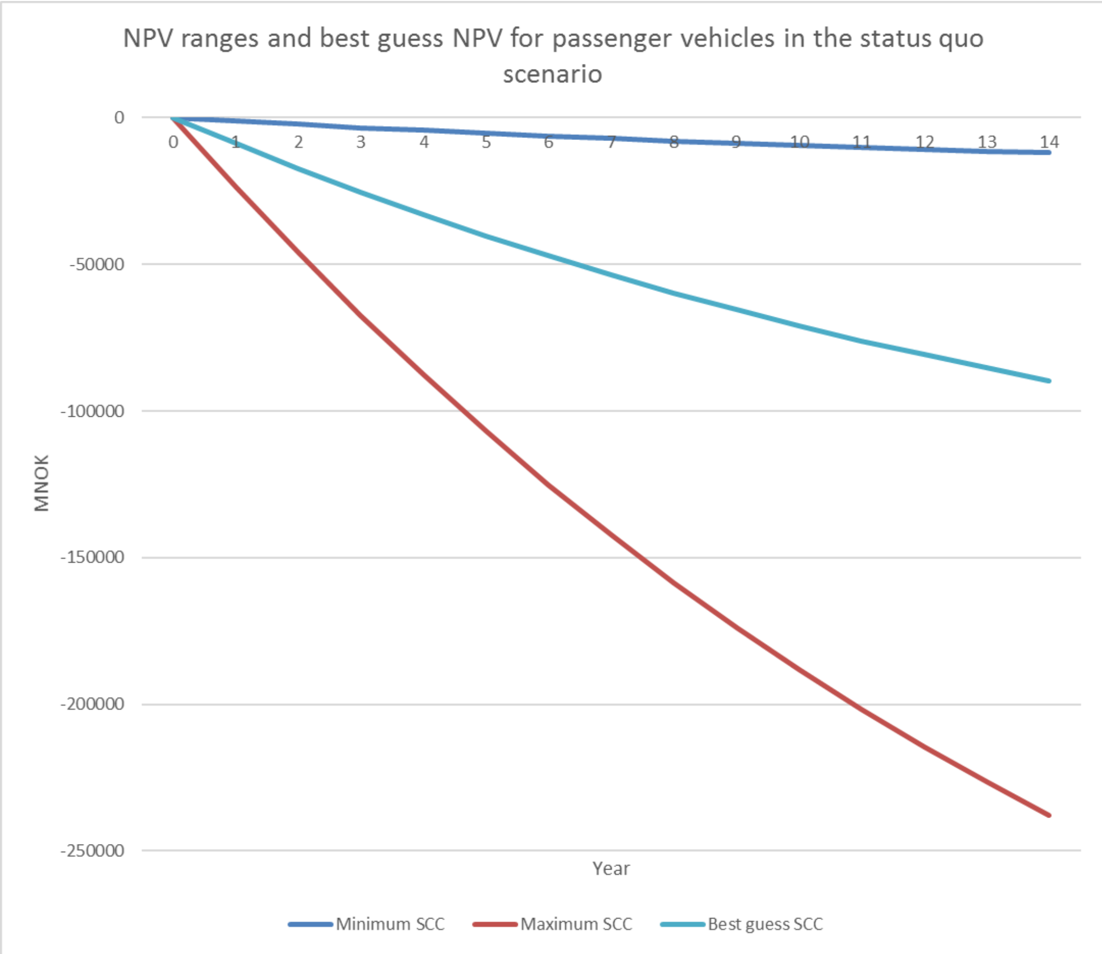

Figure 10: NPV ranges and best guess NPV for passenger vehicles in the status quo scenario

Figure 10 shows the range of net present values of the social costs of carbon in the status quo scenario. In this scenario, no zero-emission vehicles are purchased and no hydrogen fueling stations nor charging stations are established in the evaluated period. However, the total amount of passenger vehicles continues along its current path. This combined with the numbers for social and abatement costs of emissions from Table 8 and Table 9 results in the range of NPV values seen in Figure 10. The "Best guess SCC" represents estimated values based on IPCC's "best guess" value for the social cost of CO_2 (97) and combined with Table 9. See Appendix 1: Tables and calculations for more details.

Combining all previously shown results from passenger vehicles, calculations can be made for the net present value of the ultra-low emission path. This is shown in Figure 11.

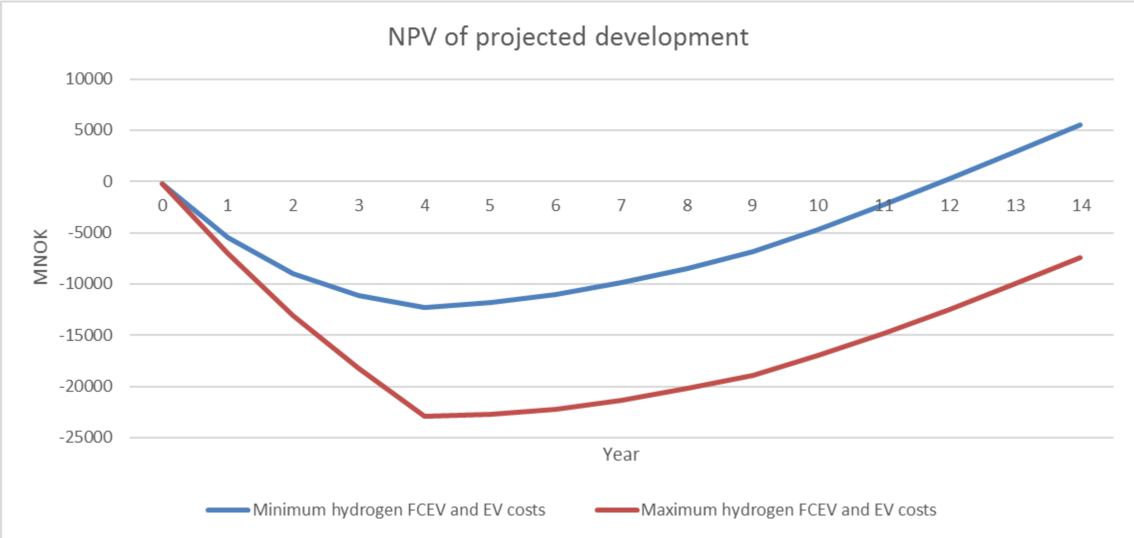

Figure 11: Net present value of the ultra-low emission path with evaluation period 2017-2030

The net present value of the ultra-low emission path involves great investments over the first four years, mostly due to public financial support of EV purchases. Assuming this investment causes the stock development of zero-emission vehicles to increase according to the Norwegian Institute of Transport Economics, reduction of emissions lead to this investment being socioeconomically sound when evaluating over a period of 14 years with an NPV of 5 533 MNOK when assuming minimum hydrogen FCEV and EV costs. When assuming maximum hydrogen FCEV and EV costs, the NPV of investment into the projected development is -7 431 MNOK. See Appendix 1: Tables and calculations for more details.

Calculations were also made for the period 2017-2050. These can be seen in Figure 12.

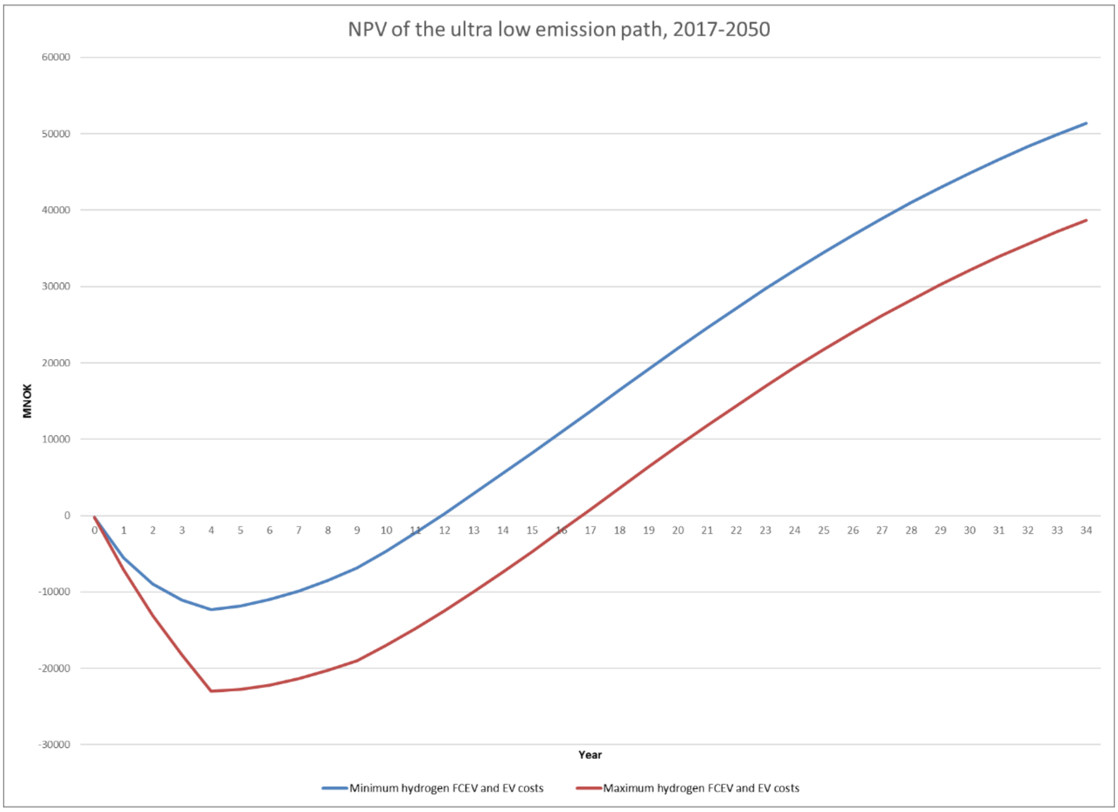

Figure 12: Net present value of the ultra-low emission path for passenger vehicles with evaluation period 2017-2050

The net present value of the ultra-low emission path involves great investments over the first four years, mostly due to public financial support of EV purchases. After these governmental expenses have ended, what remains are smaller investments in hydrogen FCEV stock, hydrogen fueling stations and rapid charging stations. Evaluating for 2017-2050 gives an NPV of 51 389 MNOK when assuming minimum hydrogen FCEV and EV costs. When assuming maximum hydrogen FCEV and EV costs, the NPV of investment into the projected development is 38 665 MNOK. See Appendix 1: Tables and calculations for more details.

3.3.2 Cargo vans

In the following calculations, parameters for governmental expenses due to purchase of passenger EVs from chapter 3.3.1 are assumed to be valid for electric and hydrogen cargo vans as well.

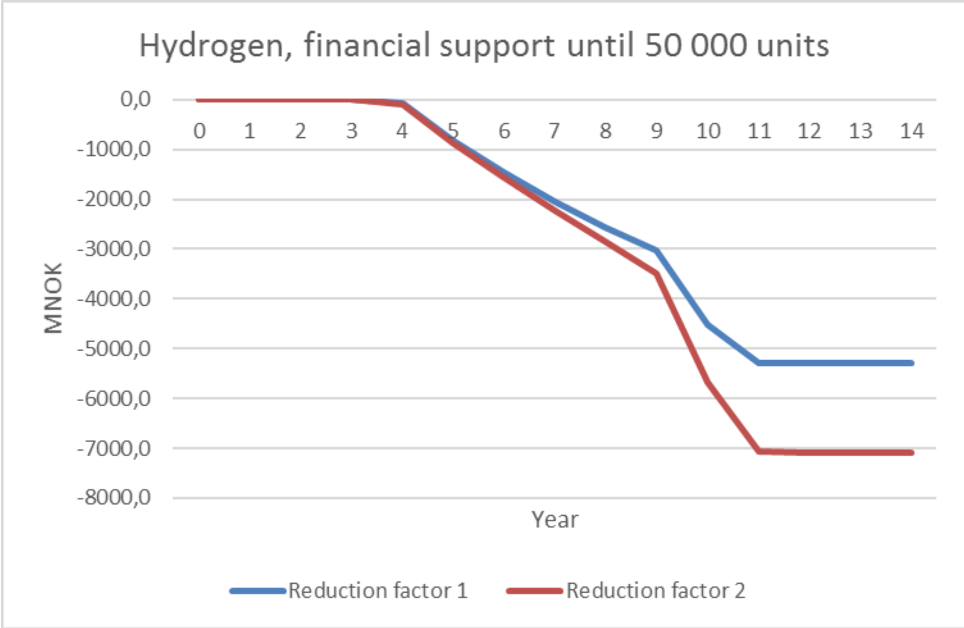

Figure 13: Net present value development for hydrogen cargo vans with financial support until 50 000 units and required fueling stations

Figure 13 shows the range of net present values of the costs for hydrogen cargo vans and required fueling stations with financial support until 50 000 units. Evaluating over the 14-year period renders net present values from -5 296 MNOK to -7 098 MNOK. The stock of hydrogen FCEVs reach 50 000 units in year 11, meaning NPV difference from years 11 to 14 only comes from public financial support for fueling stations. See Appendix 1: Tables and calculations for relevant tables.

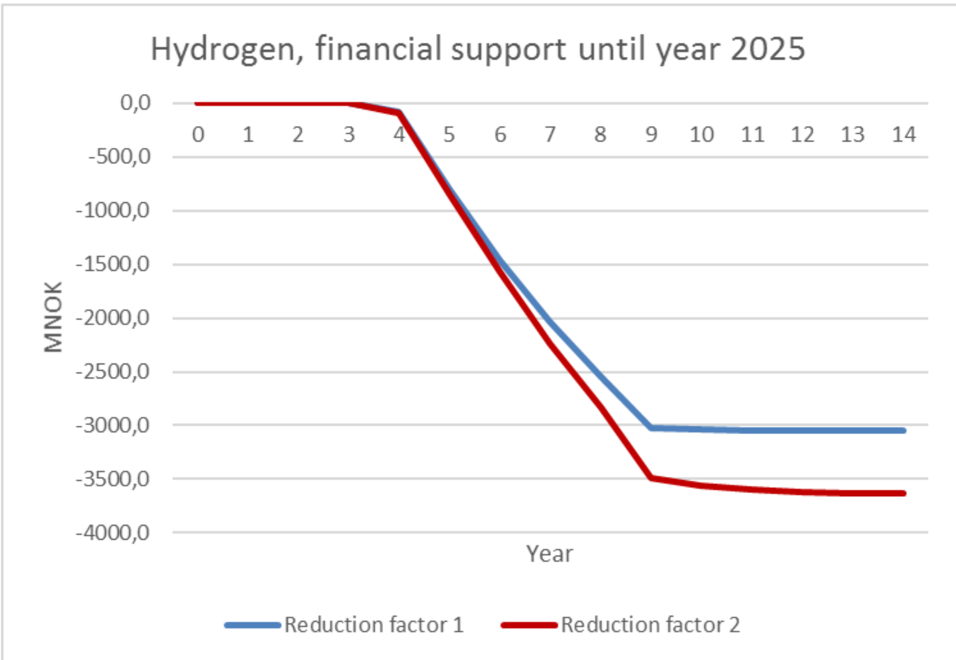

Figure 14: Net present value development for hydrogen cargo vans with financial support until year 2025 and required fueling stations

Figure 14 shows the range of net present values of the costs for hydrogen cargo vans and required fueling stations with financial support until year 2025. Evaluating over the 14-year period renders net present values from -3 047 MNOK to -3 638 MNOK. The hydrogen FCEV stock reaches 17 756 units by year 2025, which is an increase of 17 754 units from the start of 2017. The NPV difference from years 9 to 14 only comes from public financial support for fueling stations.

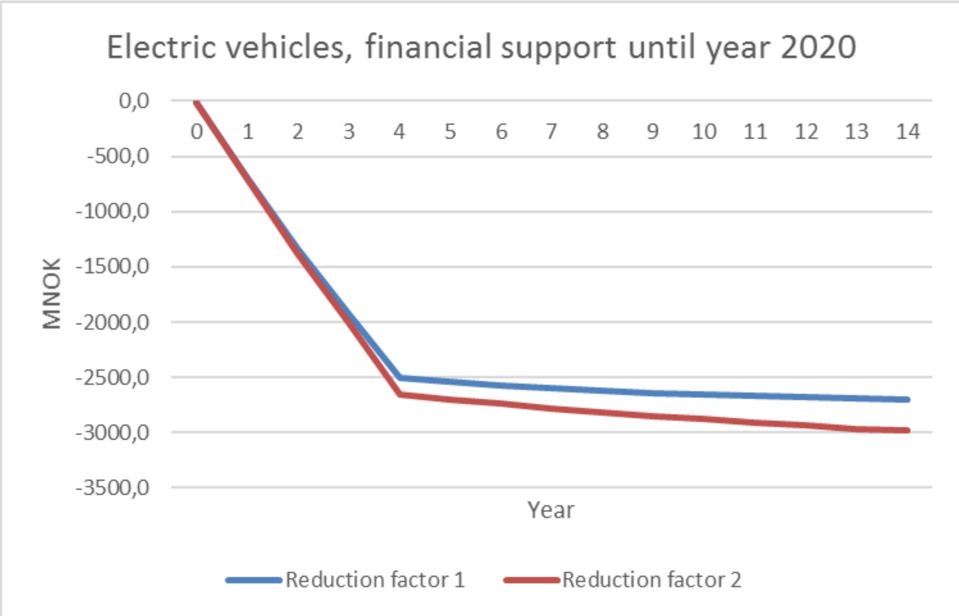

Figure 15: Net present value development for electric cargo vans with financial support until year 2020 and required rapid charging stations

Figure 15 shows the range of net present values of the costs for electric cargo vans with financial support until year 2020 and required rapid charging stations. Evaluating over the 14-year period renders NPVs from -2 699 MNOK to -2 981 MNOK. The EV stock reaches 30 231 units by 2020, which is an increase of 22 741 units from the start of 2017. The abrupt change from year 4 to 5 is due to the stop of public financial support of EV purchases and the assumption that governmental expenses to rapid charging stations decrease by 0.1 % for reduction factor 1 and 0.01 % for reduction factor 2 for each station established.

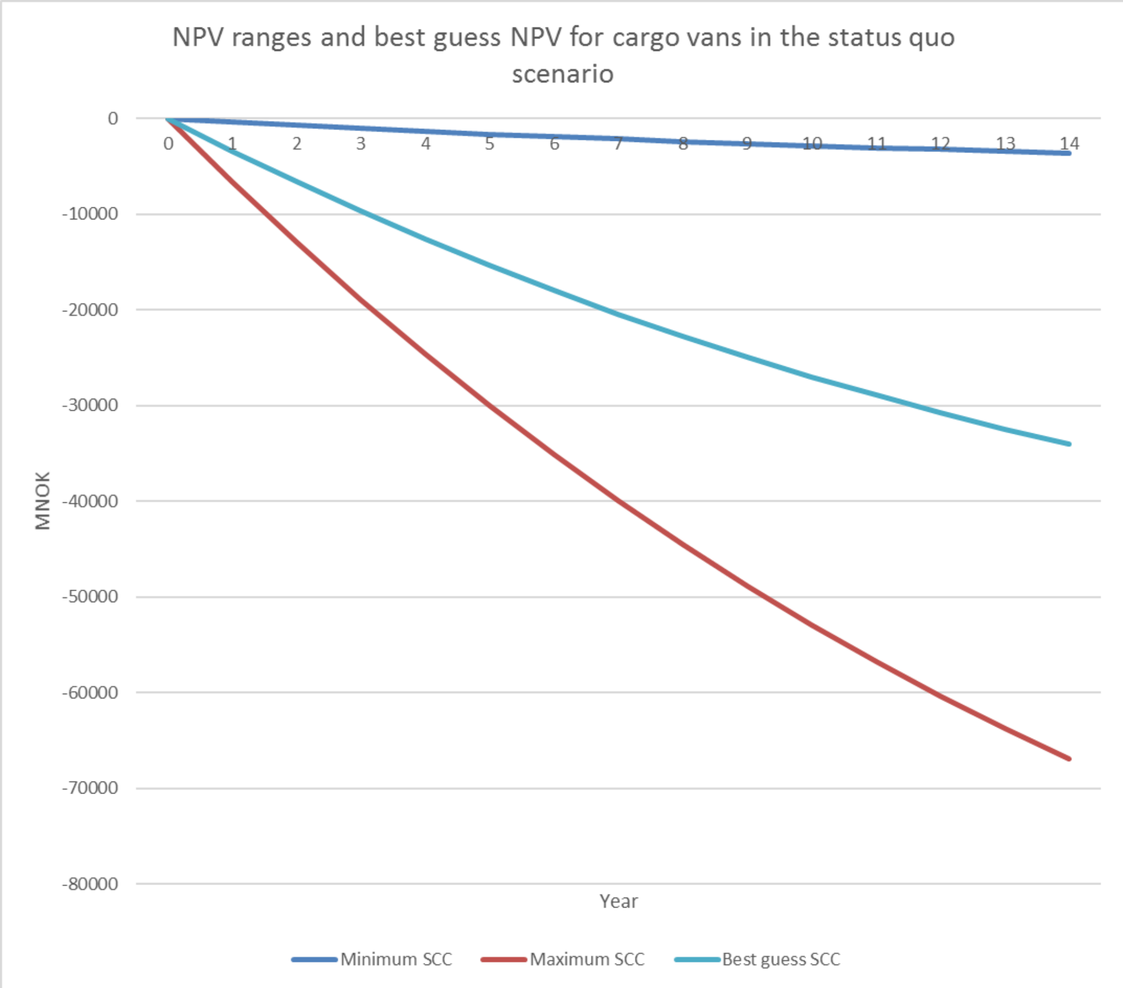

Figure 16: NPV ranges and best guess NPV for cargo vans in the status quo scenario

Figure 16 shows the range of net present values of the social costs of emissions in the status quo scenario. In this scenario, no zero-emission vehicles are purchased and no hydrogen fueling stations nor charging stations are established in the evaluated period. However, the total amount of cargo vans continues along its current path. This combined with the numbers for social and abatement costs of emissions from Table 8 and Table 9 results in the range of NPV values seen in Figure 16. The "Best guess SCC" represents estimated values based on IPCC's "best guess" value for the social cost of CO_2 (97) and combined with Table 9. See Appendix 1: Tables and calculations for more details.

Combining all previously shown results for cargo vans, calculations can be made for the net present value of the ultra-low emission path. This is shown in Figure 17.

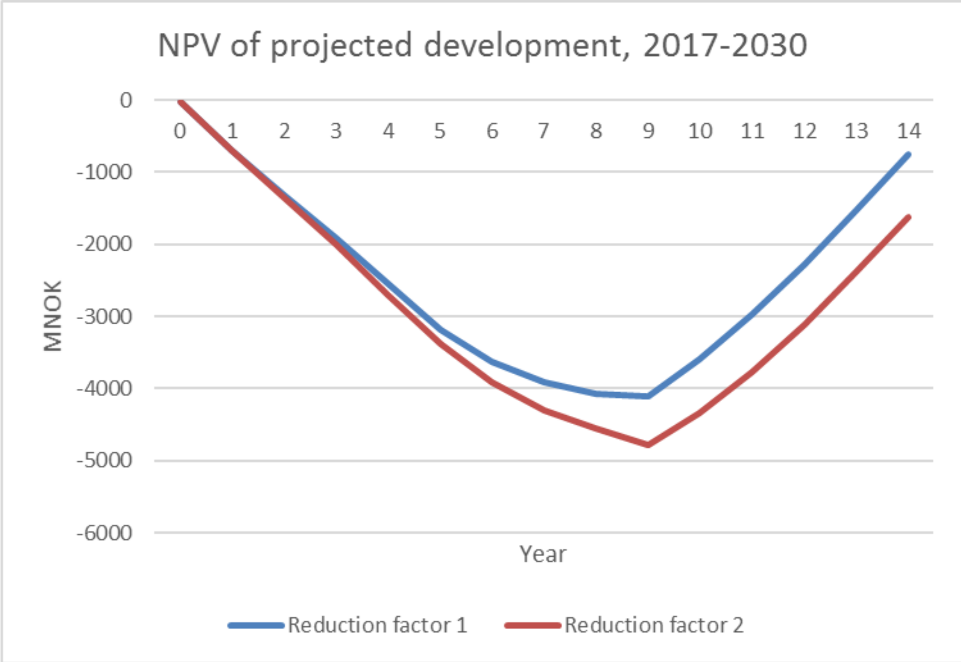

Figure 17: Net present value of the ultra-low emission path with evaluation period 2017-2030

In the projected development of cargo vans from 2017-2030, the amount of vehicles is significantly smaller than that for passenger vehicles. Due to the smaller scale than and similar assumptions to the passenger vehicles sector, investments in this sector isolated do not return positive NPVs in the evaluated period. An NPV of -744 MNOK is achieved when assuming minimum hydrogen FCEV and EV costs. When assuming maximum hydrogen FCEV and EV costs, the NPV of investment into the projected development is -1 616 MNOK. See Appendix 1: Tables and calculations for more details.

Calculations were also made for the period 2017-2050. These can be seen in Figure 18.

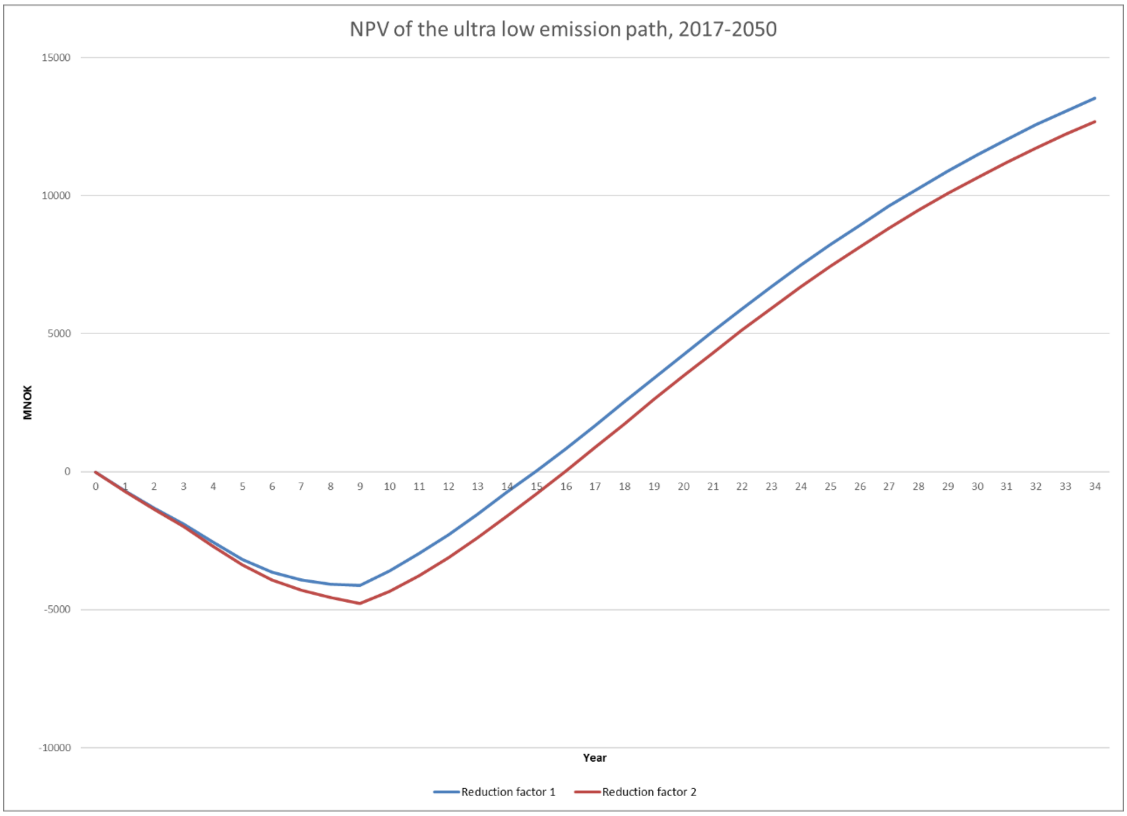

Figure 18: Net present value of the ultra-low emission path for cargo vans with evaluation period 2017-2050

Evaluating for 2017-2050 gives an NPV of 13 533 MNOK when assuming minimum hydrogen FCEV and EV costs. When assuming maximum hydrogen FCEV and EV costs, the NPV of investment into the projected development is 12 688 MNOK. See Appendix 1: Tables and calculations for more details.

3.3.3 Heavy-duty trucks

In the heavy-duty trucks sector, some major assumptions are made:

- For calculation of costs of hydrogen fueling stations connected to the heavy-duty trucks sector, the reduction factor is set to 2 %.
- As no electric heavy-duty trucks are purchased in this scenario, no values are set.
- The cost of a hydrogen heavy-duty truck today is set to 7 MNOK, based on talks with the industry (35). Governmental expenses due to purchase of hydrogen heavy-duty trucks are given in Table 25. Unlike what is done for passenger vehicles and cargo vans, national scaling of heavy-duty trucks is considered to be irrelevant to governmental expenses due to purchase of such vehicles. Instead, the year of purchase is set as the significant factor.
- Hydrogen consumption of a hydrogen heavy-duty truck is calculated to be 1 635.8 kg H_2/year based on average annual distance driven by diesel heavy-duty trucks from Table 15 and average hydrogen consumption of a Nikola One from Table 4.

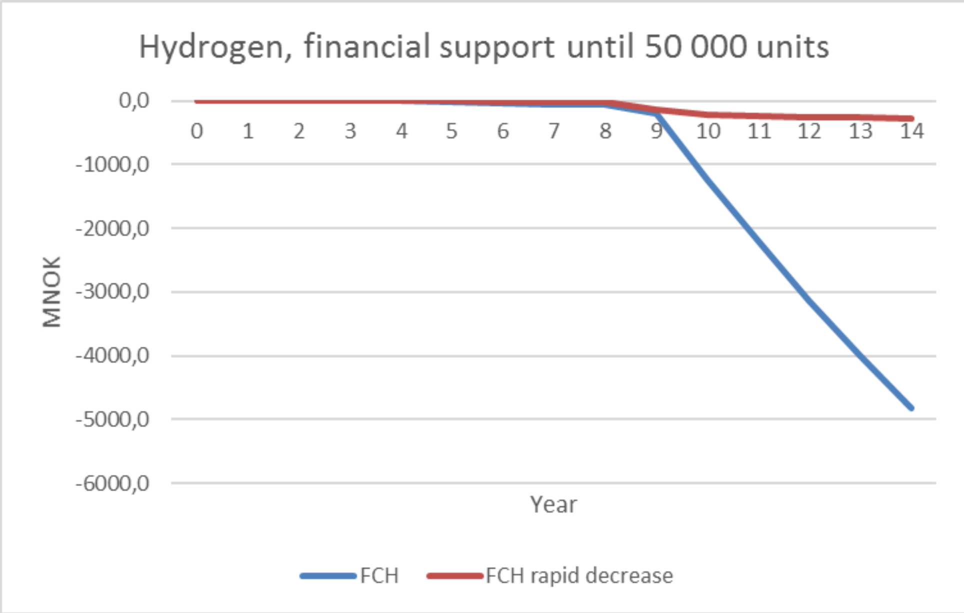

Figure 19: Net present value development for hydrogen heavy-duty trucks with financial support until 50 000 units and required fueling stations

Figure 19 shows the range of net present values of the costs for hydrogen heavy-duty trucks and required fueling stations with financial support until 50 000 units. Evaluating over the 14-year period renders net present values from -271 MNOK to -4 825 MNOK. The stock of hydrogen FCEVs reaches 50 000 units in year 2047, which does not come into account here. The major change in governmental costs from year 9 is due to the combination of the assumption of year being the significant factor for governmental expenses due to purchase of vehicles and the stock of hydrogen heavy-duty trucks increasing from 60 to 6 757 units from year 9 to 14. See Appendix 1: Tables and calculations and Table 25 for more information.

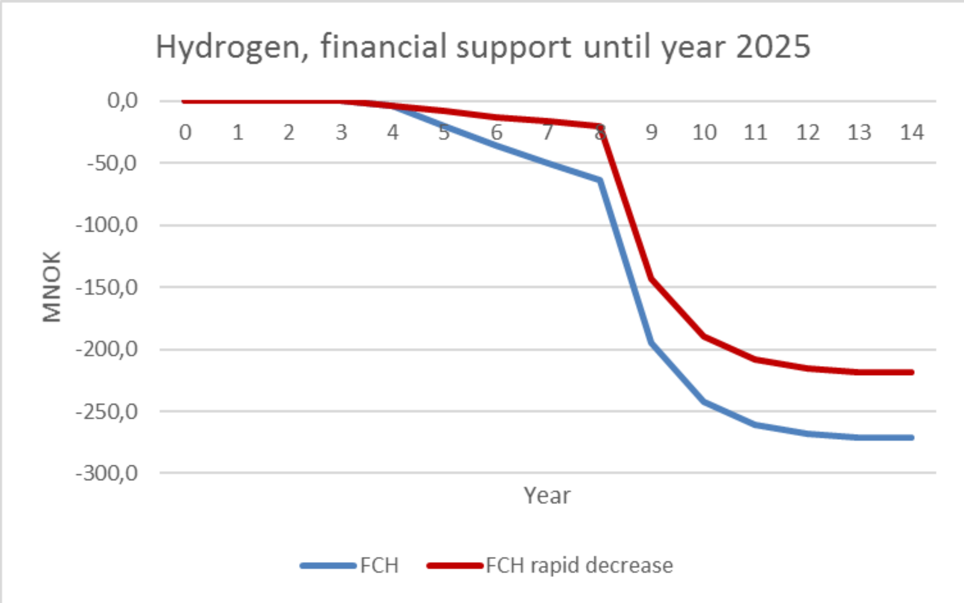

Figure 20: Net present value development for hydrogen heavy-duty trucks with financial support until year 2025 and required fueling stations

Figure 20 shows the range of net present values of the costs for hydrogen heavy-duty trucks and required fueling stations with financial support until year 2025. Evaluating over the 14-year period renders net present values from -219 MNOK to -272 MNOK. The hydrogen FCEV stock reaches 60 units by year 2025, which is an increase of 60 units from the start of 2017. The NPV difference from years 9 to 14 only comes from public financial support for fueling stations. The jump from year 8 to 9 comes mainly from the assumption that all hydrogen fueling stations are built the year prior to when the correlating number of hydrogen FCEVs are purchased.

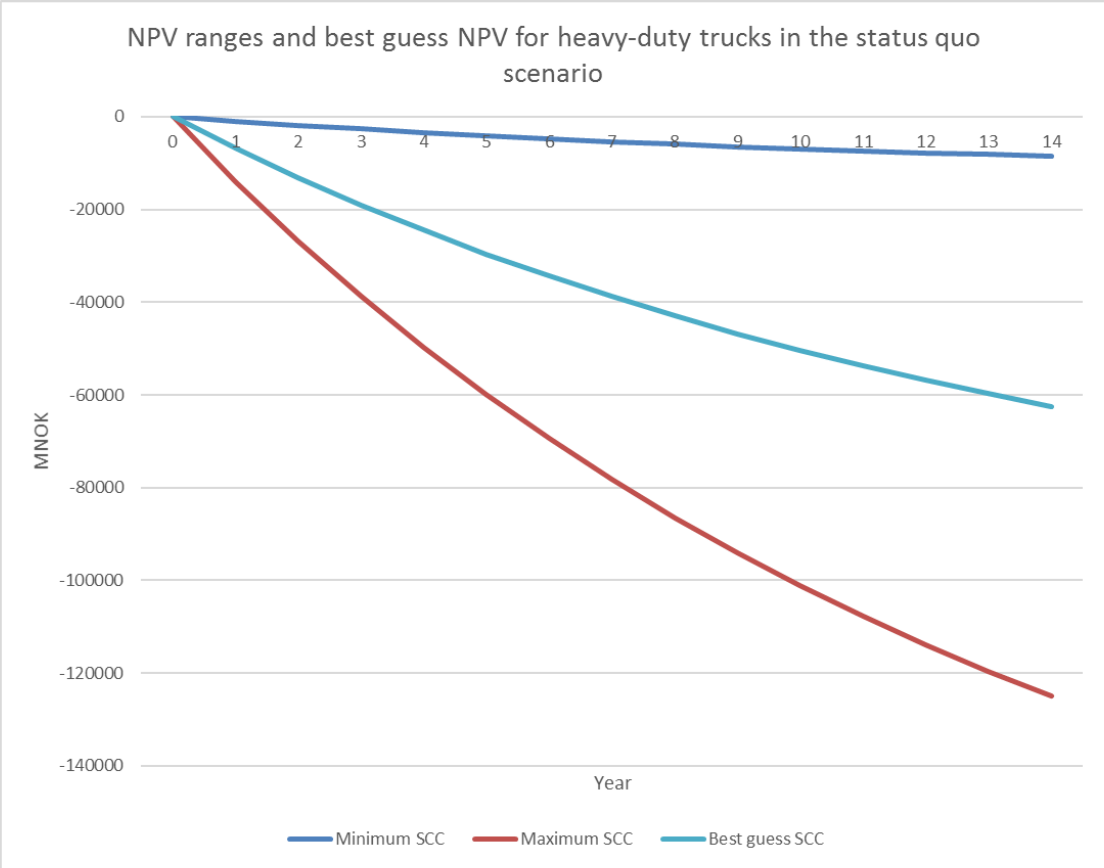

Figure 21: NPV ranges and best guess NPV for heavy-duty trucks in the status quo scenario

Figure 21 shows the range of net present values of the social costs of emissions in the status quo scenario. In this scenario, no zero-emission vehicles are purchased and no hydrogen fueling stations nor charging stations are established in the evaluated period. However, the total amount of heavy-duty trucks continues along its current path. This combined with the numbers for social and abatement costs of emissions from Table 8 and Table 9 results in the range of NPV values seen in Figure 21. The "Best guess SCC" represents estimated values based on IPCC's "best guess" value for the social cost of CO_2 (97) and combined with Table 9. See Appendix 1: Tables and calculations for more details.

Combining all previously shown results for heavy-duty trucks, calculations can be made for the net present value of the ultra-low emission path. This is shown in Figure 17.

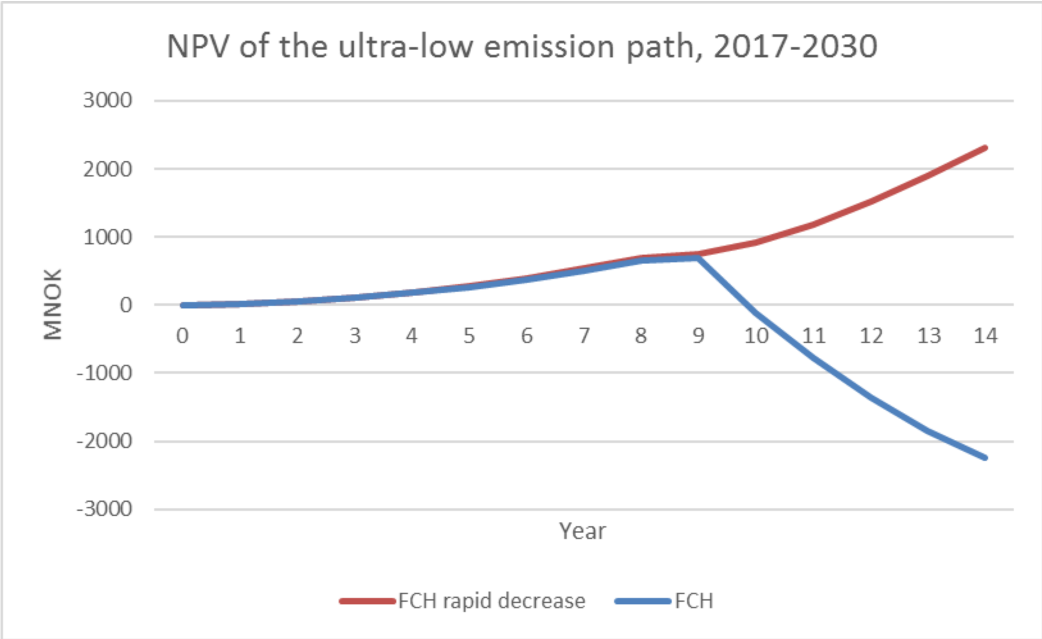

Figure 22: Net present value of the ultra-low emission path with evaluation period 2017-2030

In the projected development of heavy-duty trucks from 2017-2030, the amount of vehicles increases drastically from year 9 to 10. Due to the great difference between estimated development of production costs of hydrogen buses by FCH and ASKO (35, 90), the range of NPVs varies greatly. An NPV of -2 250 MNOK is achieved when using FCH's development of hydrogen FCEV costs. When assuming a rapid decrease of FCEV costs based on FCH's estimate and taking ASKO's prediction into account, the NPV of investment into the projected development is 2 303 MNOK. See Appendix 1: Tables and calculations for more details.

Calculations were also made for the period 2017-2050. These can be seen in Figure 23.

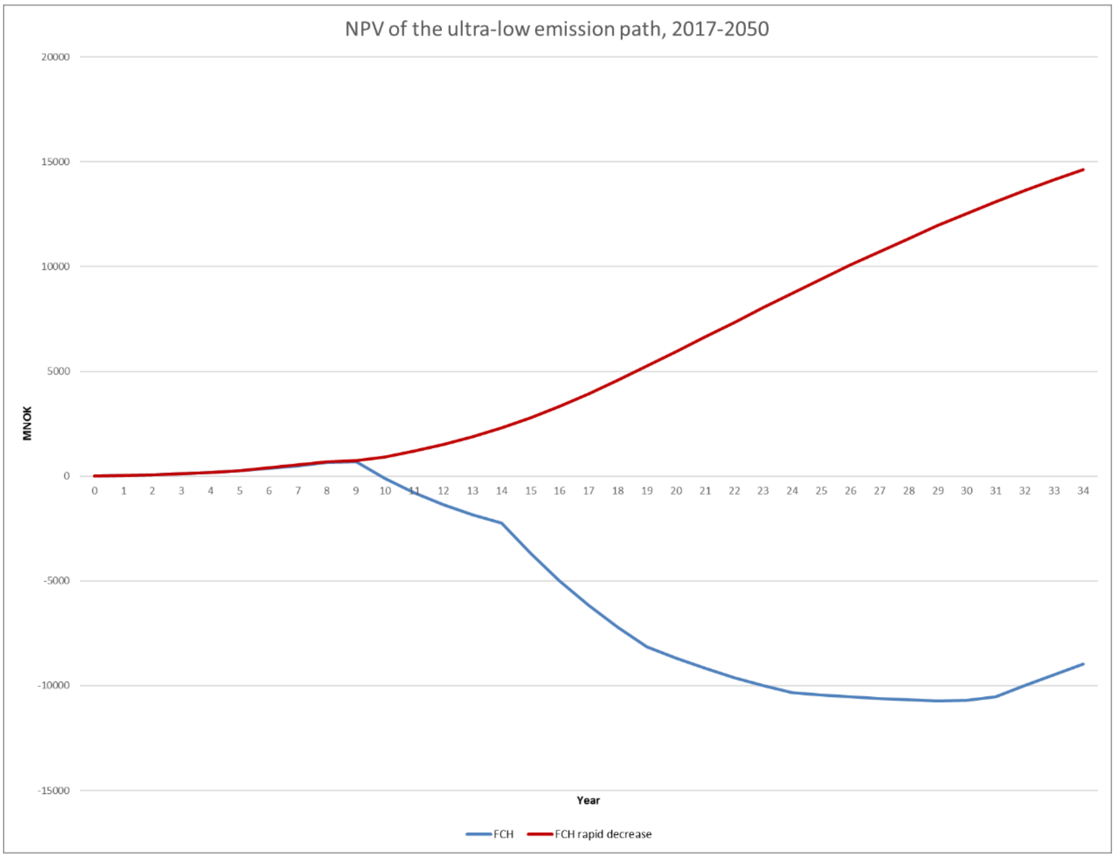

Figure 23: Net present value of the ultra-low emission path for heavy-duty trucks with evaluation period 2017-2050

Evaluating for 2017-2050 gives an NPV of 14 638 MNOK when assuming a rapid decrease of FCEV costs based on FCH's estimate and taking ASKO's prediction into account. When using FCH's development of hydrogen FCEV costs, the NPV of investment into the projected development is negative 8 980 MNOK. See Appendix 1: Tables and calculations for more details.

3.3.4 Buses

In the bus sector, some major assumptions are made:

- For calculation of costs of hydrogen fueling stations and rapid charging stations connected to the bus sector, the reduction factors are set to 2 % and 0.1 %, respectively.
- Governmental expenses due to purchase of hydrogen buses are given in Table 25. Unlike what is done for passenger vehicles and cargo vans, national scaling of buses is considered to be irrelevant to governmental expenses due to purchase of such vehicles. Instead, the year of purchase is set as the significant factor. Due to ASKO's prediction of cost parity between hydrogen and conventional diesel heavy-duty trucks (35), the FCH rapid decrease scenario is added to the bus sector as well.
- Governmental expenses due to purchase of electric buses are assumed to equal those of hydrogen.

- Hydrogen consumption of a hydrogen bus is calculated to be 4 231 kg H_2/year based on average annual distance driven by diesel buses from Table 15 and average hydrogen consumption of a Ruter's hydrogen buses in Oslo from Table 3.
- Support for electric buses is assumed to be maintained until 2025.
- One rapid charging station is established for every 7.1 electric bus.

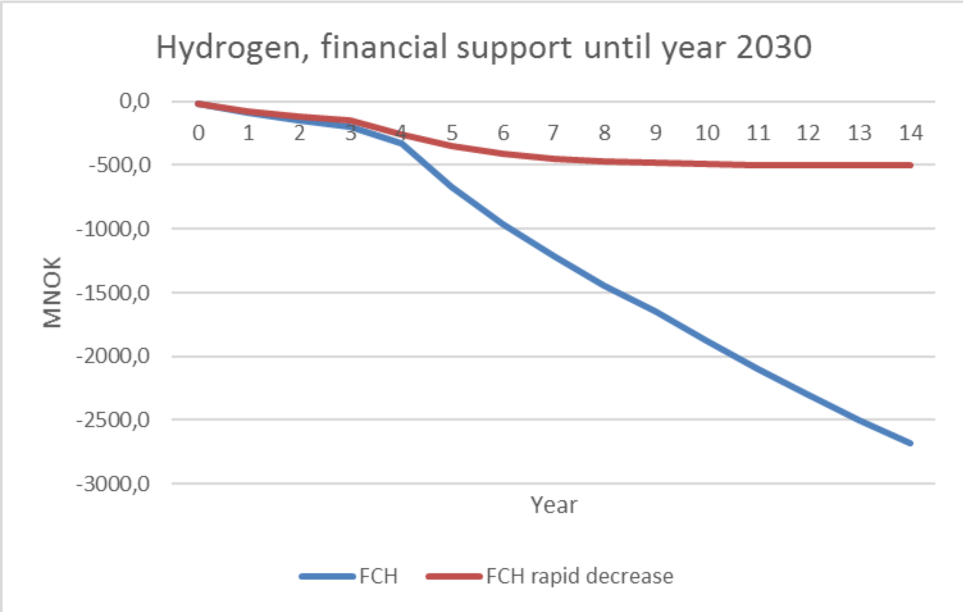

Figure 24: Net present value development for hydrogen buses with financial support until year 2030 and required fueling stations

Figure 24 shows the range of net present values of the costs for hydrogen buses and required fueling stations with financial support until year 2030. Evaluating over the 14-year period renders net present values from -2 686 MNOK to -501 MNOK. See Appendix 1: Tables and calculations and Table 25 for more information.

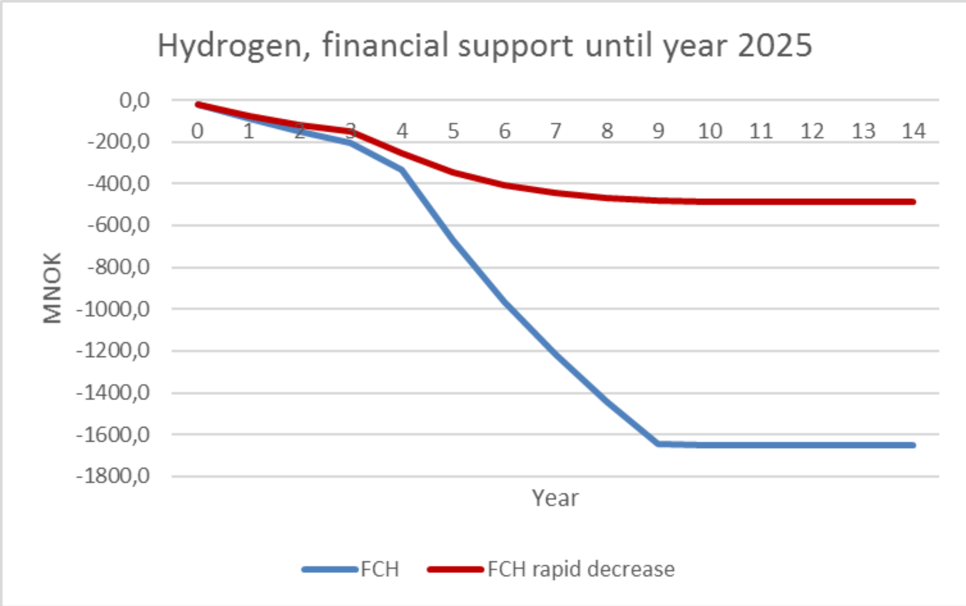

Figure 25: Net present value development for hydrogen buses with financial support until year 2025 and required fueling stations

Figure 25 shows the range of net present values of the costs for hydrogen buses and required fueling stations with financial support until year 2025. Evaluating over the 14-year period renders net present values from -1 653 MNOK to -489 MNOK. The hydrogen FCEV stock reaches 1 607 units by year 2025, which is an increase of 1 572 units from the start of 2017. The NPV difference from years 9 to 14 only comes from public financial support for fueling stations.

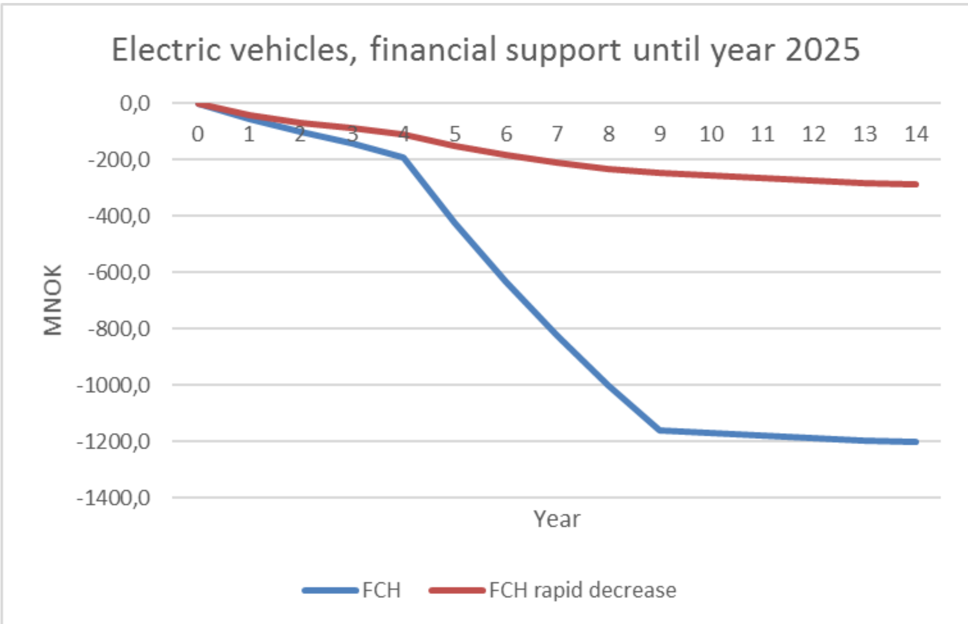

Figure 26: Net present value development for electric buses with financial support until year 2025 and required rapid charging stations

Figure 27 shows the range of net present values of the costs for electric buses with financial support until year 2025 and required rapid charging stations. Evaluating over the 14-year period renders NPVs from -289 MNOK to -1 202 MNOK. The EV stock reaches 1 281 units by 2025, which is an increase of 1 238 units from the start of 2017.

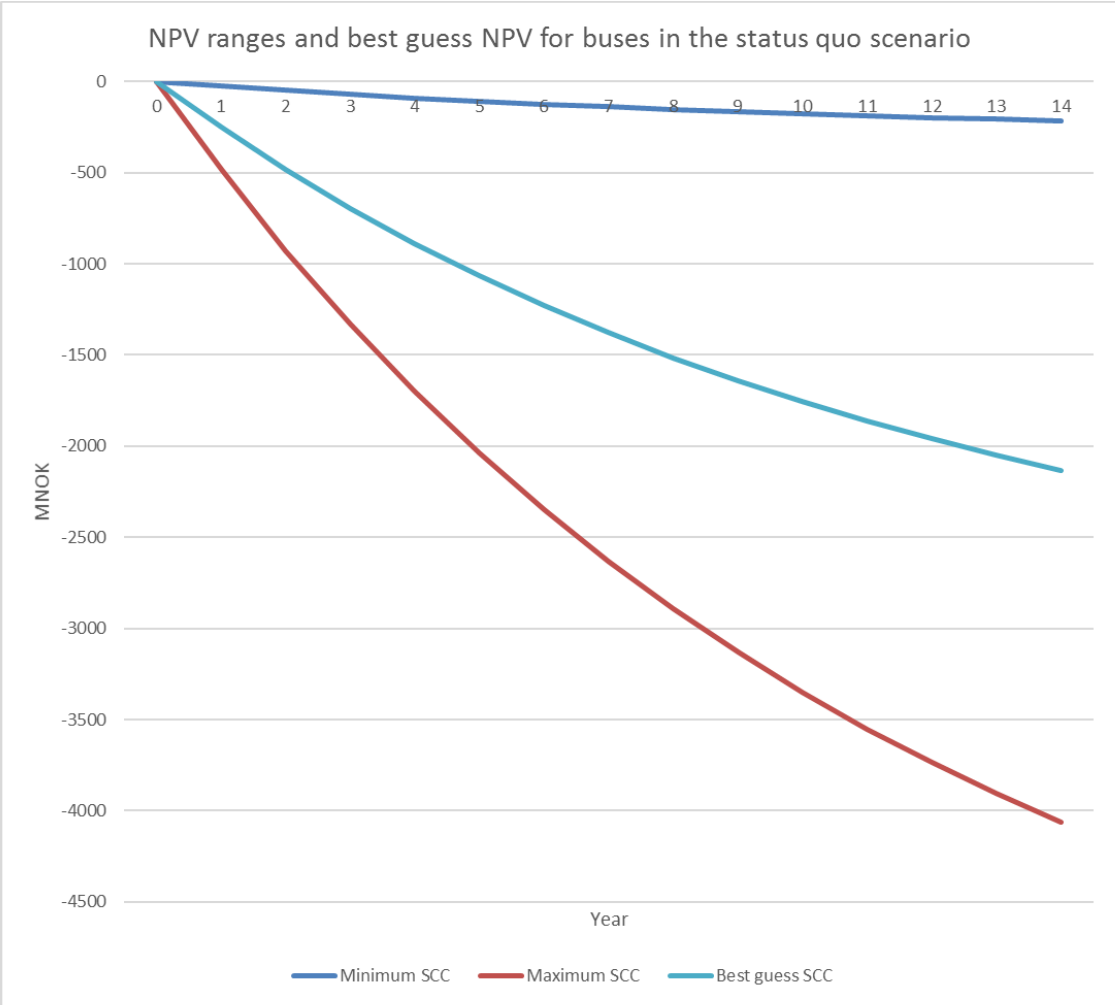

Figure 27: NPV ranges and best guess NPV for buses in the status quo scenario

Figure 27 shows the range of net present values of the social costs of emissions in the status quo scenario. In this scenario, no zero-emission vehicles are purchased and no hydrogen fueling stations nor charging stations are established in the evaluated period. However, the total amount of buses continues along its current path. This combined with the numbers for social and abatement costs of emissions from Table 8 and Table 9 results in the range of NPV values seen in Figure 27. The "Best guess SCC" represents estimated values based on IPCC's "best guess" value for the social cost of CO_2 (97) and combined with Table 9. See Appendix 1: Tables and calculations for more details.

Combining all previously shown results for buses, calculations can be made for the net present value of the ultra-low emission path. This is shown in Figure 28.

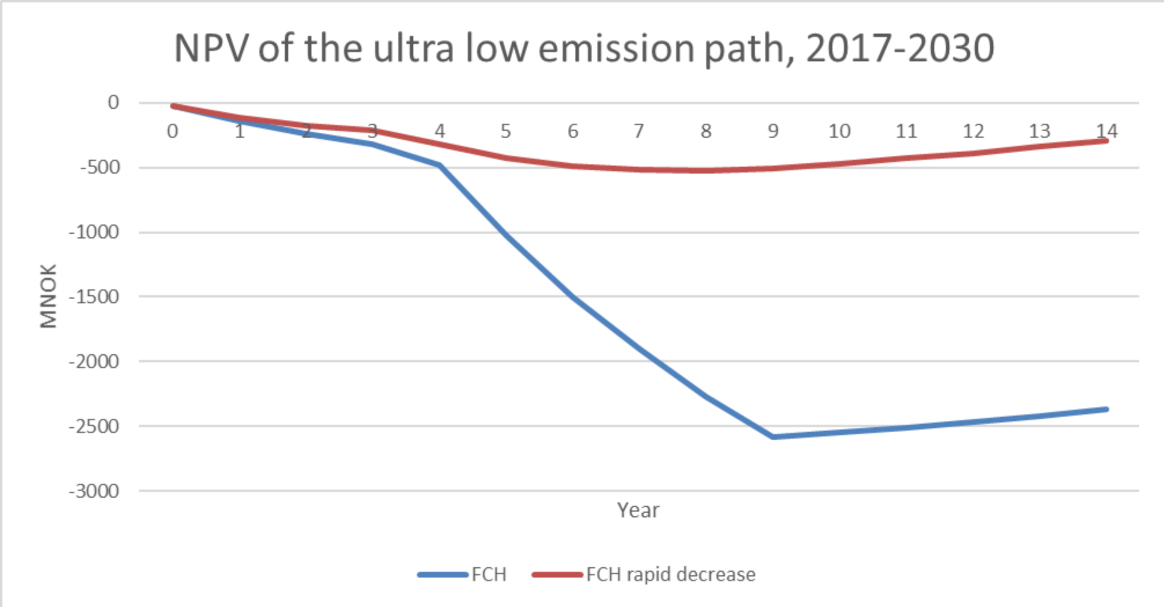

Figure 28: Net present value of the ultra-low emission path with evaluation period 2017-2030

An NPV of -2 368 MNOK is achieved when using FCH's development of hydrogen FCEV costs. When assuming a rapid decrease of FCEV costs based on FCH's estimate and taking ASKO's prediction into account, the NPV of investment into the projected development is -291 MNOK. The major development change seen from year 9 to 10 occurs due to purchases of zero-emission buses not receiving public financial support anymore. See Appendix 1: Tables and calculations for more details.

Calculations were also made for the period 2017-2050. These can be seen in Figure 29.

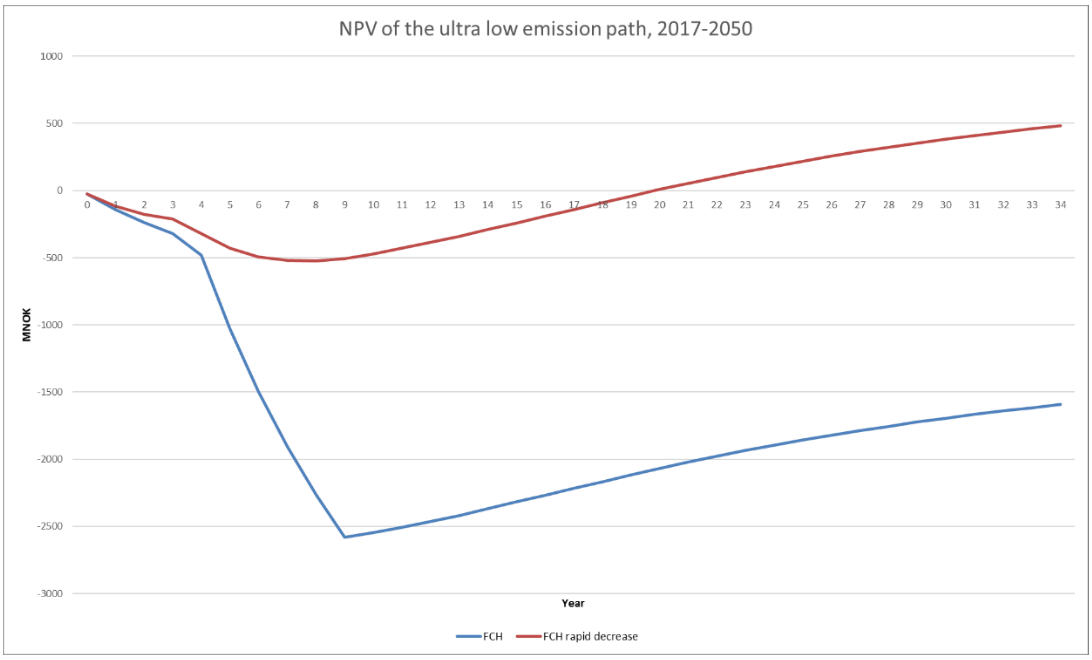

Figure 29: Net present value of the ultra-low emission path for buses with evaluation period 2017-2050

Evaluating for 2017-2050 gives an NPV of 484 MNOK when assuming a rapid decrease of FCEV costs based on FCH's estimate and taking ASKO's prediction into account. When using FCH's development of hydrogen FCEV costs, the NPV of investment into the projected development is negative 1 593 MNOK. See Appendix 1: Tables and calculations for more details.

3.3.5 The whole transport sector combined

When combining the whole transport sector, it is assumed that the amount of established hydrogen fueling stations equals the theoretically necessary number due to synergy effects of hydrogen usage in all sectors.

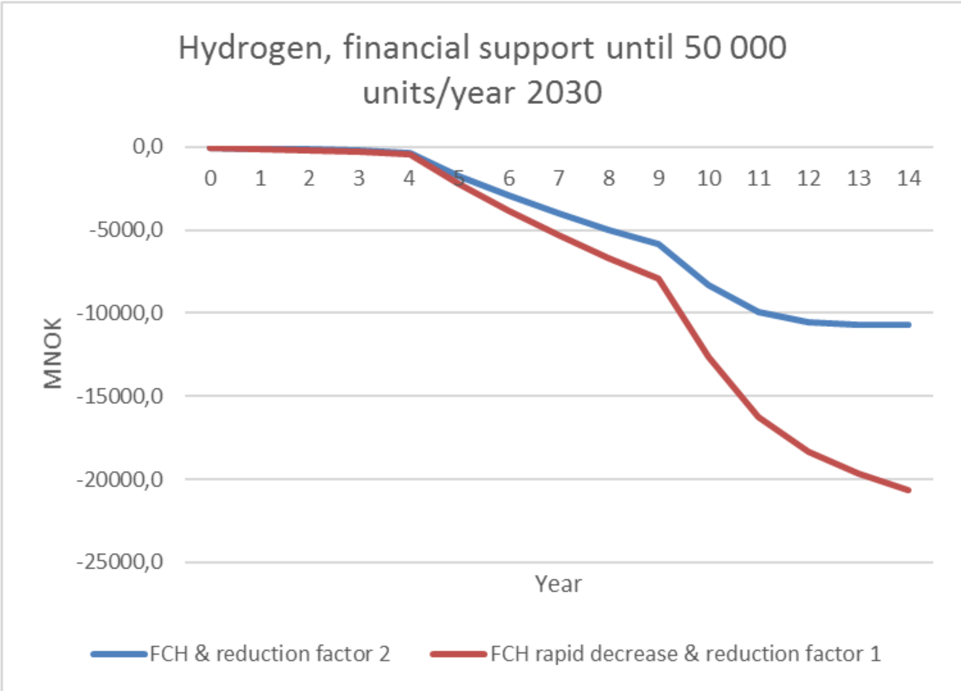

Figure 30: Net present value development for all hydrogen vehicles with financial support until year 2030 and required fueling stations

Figure 30 shows the range of net present values of the costs for all hydrogen vehicles and required fueling stations with financial support until year 2030 for heavy-duty trucks and buses and until 50 000 units for passenger vehicles and cargo vans. Evaluating over the 14-year period renders net present values from -20 651 MNOK to -10 664 MNOK. The change in costs seen from year 9 to 10 is due to the hydrogen stocks of passenger vehicles, cargo vans and heavy-duty trucks experiencing a massive increase that year. The smaller change from year 4 to 5 is mainly due to the increase of hydrogen passenger vehicles and cargo vans. See Appendix 1: Tables and calculations and Table 25 for more information.

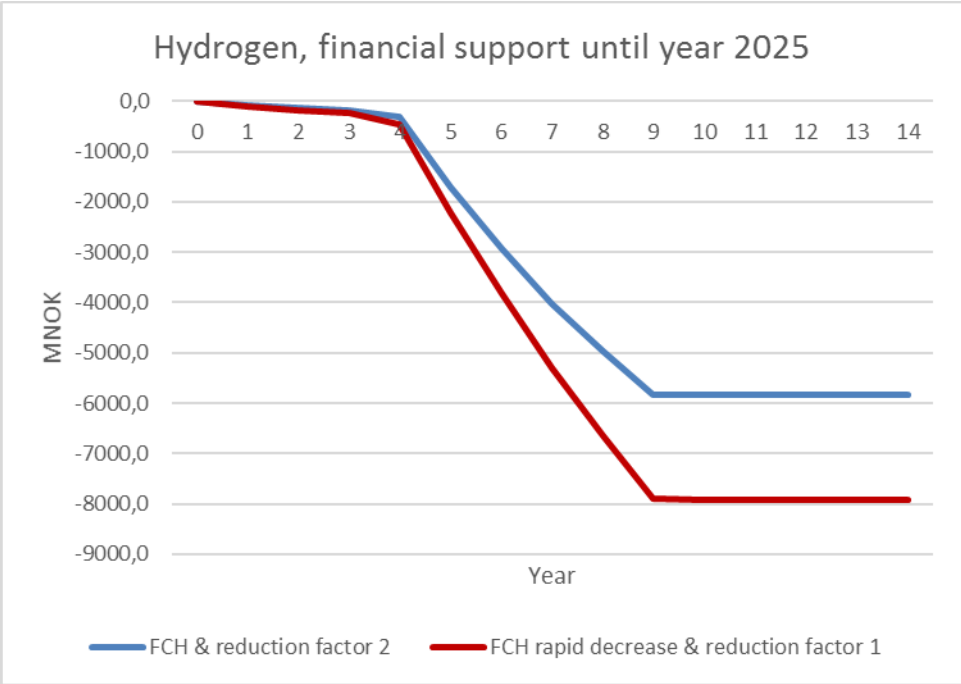

Figure 31: Net present value development for all hydrogen vehicles with financial support until year 2025 and required fueling stations

Figure 31 shows the range of net present values of the costs for all hydrogen vehicles and required fueling stations with financial support until year 2025. Evaluating over the 14-year period renders net present values from -7 925 MNOK to -5 823 MNOK. The change from year 4 to 5 is mainly due to the increase of hydrogen passenger vehicles and cargo vans, as can also be seen in Figure 30. The NPV difference from years 9 to 14, or lack thereof, only comes from public financial support for fueling stations.

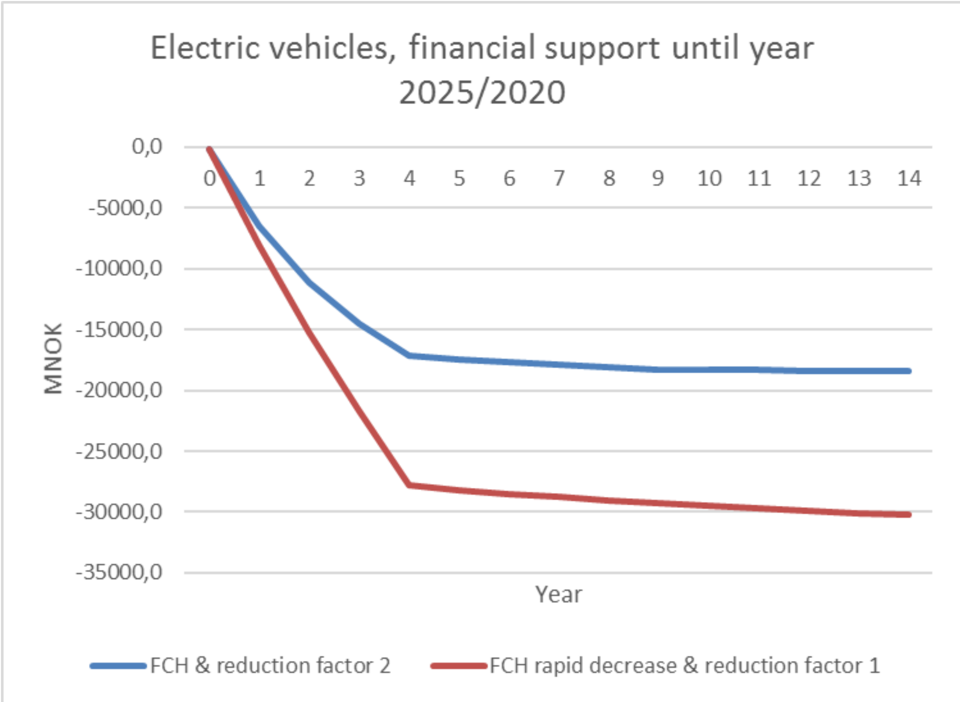

Figure 32: Net present value development for all electric vehicles with financial support until year 2025/2020 and required rapid charging stations

Figure 32 shows the range of net present values of the costs for all electric vehicles with financial support until year 2025 for buses and year 2020 for passenger vehicles and cargo vans. Evaluating over the 14-year period renders NPVs from -30 199 MNOK to -18 401 MNOK. The NPV is mostly influenced by passenger and cargo vans, which are not given public financial support after year 2020. This is what creates the spike in year 4.

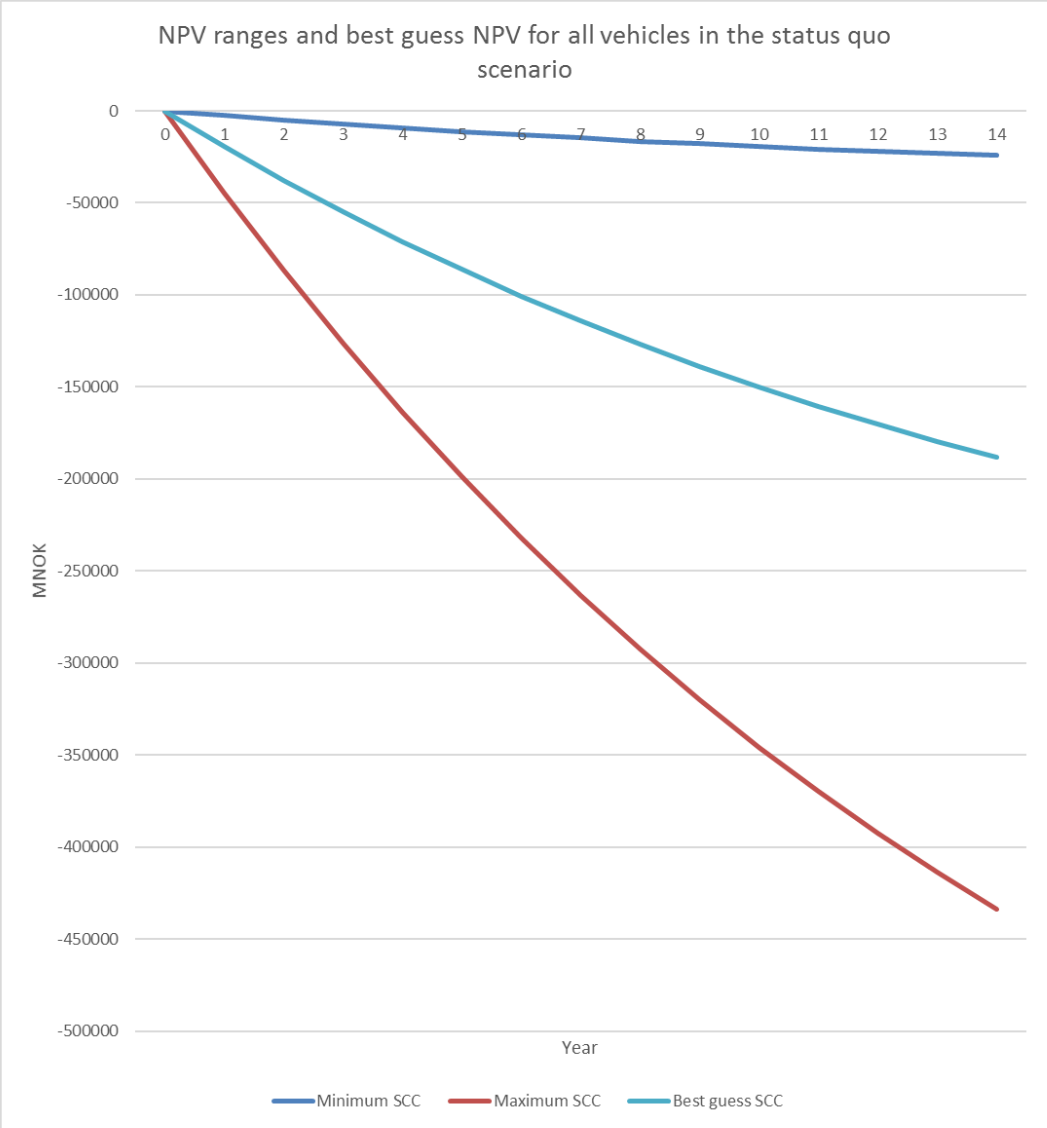

Figure 33: NPV ranges and best guess NPV for all vehicles in the status quo scenario

Figure 33 shows the range of net present values of the social costs of emissions in the status quo scenario. In this scenario, no zero-emission vehicles are purchased and no hydrogen fueling stations nor charging stations are established in the evaluated period. However, the total amount of vehicles continues along its current path. This combined with the numbers for social and abatement costs of emissions from Table 8 and Table 9 results in the range of NPV values seen in Figure 33. The "Best guess SCC" represents estimated values based on IPCC's "best guess" value for the social cost of CO_2 (97) and combined with Table 9. See Appendix 1: Tables and calculations for more details.

Combining all previously shown results for all vehicles combined, calculations can be made for the net present value of the ultra-low emission path. This is shown in Figure 34.

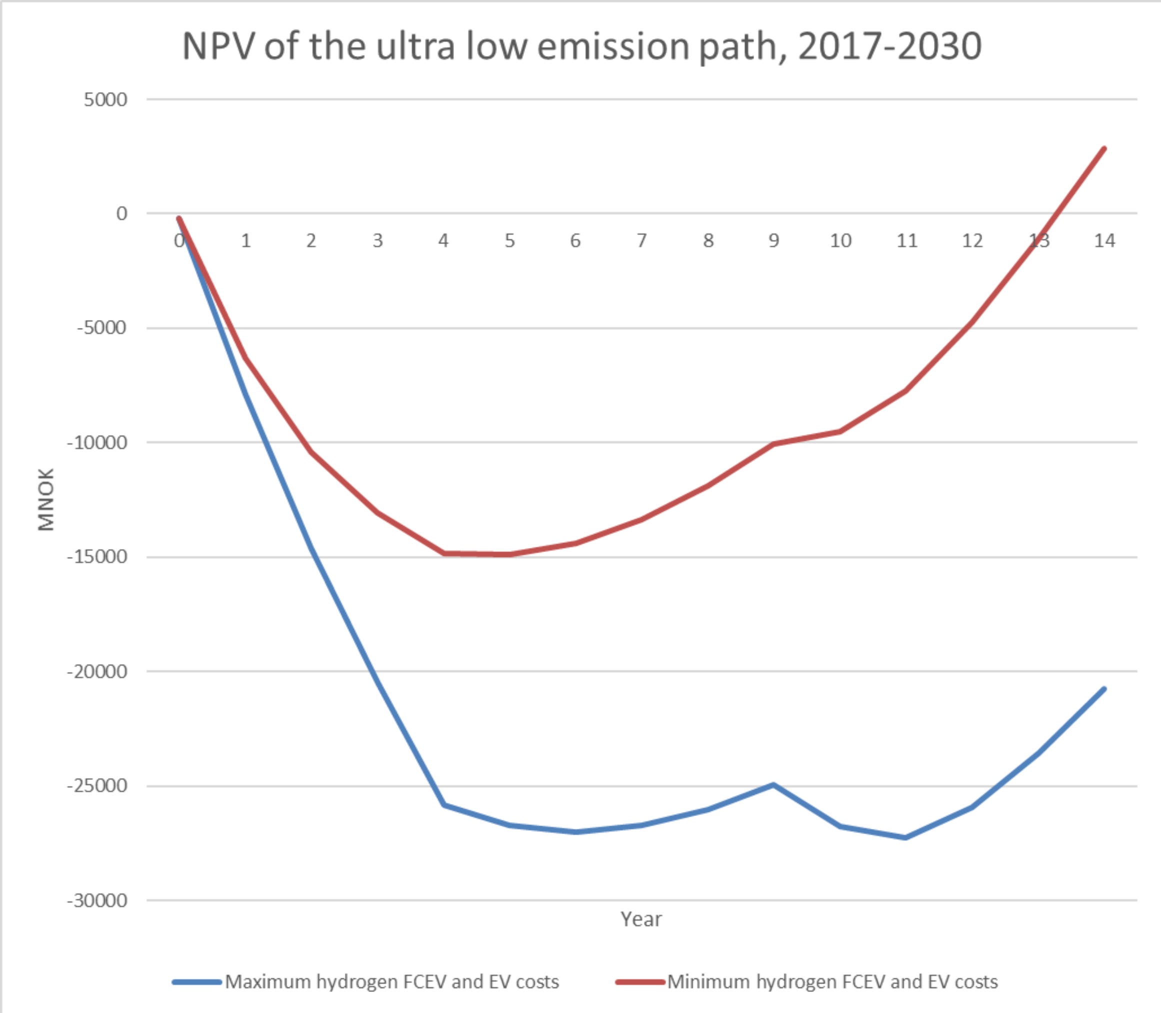

Figure 34: Net present value of the ultra-low emission path with evaluation period 2017-2030

An NPV of -20 754 MNOK is achieved when using FCH's development of hydrogen bus costs for bus and heavy-duty trucks costs, reduction factor 2 for passenger vehicles and cargo vans. The latter are given public financial support until 2020, while the former are given public financial support until 2030. When assuming a rapid decrease of heavy-duty truck and bus costs based on FCH's estimate and taking ASKO's prediction into account, in addition to using reduction factor 1 for passenger vehicles and cargo vans, the NPV of investment into the projected development becomes 2 859 MNOK. The first 4 years, cost development is dominated by EVs, while the change seen from year 9 to 11 is due to hydrogen FCEVs massively entering the market. See Appendix 1: Tables and calculations for more details.

Calculations were also made for the period 2017-2050. These can be seen in Figure 35.

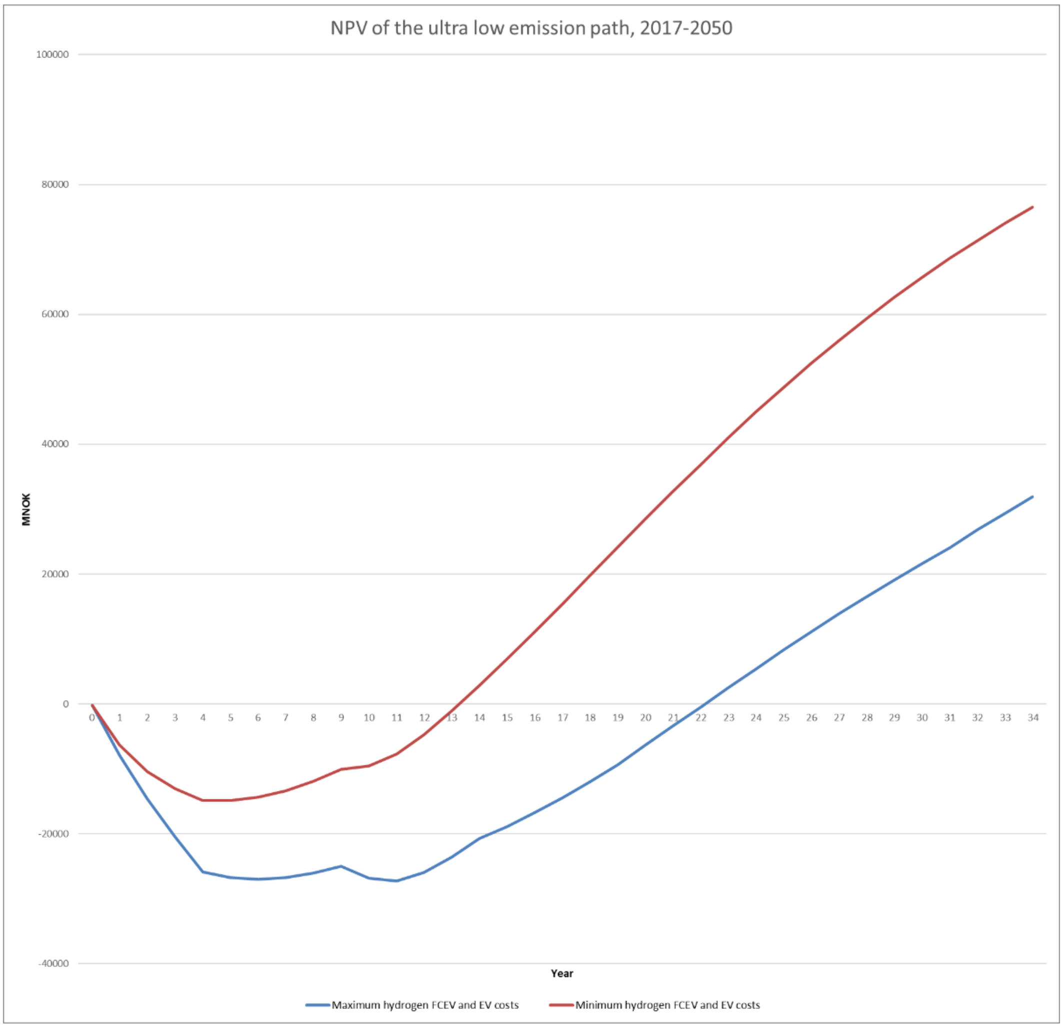

Figure 35: Net present value of the ultra-low emission path for all vehicles with evaluation period 2017-2050

An NPV of 31 887 MNOK is achieved when using FCH's development of hydrogen bus costs for bus and heavy-duty trucks costs, reduction factor 2 for passenger vehicles and cargo vans. The latter are given public financial support until 2020, while the former are given public financial support until 2050. When assuming a rapid decrease of heavy-duty truck and bus costs based on FCH's estimate and taking ASKO's prediction into account, in addition to using reduction factor 1 for passenger vehicles and cargo vans, the NPV of investment into the projected development becomes 76 525 MNOK. See Appendix 1: Tables and calculations for more details.

Cost and NPV comparisons						
Vehicle type	Fuel type	Factors of impact	Annual GHG reduction in 2030 [tonnes CO_2-equivalents]	GHG reduction cost 2017-2030 [NOK/tonne CO_2-equivalent]	Best guess SCC 2030 [MNOK]	Best guess SCC 2050 [MNOK]
Passenger vehicles	Fossil	Status quo prolonged	850739	-	-89663	-142723
	Electric	RF 1	3273977	4428	40975	122457
		RF 2	3273977	8225	28544	109452
	Hydrogen	RF 1, 50 000 units	125601	43319	-3456	7486
		RF 1, 2025	125601	23193	-929	10082
		RF 2, 50 000 units	125601	56739	-5142	4164
		RF 2, 2025	125601	27442	-1462	8014
Cargo vans	Fossil	Status quo prolonged	251704	-	-34016	-52264
	Electric	RF 1	571299	4725	10144	34157
		RF 2	571299	5217	9863	33727
	Hydrogen	RF 1, 50 000 units	313723	16882	1499	18710
		RF 1, 2025	313723	9714	3747	20959
		RF 2, 50 000 units	313723	22626	-304	16901
		RF 2, 2025	313723	11596	3157	20361
Heavy duty trucks	Fossil	Status quo prolonged	1198969	-	-48741	-71816
	Electric	2025, FCH	-98	0	0	0
		2025, FCH rapid decrease	-98	0	0	0
	Hydrogen	50 000 units, FCH	368961	13077	3903	57195
		50 000 units, FCH rapid decrease	368961	736	8456	80813
		2025, FCH	368961	735	8456	80813
		2025, FCH rapid decrease	368961	593	8509	80865
Buses	Fossil	Status quo prolonged	44739	-	-2132	-3056
	Electric	2025, FCH	14470	83096	-713	103
		2025, FCH rapid decrease	14470	19973	200	1016
	Hydrogen	50 000 units, FCH	20349	131999	-2003	-2003
		50 000 units, FCH rapid decrease	20349	81240	-971	268
		2025, FCH	20349	24628	181	1420
		2025, FCH rapid decrease	20349	24044	193	1432
All combined	Fossil	Status quo prolonged	2346152	0	-174551	-269860
	Electric	2020 + RF 2 & 2025 + FCH	3859647	92250	37694	143282
		2020 + RF 1 & 2025 + FCH rapid decrease	3859647	33415	51319	157630
	Hydrogen	50 000 units/year 2050 FCH rapid decrease & RF 1	828634	12869	5528	107278
		2025 FCH rapid decrease & RF 1	828634	7027	11521	113338
		50 000 units/year 2050 FCH & RF 2	828634	24922	-3546	76257
		2025 FCH & RF 2	828634	9564	10332	110609

Table 21: Costs of GHG reductions and NPV comparisons of all scenarios, short version

Important note: The values for this table are tailored for comparison with GHG emission statistics for Norway made by Statistics Norway, in which only the emissions CO_2, CH_4 and N_2O are accounted for, while this thesis includes CO_2, CH_4, N_2O, SO_2, NO_X, nmVOC, NH_3, PM2,5 and PM10. As such, annual GHG reduction in 2030 and 2050 only accounts for those that Statistics Norway also account for.

Table 21 shows:

- Annual GHG reduction in 2030 in tons CO_2-equivalents; meaning, by investment made into a certain scenario, the expected emission reduction in CO_2-equivalents by 2030 from the start of 2017. This is calculated due to Norway's climate goals being a GHG reduction of 40 % by 2030 when comparing with 1990-levels.
- GHG reduction cost 2017-2030 in NOK per ton CO_2-equivalent. Meaning, how much do the GHG reductions one can expect in 2030 cost per ton CO_2-equivalents for a certain scenario.
- NPV based on best guess SCC 2030 in MNOK. Meaning, what is the net present value of investment in a certain scenario when evaluating over 2017-2030 when using the best guess social costs of emissions.
- NPV based on best guess SCC 2050 in MNOK. Meaning, what is the net present value of investment in a certain scenario when evaluating over 2017-2050 when using the best guess social costs of emissions.

Conclusions from Table 21:

- Fossil fuel types, in this thesis being diesel and gasoline, will in scenario 'status quo prolonged' reduce GHG emissions by a significant amount in all sectors due to technology improvement and stock reductions. Note that passenger vehicles and cargo vans' stocks increase, while heavy-duty trucks and buses decrease. It is assumed that this development takes place without any governmental financial support. Nonetheless, social costs of emissions cause significant governmental expenses, meaning all sectors hold negative net present values for status quo prolonged.
- The various EV and hydrogen FCEV scenarios are already explained, and will not be discussed further. However, there is particularly one important aspect of these calculations that must be known: Annual GHG reduction in 2030 is calculated by multiplying the amount of zero-emission vehicles purchased from 2017-2030 in one scenario with the amount of emissions an average vehicle of the same type emits in 2016. As such, these values do not account for emissions reduced due to stock reductions and it is assumed that every purchase of a zero-emission vehicle replaces an average fossil fuel vehicle of the same vehicle type.
- The NPV values for 2017-2030 are calculated using the following formula:

$$NPV_{i,j} = NPV_{Investment i,j} - NPV_{Replaced,j}$$

Equation 44: NPV of scenario i in sector *j*

In Equation 44, $NPV_{Investment i,j}$ is the NPV of governmental expenses due to investment in scenario *i* and sector *j* evaluated from 2017-2030 and $NPV_{Replaced,j}$ is the NPV of the diesel and gasoline vehicles in sector *j* evaluated from 2017-2030 multiplied with the ratio of zero-emission vehicles in scenario *i* in 2030 to the total amount of vehicles in sector *j* in 2030.

- The NPV values for 2017-2050 are calculated using Equation 44 for 2017-2050 instead of 2017-2030.

3.4 Implications for Norway

In this chapter, the transition to a zero-emission society and its implications for Norway in the light of the results of this thesis is analyzed.

3.4.1 CCS

The development of CCS technology and competence has great export potential. In the EU alone, if CCS is integrated in existing waste incineration plants, 60-70 million tons of CO_2 emissions can be averted (98). Considering energy recovery being a globally growing industry, this number should grow. Norway has considerable potential of becoming a significant exporter of CCS technology and competence (99). The market for this technology in the future will be vast if global warming is to be limited to 2 °C, as agreed upon in Paris (2). Simultaneously, the global demand for energy is to rise, mainly causing an increase in natural gas usage and some increase in oil usage (100). In this scenario, Norway's income levels are not threatened in the near future by the transition to a zero-emission society as the demand for oil and natural gas increases, and thus the demand for Norwegian oil and gas should not decrease. In addition, if this scenario comes to be, it is not likely that the emissions of the national fossil fuel industry will decrease quickly enough for Norway to have a decent chance of reaching its climate goals of 40 % emission reduction by 2030. The most apparent solution in this scenario is to implement large scale CCS nationally and aim for export of technology and competence from this area.

In a scenario where the implementation of renewable solutions continues its fast development, causing demand for fossil fuels, including natural gas, to decline, Norway's income levels are threatened in the near future by the transition to a zero-emission society as the demand for oil and natural gas will decline. The decrease in demand increases financial risks connected to investments in the fossil industry, and increases need for new sources of income for Norway if its standard of living is to be maintained. Development of CCS is also in this scenario necessary if global warming is to be limited to 2 °C, though less critical than in the high emission scenario discussed above, as the complete implementation of renewable solutions is very unlikely to occur soon enough for this to keep global warming limited to 2 °C (63).

In 2015, global emissions amounted to 11.2 Gt carbon (101). This number is converted to CO_2-equivalents in Equation 45:

$$\text{Emissions}_{\text{Global},2015} = 11.2\ \text{Gt C} \cdot \frac{M_{CO_2}}{M_C} = 11.2\ \text{Gt C} \cdot \frac{44\,\frac{g}{mol}}{12\,\frac{g}{mol}} = \underline{41.1\ \text{Gt } CO_2}$$

Equation 45: Global emissions of 2015 in Gtons CO_2

The average emissions from 2006-2015 amounted to 10.3 Gt C/year, which converted to Gt CO_2/year as in Equation 45 equals 37.8 Gt CO_2/year (101).

IPCC report that by 2011, 1 900 GtCO_2 had been emitted by human activities (97). This leaves a budget of approximately 1 000 GtCO_2 to be consistent with the goal of limiting global warming to 2 °C (97).

Utilizing the average emissions between 2011 and 2015, the carbon budget remains at 848.8 Gt CO_2 at the beginning of 2015. Using global emissions from 2015 for 2015 and 2016 means the remaining carbon budget from 2017 and onwards amounts to 766.6 Gt CO_2.

The amount of CO_2-equivalents which must be stored in order to not blow the carbon budget is given in Equation 46:

$$S_{CO_2} = \sum_{2017}^{2100} E_{\text{Global,Annual}} - 766.6\ \text{Gt } CO_2$$

Equation 46: Amount of stored CO_2-equivalents required to not exceed the carbon budget

The amount of CO_2-equivalents actually emitted from 2017 is very uncertain. Many reports have been published on the matter, and most present roughly the same scenarios. IPCC's scenarios range from annual GHG emissions reaching zero in approximately 2080 in RCP2.6 to emissions increasing and exceeding 100 GtCO_2/year in 2080 in RCP8.5 (97). Basing calculations on limiting global warming to 2 °C, i.e. RCP2.6, a linear approximation from today's emissions of 41.1 GtCO_2/year to zero-emissions in 2080, 63 years from 2017, means total emissions amount to 1 294.7 GtCO_2. The total amount of stored CO_2-equivalents becomes

$$S_{CO_2,\text{RCP2.6}} = (1294.7 - 766.6)\ \text{Gt } CO_2 = \underline{528.1\ \text{Gt } CO_2}$$

Equation 47: Total amount of stored CO_2-equivalents by the RCP2.6 scenario

This estimate does not take into account whether or not it is practically possible to capture this amount of CO_2. An example of this not being viable is in the transport sector.

Norway's CO_2 storage potential accumulates to roughly 86.15 Gt CO_2 (55-57). Based on IPCC's predictions, large scale CCS must be established regardless of it being neither socioeconomically nor commercially viable if global warming is to be limited to 2 °C (53).

Crucial for this industry to thrive without governmental financial support, is that the price on CO_2 increases to a point where this industry becomes commercially viable (53).

3.4.2 The transport sector

As presented in Table 21, by following ITE's ultra-low emissions path, there is potential for annual reduction of GHG emissions in 2030 of 3.37 Mt CO_2-equivalents for electric vehicles in the transport sector. For hydrogen FCEVs in the transport sector, there is potential for annual reduction of GHG emissions in 2030 of roughly 183 000 tons CO_2-equivalents. With 2015's total emissions amounting to 10.3 Mt CO_2-equivalents (5), this transition represents a reduction of 34.5 % from 2015-2030. However, Norway's climate goals state a reduction of 40 % by 2030 with respect to 1990-levels, which in the transport sector amounted to 7.77 Mt CO_2-equivalents. With basis in ITE's ultra-low emissions path, the transport sector reduces emissions by roughly 13 % with respect to 1990-levels. If Norway is to uphold its climate goals with this development in the transport sector, other sectors must decrease emissions by far more. This is contradictory to the Norwegian Environment Agency's claims that the greatest potential for emission reductions for sectors not subject to the quotas trading system lies in the transport sector (102).

4 Discussion

In the following, the analyses made in this thesis will be discussed separately.

4.1 The TiZir case

In TiZir Titanium & Iron's transition from using coal to using hydrogen as a chemical component in their production process, only SMR and water electrolysis are considered as viable options in this thesis. As both technologies are well known, assuming no technical difficulties in establishment nor operation appears natural.

When discussing which solution represents the best investment case, the perspective from which the discussion is made is important. Here, it is natural to separate between TiZir's, Norway's and the climate goals perspective.

TiZir's perspective

From TiZir's perspective, the most natural factor to start with is price. Based on the results from this thesis, the scale of which TiZir requires means water electrolysis represents an economically more reasonable choice than SMR. In addition, when considering the development of CO_2-taxations, costs are most likely to increase. How significant this increase will be is very unclear and subject to a vast number of variables. Not least of which is political.

Another factor, which TiZir might be concerned with, is their company's carbon footprint. There is potential for climate friendly commodities being more attractive on the market than others, meaning the market might be willing to pay more solely based on a commodity being a climate friendly product. If this is the case, water electrolysis is more beneficial than SMR.

Another aspect, which might become relevant, is the fact that global warming acts as a disruptor on the weather systems we know today. As a result, there is potential for escalated frequency of weather occurrences leading to loss of power grid stability and thus hydrogen production stability if using water electrolysis.

Norway's perspective

Norway's interests in this situation are assumed to be the reduction of GHGs, development of technology and creating jobs.

When considering the potential of GHG reduction, there are two aspects: Direct reduction from TiZir's facility and repercussions from TiZir's transition. When looking at direct reduction of GHGs, it is clear that water electrolysis represents the greater reduction. Note that this would not be the case if

Norway's electricity production was not mostly based on hydro power. Repercussions from TiZir's transition for SMR involve establishment of CCS infrastructure which can be used for other projects as well. Additionally, such a project could increase national actors' competence on CCS, which on the long term can be very useful if global warming is to be limited to 2 °C. For electrolysis, it represents the potential of massively reducing hydrogen production costs due to the large scale. A scenario exists where production capacity is increased to some extent, enabling sale of hydrogen to other sectors, such as the transport and maritime sector. It also represents increased competence on renewable hydrogen production, which can be exported. Job creation appears greater if using SMR, due to the massive infrastructure project necessary to facilitate CCS.

Climate goal

Both solutions represent GHG reductions in their own way. Directly, electrolysis causes a greater reduction than SMR. However, establishment of large scale CCS has potential for great reduction of GHGs nationally and globally. On another note, special adviser for Norwea, Andreas Aasheim, claims that CCS would be a waste of resources if invested for use in the energy production sector due to renewable energy prices declining rapidly (103).

4.2 Hydrogen usage in the transport sector, socioeconomic analysis

In this chapter, the socioeconomic analyses of hydrogen usage in the transport sector are discussed. First, the assumptions and simplifications made in the calculations are considered. Second, the results of the analyses are discussed.

Assumptions and simplifications

In the analysis of hydrogen usage in the transport sector, biofuels are not included. As such, the analysis does not cover enough to give a complete understanding of the socioeconomic benefits of investment in hydrogen FCEVs and EVs.

The development of vehicle stocks are set from ITE's report from 2016 (68). Since the scaling of a certain vehicle type's stock has a great impact on its net present value, the NPV is somewhat predetermined by the used projections for development of vehicle stocks. For a more accurate understanding of hydrogen's potential in the transport sector, the analysis should be set free from stock development projections. If this is done, it is possible to estimate which specific vehicle stock development represents the greatest socioeconomic return on investment. In such a case however, one might achieve results, which require unlikely stock developments.

Assumption of governmental expenses due to purchase of electric passenger vehicles is based on the Norwegian Environment Agency's estimates (95). For hydrogen passenger vehicles, hydrogen and electric cargo vans, heavy-duty trucks and buses, these were assumed or estimated. Proper values for these parameters could increase the accuracy of the results of this report significantly.

The disparity of cost parity estimates between Endresen and FCH cause some uncertainty as to when cost parity can actually be expected to occur (35, 90). This is reflected in the NPVs of heavy-duty trucks and buses. While the ranges of NPVs of passenger vehicles and cargo vans are quite small, the ranges of NPVs of heavy-duty trucks and buses are rather large.

The numbers for emissions by vehicle and fuel type are for 2013. These can be seen in Table 14. They are combined with values for distances driven by vehicle and fuel type, which are for 2015. These can be seen in Table 15. This obviously causes wrong numbers for emissions to be used in this thesis and most likely is the reason why gasoline heavy-duty trucks' emission values are so high. Therefore, they are not used. Using values from the same year would definitely increase accuracy of the results of this report.

Some of the best guess abatement and social costs of emissions are averages of the respective minimum and maximum values. See Table 24 for more details. These averages, in addition to the use of minimum abatement costs for CH_4 and N_2O, represent potential weaknesses of the legitimacy of the best guess costs actually being the best guess.

For hydrogen FCEVs, the reduction factor of 2 % for each hydrogen fueling station established and for every thousandth hydrogen vehicle purchased is a value, which is not based on any previous works, only the fact that commercialization of hydrogen FCEVs has just began. Since commercialization of EVs began 5-10 years ago, they are given smaller reduction factors.

In one scenario, buses and heavy-duty trucks are assumed to be given public financial support until 2050. This is done because of the major disparity between estimates of cost parity between renewable and non-renewable versions of these vehicles.

In the status quo prolonged scenario, it is assumed that 55 % and 45 % of all new vehicles in the period 2017-2050 are respectively diesel and gasoline vehicles. This is used as a reference scenario. It does not represent reality, rather a worst-case scenario where the government does not have any further expenses due to zero-emission vehicles, charging stations nor fueling stations. Thus, calculating NPVs which, use the NPVs of status quo prolonged scenarios, do not give completely accurate results.

All hydrogen FCEVs and EVs are assumed to be bought at the very end of their respective year of purchase. As such, no emissions are reduced by the purchase of a zero-emission vehicle until the year after purchase. This is incorrect, and the accuracy of the results would be better if actual conditions for this were taken into account.

Purchases of hydrogen passenger vehicles are signaled by the Norwegian government to be given public financial support until 2025 or until 50 000 units have been purchased. Both these cases have been analyzed. Considering the stock is estimated to reach 50 000 units after 2025, it appears most likely that public financial support will seize after 2025. Therefore, this is what is included in the NPVs for projected developments.

Purchases of zero-emission cargo vans are assumed to be given the same governmental financial support as those for passenger vehicles. Most likely, this value should be increased.

Governmental expenses due to purchase of electric buses are assumed to equal those of hydrogen buses. This is most likely not accurate.

In the calculations of the NPVs of hydrogen FCEVs and EVs shown in Table 21, the NPVs of the status quo scenarios are divided by the total number of vehicles of a given sector of the final year of evaluation. This is done in order to get values for how much money one hydrogen FCEV or EV saves society. This is inaccurate because if the stock decreases in the period of evaluation, then money saved per vehicle is increased to more than it should be. Also vice versa, if the stock increases in the period of evaluation, then money saved per vehicle decreases to less than it should be. The latter is the case for electric passenger vehicles for instance. As such, the NPV of electric passenger vehicles would be higher if this simplification was not made. Additionally, with the same logic, the NPVs of hydrogen heavy-duty trucks would be smaller if this simplification was avoided.

The NPVs with investments into zero-emission vehicles are compared with the status quo scenarios, which are the worst-case scenarios. In reality, if there were no more governmental expenses due to purchase of zero-emission vehicles nor fueling or charging stations, the EV and hydrogen FCEV stock would still continue to increase somewhat due to prior investments. Thus, future sales of vehicles would not only be of diesel and gasoline. As such, the more realistic scenario represents less savings due to investments in zero-emission vehicles. The extent of which is unclear.

The emissions of fossil fueled buses are assumed to equal those of fossil fueled cargo vans. This is most likely less than what is realistic, which portrays zero-emission buses as less beneficial than they should be. The reason for this is that every zero-emission bus is estimated to displace fewer emissions than it in reality would.

The calculations are not as accurate and thus the curve is not as smooth as it could have been due to linear interpolation between the five year intervals of stock values collected from the ITE (68).

Cost development due to scaling of hydrogen FCEVs and EVs is only based on national stock development, not global development. Given the small share of hydrogen FCEVs in the passenger vehicle sector, the cost development of hydrogen FCEVs does not decrease as rapidly as what might become reality. Depending on the development of the global share of hydrogen FCEVs, governmental expenses due to purchase of said vehicles might be greater or less than what is assumed in this thesis.

Analyses

Even in the status quo scenarios, which are the worst-case scenarios, technology development causes fossil fuel vehicles to reduce annual GHG emissions in 2030. Assuming this development causes no governmental expenses in and of itself, this significant emission reduction has no direct costs for Norway. However, by accounting for social costs of emissions, the NPVs of making no investments in the transport sector show this to be very costly for the Norwegian society. In the case of all combined from 2017-2050, the cost of doing nothing ranges from 37.5 to 677.5 billion NOK, with 270 billion NOK being the estimate from the best guess SCCs.

Meanwhile, the NPVs of investments into hydrogen FCEVs and EVs are in this thesis for the most part estimated to save the Norwegian society money in the 2050-perspective with best guess SCCs. Electric passenger vehicles are the ones projected to reduce annual GHG emissions in 2030 by the largest amount. Also, with the smallest cost and the best NPV both in 2017-2030 and in 2017-2050. Hydrogen's best results come from heavy-duty trucks and buses, where they are calculated to achieve better NPVs overall than EVs. An important note to make is this: the main reason behind electric passenger vehicles' superior NPVs vs. the others is because of the large share of electric passenger vehicles projected by ITE. Meaning, the purchases of electric passenger vehicles are only given governmental financial support until 2020, with the repercussion still being that the passenger vehicle sector in 2050 mostly consists of EVs. This fact does not, however, discredit the legitimacy of the NPV of electric passenger vehicles of roughly 110-120 billion NOK. No other sector is projected to experience the same repercussion, though hydrogen heavy-duty trucks come close with their 60-80 billion NOK.

A very interesting thing to note is that even though hydrogen heavy-duty trucks do not provide the highest NPV, they do provide the lowest overall GHG reduction cost. This is, unless hydrogen heavy-duty truck purchases are given public financial support until 50 000 units are purchased and the cost development of the units follow the prediction of FCH. However, even if that is the case, it is still a sound investment as the net present value clearly shows.

Overall for hydrogen investments, when looking at all combined, only one of 12 cases shows a negative NPV. This case is based on the maximum cost development, the maximum amount of units purchased, which are publicly financially supported, and the minimum social costs of emissions. With fair certainty, it can be established that the Norwegian society will benefit from investments into hydrogen vehicles, with the largest benefits coming from heavy-duty trucks and cargo vans.

Overall for investments into electric vehicles, when looking at all combined, only one of 6 cases shows a negative NPV. This case is also based on the maximum cost development, the maximum amount of units purchased which are publicly financially supported and the minimum social costs of emissions. In addition, it is certain that the Norwegian society will benefit from investments into electric vehicles, with the largest benefits coming from passenger vehicles and cargo vans.

4.3 Implications for Norway

CCS is a challenging technology. Many environmentalists do not wish for large scale CCS due to fear that it will become an excuse for more intensive extraction of fossil resources. For businesses, it is not an attractive option due to low CO_2-taxes (53). Socioeconomically it is deemed unviable (53). Scientists are also arguing whether the technology of CCS is good enough to ensure no leakage of the stored CO_2 (52).

However, the question is if global warming can be kept under or to 2 °C without CCS. Aasheim seems to think the energy production sector can hold their own in this matter due to renewable energy prices declining rapidly (103). If IPCC's projections for a 2 °C scenario are correct (97), one might need to store or find some other use for 528.1 Gt CO_2.

In a world where all or most countries account for the social costs of emissions, CCS becomes a much more attractive alternative than it is today. If this is the case, then Norway might have a substantial source of income in storage of other nations' CO_2. Perhaps the first step in this direction would be to work for a global price on CO_2.

As for Norway's own climate goals, the GHG reductions analyzed in this thesis only amount to roughly 13 % reduction of the transport sector's emissions in the period 2017-2030 with respect to 1990-levels. If the transport sector is to reduce more than the other sectors (102), relatively, then annual emissions here must be reduced by at least an additional 2.1 Mt CO_2-equivalents by 2030. As such, ITE's projections for the transition to a zero-emission society do not hold in a climate goals perspective, and must be escalated.

4.4 Overall considerations

Biofuels are not included in this thesis. Biofuels must reduce emissions by a minimum of 35 % today, and will be increased to a minimum of 50 % by 2018 with respect to fossil fuels when the whole value chain for the biofuel is included (104). As Norwegian political parties focus on biofuels as a good environmental measure, inclusion of these would bear some significance (91). It is unclear how much, if any, governmental expenses would be required to develop a market for this in Norway. The benefit and costs of biofuels depends heavily on this.

Norway is world leading in fossil fuel technologies. This fact gives this country great potential to continue development within CCS. By this, one can generate more export of technology and competence while the export of fossil commodities decreases and thus not suffer a loss of welfare in Norway. Our great competence within fossil fuel technologies could also make the transition to a zero-emission society and becoming world leading in renewable technologies a path of little resistance.

On the very long term, even the utilization of CCS in waste treatment might become obsolete, as manufacturing of products at some point could become a closed-loop supply chain (105). However, this does not mean that CCS is not worth developing.

In a report by RethinkX , the author claims that by 2030, 95 % of all passenger miles in the U.S. will be served by transport-as-a-service providers (106). This means most people will not be in possession of their own vehicle. This is a very important piece of information when planning for the future. The question is, however, if it changes the results obtained in this report in case this should also be valid for Norway? One could argue that it does not, based on the following assumptions:

1. The number of passenger miles is independent of ownership of vehicle.
2. Large scale implementation of this solution does not impact the number of EV and hydrogen FCEV purchases granted public financial support.

Based on assumption number 1, the fuel/energy consumption in an ideal system should be unaffected by most people not being in possession of their own vehicle. As such, the amount of fueling stations should also be unaffected by this and thus the governmental expenses for fueling stations. By assumption 2, governmental expenses from purchases of EVs and hydrogen FCEVs remain unaffected by this solution. What might influence governmental expenses is the fact that such a solution presents potential for a much more rapid transition towards a zero-emission stock of vehicles. If this is the case, one might see a significant decrease in governmental expenses due to pollution from fossil fueled vehicles which weakens the socioeconomic argument for financially supporting EVs and hydrogen FCEVs.

ITE's report does not take into account increased usage of car sharing and increased market share for companies like Uber (68). These represent solutions potentially pushing the car stock downwards, as fewer and fewer people need to own their own vehicle with these solutions. The scale on which these solutions will be implemented globally is unclear, especially in lesser-developed countries.

5 Conclusion

Hydrogen is a promising energy carrier for Norway in the transition to a zero-emission society. Norway should not limit its efforts to either renewable hydrogen or fossil hydrogen with CCS. Both technologies should be focused on. However, costs of solar and wind power are rapidly decreasing. CCS is not socioeconomically viable, not attractive due to low CO_2-taxes and there is uncertainty as to whether the technology is good enough or not. It is therefore concluded in this thesis that hydrogen produced with fossil fuels at best is as good as hydrogen produced with energy from renewable sources. The uncertain factors connected to hydrogen produced from fossil energy sources imply great investment risks on the long term.

Even without the increase of costs related to emission of CO_2, which means CCS remains economically unviable, it is still strongly suggested that further development of this technology is pursued. This is based on IPCC's statements about CCS being necessary for limiting global warming to 2 °C.

The key findings in this thesis are given in the following five paragraphs:

Hydrogen produced by water electrolysis is the economically better choice for TiZir. It is also the better choice in terms of carbon footprint and risk of increased CO_2-taxes. Socioeconomically, water electrolysis represents the greater reduction of GHGs, while SMR represents more jobs created. In development of technology, the alternatives are considered equal. Overall, water electrolysis is the recommended solution in the TiZir case.

Hydrogen's most beneficial role in the Norwegian transport sector is estimated to lie with heavy-duty trucks where the socioeconomic net present value amounts to 60-80 billion NOK evaluated from 2017-2050. Cargo vans also represent a good investment case. Due to lack of data on buses, it cannot be concluded that the Norwegian society will benefit similarly from investments into hydrogen buses. However, it is found to be likely that this is also the case.

Norway benefits greatly socioeconomically on investments into the transition from fossil fueled vehicles to zero-emission vehicles. The costs of doing nothing are potentially tremendous.

CCS most likely is necessary to some extent if global warming is to be limited to 2 °C. However, global unity is required for this to become a relevant industry.

Norway's climate goals will not be met if escalated actions are not taken based on the GHG reductions found in this thesis.

6 Suggested further work

For further work on this matter, the number of simplifications used in the calculations needs to be reduced. The key assumptions and simplifications given in the following should be addressed.

This thesis' basis on ITE's projections should be removed. This is due to NPVs being dependent on scale of purchase of vehicles as well as the vehicles' potency in itself.

Biofuels should be included in the analysis such that a wider understanding of the socioeconomic benefits of investments can be reached.

Governmental expenses due to purchases of zero-emission vehicles should be further researched as these impact results greatly.

Estimates on cost development of heavy-duty trucks and buses vary greatly. The range of these should be shortened.

References:

1. Ryggvik H. Norsk Oljehistorie Store norske leksikon [May 30th 2017]. Available from: https://snl.no/Norsk_oljehistorie.
2. Miljødirektoratet. Parisavtalen 2016 [March 3rd 2017]. Available from: http://www.miljostatus.no/parisavtalen/.
3. OED. Statens inntekter [May 30th 2017]. Available from: http://www.norskpetroleum.no/okonomi/statens-inntekter/.
4. Moe S, Fedoryshyn N, Bøeng A. Produksjon og forbruk av energi, energibalanse, 2014-2015, endelige tall [May 30th 2017]. Available from: https://ssb.no/energibalanse.
5. SSB. Utslipp av klimagasser, 1990-2015, endelige tall Statistisk Sentralbyrå 2016 [March 3rd 2017]. Available from: https://www.ssb.no/klimagassn/.
6. Barstad S. Arbeiderpartiet vil rydde i den kaotiske klimadebatten [May 30th 2017]. Available from: http://www.aftenposten.no/norge/politikk/Arbeiderpartiet-vil-rydde-i-den-kaotiske-klimadebatten-619154b.html.
7. Eriksen J, Gjerlow JC, Vik KE, Halvorsen BG, Rambeck EL, Rød BM, et al. Blue Move - Mulighetsstudie for hydrogen produksjon, industri, lagring og distribusjon. 2017.
8. IEA. Technology Roadmap, Hydrogen and Fuel Cells. 2015.
9. Hofstad K. Dampreformering Store Norske Leksikon 2017 [March 8th 2017]. Available from: https://snl.no/dampreforming.
10. Nikolaidis P, Poullikkas A. A comparative overview of hydrogen production processes. Renewable and Sustainable Energy Reviews. 2016;67(2017):597-611.
11. Rönsch S, Schneider J, Matthischke S, Schlüter M, Götz M, Lefebvre J, et al. Review on methanation - From fundamentals to current projects. Fuel. 2015;166(2016):276-96.
12. Pedersen B. Pyrolyse Store Norske Leksikon [April 10th 2017]. Available from: https://snl.no/pyrolyse.
13. Dincer I, Acar C. Review and evaluation of hydrogen production methods for better sustainability. International journal of hydrogen energy.40(2015):11094-111.
14. Das D, Veziroglu N. Hydrogen production by biological processes: a survey of literature. International journal of hydrogen energy.26(2001):13-28.
15. Ditlefsen A. Fermentering Store Norske Leksikon [April 11th 2017]. Available from: https://snl.no/fermentering.
16. Azwar M, Hussain M, Abdul-Wahab A. Development of biohydrogen production by photobiological, fermentation and electrochemical processes: A review. Renewable and Sustainable Energy Reviews.31(2014):158-73.
17. EERE. Hydrogen production: Electrolysis Energy.gov Office of Energy Efficiency & Renewable Energy [April 5th 2017]. Available from: https://energy.gov/eere/fuelcells/hydrogen-production-electrolysis.
18. Markillie R. First hydrogen refuelling station with Shell opens ITM Power [April 5th 2017]. Available from: http://www.itm-power.com/news-item/first-hydrogen-refuelling-station-with-shell-opens.
19. NEL. H2 Station CAR-200 [April 5th 2017]. Available from: http://h2logic.com/products-services/h2station-car-200/.
20. Lorentzen M. Hydrogengjennombrudd i USA, E24, 2017 [April 5th 2017]. Available from: http://e24.no/boers-og-finans/nel-asa/gjennombrudd-for-nel-hydrogen-i-california/23929600.
21. Gahleitner G. Hydrogen from renewable electricity: An international review of power-to-gas pilot plants for stationary applications. International journal of hydrogen energy.38(2013).
22. Ni M, Leung MKH, Leung DYC. Energy and exergy analysis of hydrogen production by solid oxide steam electrolyzer plant. International journal of hydrogen energy. 2007;32(2007):4648-60.
23. Veras TdS, Mozer TS, Santos D. Hydrogen: Trends, production and characterization of the main process worldwide. International journal of hydrogen energy. (2016):1-16.

24. Markali J, Fjellvåg H. ammoniakk Store Norske Leksikon2017 [April 13th 2017]. Available from: https://snl.no/ammoniakk.
25. AIP. Refining of petroleum Australian Institute of Petroleum [April 13th 2017]. Available from: http://www.aip.com.au/industry/fact_refine.htm.
26. NETL. Syngas conversion to methanol National Energy Technology Laboratory: U.S. Department of Energy; [April 15th 2017]. Available from: https://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/methanol.
27. Holtebekk T. Brenselcelle Store Norske Leksikon2014 [April 15th 2017]. Available from: https://snl.no/brenselcelle.
28. Bilprodusenter og introduksjonsår for hydrogenbiler Norsk hydrogenforum 2017 [April 15th 2017]. Available from: http://www.hydrogen.no/om-hydrogen/ofte-stilte-sporsmal/.
29. Dalløkken P. For to år siden kostet denne 1,2 millioner kroner ny. Nå selges den for under halvparten. Teknisk Ukeblad. 2015 [April 17th 2017]. Available from: https://www.tu.no/artikler/for-to-ar-siden-kostet-denne-1-2-millioner-kroner-ny-na-selges-den-for-under-halvparten/222487.
30. Frihammer V. Personal communication with Vegard Frihammer, Greenstat AS (vegard@greenstat.no). Intensjonsavtale. Greenstat.
31. Smits J-R, Weston M. Clean hydrogen in European cities. Fuel cell electric buses: A proven zero-emission solution. 2016.
32. Alstom. Alstom's hydrogen train Coradia iLint first successful run at 80 km/h. [April 19th 2017]. Available from: http://www.alstom.com/press-centre/2017/03/alstoms-hydrogen-train-coradia-ilint-first-successful-run-at-80-kmh/.
33. ASKO. Vi forsyner Norge med mat. [April 20th 2017]. Available from: https://asko.no/om-oss/.
34. ASKO. Asko skal samarbeide med Scania om hydrogendrevne lastebiler. 2016. [April 20th 2017]. Available from: http://www.norgesgruppen.no/presse/nyhetsarkiv/aktuelt/asko-skal-samarbeide-med-scania-om-hydrogendrevne-lastebiler/.
35. Endresen J. Personal communication with Jørn Endresen, ASKO (Jorn.endresen@asko.no). Masteroppgåve - samfunnsøkonomi og hydrogen si rolle i Noreg. In: Solheimslid T, editor. 2017.
36. Nikola. Nikola One Nikola Motor Company [April 20th 2017]. Available from: https://nikolamotor.com/one.
37. Cengel YA, Boles MA. Thermodynamics, an engineering approach. 7 ed: McGraw Hill; 2011.
38. Dalløkken P. Dette er bilen som skal ta tungtransporten vekk fra diesel. Teknisk Ukeblad. [April 20th 2017]. Available from: https://www.tu.no/artikler/dette-er-bilen-som-skal-ta-tungtransporten-vekk-fra-diesel/365713.
39. Renault. The French post office and Renault trucks jointly test a hydrogen-powered truck running on a fuel cell. [April 20th 2017]. Available from: http://corporate.renault-trucks.com/en/press-releases/2015-02-23-the-french-poste-office-and-renault-trucks-jointly-test-a-hydrogen-powered-truck-running-on-a-fuel-cell.html.
40. Europe E-t. Trial E-Truck on hydrogen successful. [April 20th 2017]. Available from: http://e-truckseurope.com/en/news/3.
41. WaterstofNet. Waste collection vehicle using a hydrogen fuel cell. [April 20th 2017]. Available from: http://www.waterstofnet.eu/en/hydrogen-waste-collection-vehicle.
42. ESORO. The world's first fuel cell heavy goods vehicle able to fulfil Coop's logistics requirements.
43. Nikola. FAQs [May 13th 2017.]. Available from: https://nikolamotor.com/#faqs.
44. Renault. Symbio's hydrogen fuel cell integration to Nissan electric vehicle Symbio [April 15th 2017]. Available from: http://www.symbiofcell.com/en/.
45. IE. Det grønne skiftet tar form i Tyssedal Industri Energi. [April 20th 2017.]. Available from: https://www.industrienergi.no/nyheter/det-gronne-skiftet-tar-form-i-tyssedal/.
46. Lobo S. Experimental Investigations and Modelling of Solid-State Ilmenite Reduction with Hydrogen and Carbon Monoxide. : NTNU; 2015.

47. Fiksdal T. Distribution of hydrogen. Personal communication with Tomas Fiksdal, Greenstat AS (Tomas@greenstat.no). 2017.
48. Kamiya S, Nishimura M, Harada E. Study on Introduction of CO2 Free Energy to Japan with Liquid Hydrogen. . Physics Procedia 2015. ;67(2015.):11-9.
49. VSG. The CarbonNet Project. [May 4th 2017.]. Available from: http://earthresources.vic.gov.au/earth-resources/victorias-earth-resources/carbon-storage/about-carbon-capture-and-storage/the-carbonnet-project.
50. Fiksdal T. Transportation costs of hydrogen. Personal communication with Tomas Fiksdal, Greenstat AS (Tomas@greenstat.no). 2017.
51. IEA. Technology Roadmap, Carbon capture and storage. International Energy Agency; 2013.
52. Braend T. CCS is still a failure. [May 29th 2017]. Available from: http://www.airclim.org/acidnews/ccs-still-failure.
53. Bastviken P, Sæther E. Kvalitetssikring (KS1) av KVU om demonstrasjon av fullskala fangst, transport og lagring av CO2. Oslo Economics. Atkins; 2016. .
54. Knoope M, Ramírez A, Faaij A. Investing in CO2 transport infrastructure under uncertainty: A comparison between ships and pipelines. International journal of greenhouse gas control 2015. ;41(2015):174-93.
55. NPD. CO2 storage Atlas Norwegian north sea. Norwegian Petroleum Directorate; 2012.
56. NPD. CO2 storage Atlas Norwegian sea. Norwegian Petroleum Directorate; 2011. .
57. NPD. CO2 storage Atlas Barents sea. Norwegian Petroleum Directorate; 2011. .
58. Ozbilen A, Dincer I, Rosen M. Comparative environmental impact and efficiency assessment of selected hydrogen production methods. Environmental Impact Assessment Review.42(2013):1-9.
59. Bhandari R, Trudewind C, Zapp P. Life cycle assessment of hydrogen production via electrolysis - a review. Journal of Cleaner Production.85(2014):151-63.
60. Koroneos C, Dompros A, Roumbas G, Moussiopoulos N. Life cycle assessment of hydrogen fuel production processes. International journal of hydrogen energy.29(2004):1443-50.
61. Spath P, Mann M. Life cycle assessment of renewable hydrogen production via wind/electrolysis. National Renewable Energy Laboratory; 2004.
62. Spath P, Mann M. Life cycle assessment of hydrogen production via natural gas steam reforming. National Renewable Energy Laboratory; 2001.
63. Seyboth K, Eickemeier P, Matschoss P, Hansen G, Kadner S, Schlömer S, et al. Renewable Energy Sources and Climate Change Mitigation. Intergovernmental Panel on Climate Change. ; 2012.
64. Selvig E. Marginale miljøkostnader ved luftforurensning. Statens forurensningstilsyn; 2005.
65. SSB. Utvidet kvoteplikt fra 2013 Statistisk Sentralbyrå2014 [April 17th 2017]. Available from: https://www.ssb.no/natur-og-miljo/artikler-og-publikasjoner/utvidet-kvoteplikt-fra-2013.
66. OED. Kraft til endring, energipolitikken mot 2030. Det kongelige olje- og energidepartementet; 2016.
67. Samferdselsdepartementet. Nasjonal transportplan 2018-2029. Det kongelige samferdselsdepartement; 2017.
68. Fridstrøm L, Østli V. Kjøretøyparkens utvikling og klimagassutslipp. Framskrivinger med modellen BIG. Institute of Transport Economics; 2016.
69. Falk-Petersen D, Enger E, Dimmen A, Gustavsen T. Grunnlagsdokument nasjonal transportplan 2018-2029. Avinor. Jernbaneverket. Kystverket. Statens vegvesen.; 2016.
70. Bartels JR, Pate MB, Olson NK. An economic survey of hydrogen production from conventional and alternative energy sources. International journal of hydrogen energy. 2010;35:8371-84.
71. Gray D, Tomlinson G. Hydrogen from coal. Mitretek Technical Paper. 2002.
72. BLS. Archived Consumer Price Index Detailed Report Information Bureau of Labor Statistics 2017 [22th February]. Available from: https://www.bls.gov/cpi/cpi_dr.htm#2017.
73. Penner SS. Steps toward the hydrogen economy. Energy. 2006;31(2006):33-43.
74. EIA. Natural Gas Prices U.S. Energy Information Administration 2017 [March 21st 2017]. Available from: https://www.eia.gov/dnav/ng/ng_pri_sum_a_epg0_pin_dmcf_m.htm.

75. EIA. Frequently asked questions. U.S. Energy Information Administration. 2016. [April 27th 2017.]. Available from: https://www.eia.gov/tools/faqs/faq.php?id=45&t=8.
76. Rutkowski M. Production Case Studies: U.S. Department of Energy. ; 2005 [May 24th 2017.]. Available from: https://www.hydrogen.energy.gov/h2a_prod_studies.html.
77. Padró C, Putsche V. Survey of the Economics of Hydrogen Technologies. National Renewable Energy Laboratory; 1999.
78. Fiksdal T. Relevant hydrogen production technologies. Personal communication with Tomas Fiksdal, Greenstat AS (Tomas@greenstat.no). 2017.
79. Stensvold T. Denne konstruksjonen skjuler det som kan bli en fremtidig energigullgruve. Teknisk Ukeblad. 2016. [April 27th 2017.]. Available from: https://www.tu.no/artikler/denne-konstruksjonen-skjuler-det-som-kan-bli-en-fremtidig-energigullgruve/365695.
80. Jakobsen D, Åtland V. Concepts for Large Scale Hydrogen Production: NTNU; 2016.
81. Frihammer V. Information on Greenstat's TiZir project. Personal communication with Vegard Frihammer, Greenstat AS (vegard@greenstat.no). 2017.
82. Teigenes K. Information on upgrading the central power grid. Personal communication with Kenneth Teigenes, Sunnhordland kraftlag (kenneth.teigenes@skl.as). 2017.
83. Miljødirektoratet. Klimakvoter. [April 27th 2017.]. Available from: http://www.miljodirektoratet.no/no/Tema/klima/CO2_kvoter/.
84. Gade H. Vedtak om tildeling av vederlagsfrie kvoter for perioden 2013-2020 til TiZir Titanium & Iron. Klima- og forurensningsdirektoratet; 2012.
85. Lindegaard A, Laird B. Klimatiltak og utslippsbaner mot 2030. Miljødirektoratet; 2015.
86. Chen B, Liao Z, Wang J, Yu H, Yang Y. Exergy analysis and CO2 emission evaluation for steam methane reforming. International journal of hydrogen energy. 2011;37(2012):3191-200.
87. Svendsen T. Information on SMR and CCS. Personal communication with Tjalve Svendsen, CMR Prototech AS (Tjalve.Magnusson.Svendsen@prototech.no). 2017. .
88. Hagen K. Norges offentlige utredninger 2012:16. Samfunnsøkonomiske analyser. 2012.
89. NBIM. Oljefondet: Norges Bank Investment Management; [May 26th 2017.]. Available from: https://www.nbim.no/fondet/.
90. Berger R. Fuel Cell Electric Buses - Potential for Sustainable Public Transport in Europe. 2015.
91. Finansdepartementet. Nasjonalbudsjettet 2017.
92. NPRA. Utslipp til luft. [May 12th 2017.]. Available from: http://www.vegvesen.no/fag/Trafikk/Nokkeltall+transport/Konsekvenser/Utslipp.
93. Wethal A, Granerud N. Kjørelengder, 2015. [May 12th 2017.]. Available from: https://www.ssb.no/transport-og-reiseliv/statistikker/klreg/aar/2016-04-22.
94. Dalløkken P. Toyota flytter hydrogenteknologi fra personbil til lastebil. Teknisk Ukeblad. 2017 [May 13th 2017.]. Available from: https://www.tu.no/artikler/toyota-flytter-hydrogenteknologi-fra-personbil-til-lastebil/381985.
95. Birkeli K, Håmsø B, Kalland L-E, Lindegaard A, Molin D. Tiltakskostnader for elbil, samfunnsøkonomiske kostnader ved innfasing av elbiler i personbilparken. Miljødirektoratet; 2016.
96. Bergsaker T-K. Personal communication with Tor-Kjetil Bergsaker, Uno-X (tor.kjetil.bergsaker@unox.no). Information on hydrogen fueling stations. In: Solheimslid T, editor. 2016.
97. IPCC. Climate Change 2014 Synthesis Report. International panel on climate change; 2014.
98. Stuen J. Feasability Study of Capturing CO2 from the Klemetsrud CHP Waste-to-Energy Plant in Oslo.
99. Gassnova. Record participation and exciting international cooperation Climit [May 24th 2017]. Available from: http://www.climit.no/en/record-participation-and-exciting-international-cooperation.
100. IEA. World energy outlook 2016 executive summary. International Energy Agency; 2016.
101. Quéré C, Andrew R, Canadell J, Sitch S, Korsbakken J. Global Carbon Budget 2016. Earth System Science Data.

102. Rosland A. Mulige klimatiltak og reduksjon i utslipp mot 2030. [May 27th 2017.]. Available from: http://www.miljodirektoratet.no/no/Nyheter/Nyheter/2015/Juni-2015/Mulige-klimatiltak-og-reduksjon-i-utslipp-mot-2030/.
103. Aasheim A. Opinion on CCS in energy production sector vs industry. Personal communication with Andreas Aasheim, Norwea (aasheim@norwea.no). 2017.
104. Melbye A, Asheim K, Brenna K. Bærekraftig biodrivstoff. 2017.
105. Apple. In the future, can we make products without taking finite resources from the earth? [April 25th 2017.]. Available from: https://www.apple.com/environment/resources/.
106. Arbib J, Seba T. Rethinking Transportation 2020-2030. 2017.

Appendix 1: Tables and calculations

Common tables and calculations

In the following, tables and calculations relevant for calculations of all or several sectors are presented.

Vehicle stock development, current path								
Year	2015	2020	2025	2030	2035	2040	2045	2050
Cargo vans	430170	475678	515494	542128	552762	556363	567368	590971
Heavy duty trucks	60572	51232	49183	48343	47919	48027	48556	49506
Buses	16484	13656	11737	10586	10427	10596	10689	10688
Passenger vehicles	2578424	2758593	2910881	3074099	3256107	3449440	3629604	3759532

Table 22: Vehicle stock development, current path

Table 22 shows vehicle stock development for the current path scenario. This table is developed by the Norwegian Institute of Transport Economics' report and is used as basis for calculation of gasoline and diesel net present values (68). Linear interpolation is performed as the report only includes estimates for every fifth year (68).

Emissions, by vehicle and fuel type												
Vehicle type	Fuel type	Million kilometers driven	Average annual km/vehicle	kg CO_2/km	kg CH_4/km	kg N_2O/km	kg SO_2/km	kg NO_X/km	kg NMVOC/km	kg NH_3/km	kg PM10/km	kg PM2,5/km
Passenger vehicles	Gasoline	12110,2	9259	0,2123	0,0000293	0,0000033	0,0000006	0,0003367	0,0005041	0,0000823	0,0000032	0,0000032
	Diesel	20420	15322	0,1441	0,0000008	0,0000041	0,0000007	0,0004276	0,0000312	0,0000009	0,0000172	0,0000275
Cargo vans	Gasoline	268	7764	0,2832	0,0000596	0,0000112	0,0000000	0,0006520	0,0010358	0,0000857	0,0000075	0,0000002
	Diesel	6984	14883	0,2089	0,0000010	0,0000043	0,0000010	0,0007549	0,0000405	0,0000010	0,0000521	0,0000286
Heavy duty trucks	Gasoline	0,1	1512	330,0000	0,0600000	0,0000000	0,0000000	2,9700000	1,7800000	0,0000000	0,0000000	0,0000000
	Diesel	1971	35561	1,4443	0,0000056	0,0000330	0,0000066	0,0082006	0,0002207	0,0000041	0,0001324	0,0000205
Buses	Gasoline	2	5980	0,2832	0,0000596	0,0000112	0,0000000	0,0006520	0,0010358	0,0000857	0,0000075	0,0000002
	Diesel	527	32053	0,2089	0,0000010	0,0000043	0,0000010	0,0007549	0,0000405	0,0000010	0,0000521	0,0000286

Table 23: Emissions and distance driven, by vehicle and fuel type

Table 23 shows emissions and distance driven, by vehicle and fuel type. These numbers for emissions are collected from the Norwegian Public Roads Administration (92) for 2013, combined with numbers for distances driven which are collected from Statistics Norway (93) for 2015. As stated in chapter 3.3.3, the numbers for emissions for heavy-duty trucks running on gasoline appear to be wrong, thus the numbers for diesel are used here instead. This is likely to be due to the combination of 2015 and 2013 numbers.

	SFT						IPCC		
Greenhouse gas	Minimum abatement cost (NOK/kg)	Best guess abatement cost (NOK/kg)	Maximum abatement cost (NOK/kg)	Minimum social cost (NOK/kg)	Best guess social cost (NOK/kg)	Maximum social cost (NOK/kg)	Minimum social cost (NOK/kg)	Best guess social cost (NOK/kg)	Maximum social cost (NOK/kg)
CO_2	-		-	-		-	0,182	0,964	3,748
CH_4	5,36		-	-		-	-	-	-
N_2O	79,18		-	-		-	-	-	-
SO_2	15		23	19		166	42,8	75,0	107,1
NO_X	26		38	32		153	21,4	64,3	107,1
nmVOC	1	1,5	2	-		-	-	-	-
NH_3	-		-	0	4	8	-	-	-
PM10	-		-	255	3895	7 535	107,1	3821,0	7535,0

Table 24: Abatement and social costs of emissions, SFT and IPCC

Table 24 shows abatement and social costs of emissions based on SFT and IPCC's numbers (64, 97). The values with colored background are the ones used for the best guess scenarios. The ones with yellow background are values directly collected from either SFT or IPCC's reports, while the ones with red background are averages of the respective maximum and minimum values. Combined with the assumptions mentioned in chapter 3.3, all NPVs for diesel and gasoline vehicles are developed. These are not further explained, but the results are listed under their respective sector.

For hydrogen FCEV calculations, the following values are commonly used among the sectors:

- Governmental expenses connected with establishment of a hydrogen fueling station today is 10 MNOK. Such a station has the capacity to produce 200 kg H_2/day, which translates to roughly 73 000 kg H_2/year.
- A reduction factor is used in the calculations. This amounts to a reduction of marginal governmental expenses connected with establishment of hydrogen fueling stations by 2 % for each hydrogen fueling station established and a reduction of marginal governmental expenses connected with purchases of hydrogen vehicles by 2 % for every thousandth hydrogen vehicle purchased. For situations where several thousand hydrogen vehicles

are bought within a single year, it is assumed that governmental expenses due to purchase of these vehicles is equal for all hydrogen vehicles bought that year and the reduction factor used is based on the number of hydrogen vehicles at the end of that year in that sector. For passenger vehicles and cargo vans, two different reduction factors are used. See respective sector for further information.

- Financial support for purchase of hydrogen FCEVs is signaled by the Norwegian government to last until a stock of 50 000 units is achieved or until 2025, whichever comes first (91). Both of these scenarios are evaluated for all sectors, even though this only is meant to apply to passenger vehicles and in all cases a stock of 50 000 units is only achieved after 2025.

For EV calculations, the following values are commonly used among the sectors:

- Governmental expenses due to establishment of a rapid charging station today is 600 000 NOK (95).

Vehicle costs and public financial support development [MNOK]																																				
Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Hydrogen bus costs FCH	5,96	5,70	5,44	5,18	4,91	4,65	4,54	4,42	4,31	4,20	4,09	4,07	4,05	4,03	4,01	3,99	3,98	3,97	3,96	3,95	3,95	3,94	3,93	3,92	3,91	3,90	3,89	3,88	3,87	3,86	3,85	3,83	3,81	3,79	3,78	3,76
Hydrogen buses Public financial support FCH	1,89	1,76	1,63	1,50	1,37	1,24	1,18	1,12	1,07	1,01	0,95	0,94	0,93	0,93	0,92	0,91	0,90	0,90	0,89	0,89	0,88	0,88	0,87	0,87	0,86	0,86	0,85	0,85	0,85	0,84	0,84	0,83	0,82	0,81	0,80	0,79
Hydrogen heavy duty trucks Public financial support FCH	2,22	2,07	1,91	1,76	1,60	1,45	1,38	1,32	1,25	1,19	1,12	1,11	1,10	1,09	1,08	1,06	1,06	1,05	1,05	1,04	1,04	1,03	1,03	1,02	1,01	1,01	1,00	1,00	0,99	0,99	0,98	0,97	0,96	0,95	0,94	0,93
Hydrogen bus costs FCH rapid decrease	5,96	5,28	4,59	3,91	3,22	2,54	2,48	2,41	2,35	2,29	2,23	2,22	2,21	2,20	2,19	2,18	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Hydrogen buses Public financial support FCH rapid decrease	1,89	1,55	1,21	0,86	0,52	0,18	0,15	0,12	0,09	0,06	0,03	0,02	0,02	0,01	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Hydrogen heavy duty trucks Public financial support FCH rapid decrease	2,22	1,82	1,42	1,01	0,61	0,21	0,17	0,14	0,10	0,07	0,03	0,02	0,02	0,01	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Table 25: Vehicle costs and public financial support development, buses and heavy-duty trucks [MNOK]

Table 25 shows vehicle costs and public financial support development for buses and heavy-duty trucks. These estimates are based on projected costs of hydrogen buses by The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) (90). Row one in Table 25 uses these projected costs with interpolation as the FCH report only gives values for every fifth year. The initial value for the public financial support is set to be half of the cost difference between the hydrogen buses and the conventional diesel buses. The cost of conventional diesel buses in 2015 was 2.179 MNOK (90).

For hydrogen heavy-duty trucks, ASKO states that one such truck costs 7 MNOK (35). It is assumed that the cost ratio between diesel and hydrogen heavy-duty truck is the same as for diesel and hydrogen buses. By this assumption, the cost of a diesel heavy-duty truck is 2.558 MNOK. The initial value for the public financial support for heavy-duty trucks is set to be half of the cost difference between the hydrogen and diesel heavy-duty trucks.

Due to ASKO director Jørn Endresen's estimates of cost compatibility between hydrogen and diesel heavy-duty trucks by the early 2020s (35), another scenario is added where governmental expenses due to purchase of hydrogen heavy-duty trucks converges to zero in 2030. Convergence by early 2020s is not included due to the major disparity in estimates by Endresen and FCH.

Passenger vehicles

The following assumptions and values are used in these calculations:

- For hydrogen FCEVs, the reduction factors 1 and 2 are set to respectively 2 % and 1 %.
- For EVs, the reduction factors 1 and 2 are set to respectively 0.1 % and 0.01 %. The basis for this is that EVs have a significantly greater market share than hydrogen vehicles, making it natural that cost reductions in this sector does not occur as dramatically as for hydrogen vehicles.
- Initial value for governmental expenses due to purchase of EVs and hydrogen FCEVs are set to respectively 124 750 NOK and 249 500 NOK. This is based on values from a report of the Norwegian Environment Agency stating that governmental expenses due to purchase of EVs amount to 70 000 NOK for a small EV and 435 000 NOK for larger EVs (95), in addition to the assumption that 15 % of all EVs are large EVs and 85 % of all EVs are small EVs.
- Hydrogen consumption of a hydrogen FCEV passenger vehicle is assumed to be 150 kg H_2/year based on talks with the industry (96).
- Support for electric passenger vehicles is assumed to be maintained until 2020, which is what the Norwegian government signals (91).
- One rapid charging station is sufficient to cover the consumption of 200 EVs.

Passenger vehicles stock projection, by fuel								
Year	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	1237057	871805	571155	329243	149564	55153	20049	7287
Diesel	1220981	1263550	1020751	627367	315364	140470	59417	24032
BEV	68995	377987	1058034	1901929	2634358	3159089	3472458	3607597
Hydrogen	19	374	16591	68037	136801	206485	266656	348616

Table 26: Passenger vehicles stock development, by fuel (68)

Table 26 shows passenger vehicles stock development for the ultra-low emissions scenario. This table is developed by the Norwegian Institute of Transport Economics' report and is used as basis for calculation of EVs and hydrogen FCEV's net present values (68). Linear interpolation is performed as the report only includes estimates for every fifth year (68).

Hydrogen - passenger vehicles, support until 50 000 units. Reduction factor 1																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Fueling stations	-2,2	-2,2	-2,1	-2,1	-79,8	-65,2	-53,3	-43,5	-35,6	-59,5	-31,3	-16,5	-8,7	-4,6	-119,8	-96,9	-78,3	-63,3	-51,2	-41,8	-33,7	-27,2	-21,9	-17,7	-12,7	-10,5	-8,7	-7,3	-6,0	-6,4	-4,9	-3,8	-3,0	-2,3	0,0
	Vehicle stock projection		-17,7	-17,6	-17,6	-17,6	-752,2	-704,5	-659,8	-618,0	-578,8	-1491,4	-1211,5	-984,1	-197,5																					
Net present value (MNOK)	-5748,4	-2	-19,1	-18,3	-17,6	-83,2	-671,9	-598,9	-534,5	-477,5	-448,4	-1028,7	-797,7	-620,1	-121,3	-69,2	-53,8	-41,8	-32,5	-25,3	-19,9	-15,4	-11,9	-9,3	-7,2	-4,9	-3,9	-3,2	-2,5	-2,0	-2,0	-1,5	-1,1	-0,8	-0,6	0,0

Table 27: Hydrogen passenger vehicles, support until 50 000 units, reduction factor 1

Table 27 shows the cash flow and NPV of investment into hydrogen passenger vehicles when evaluating over the period 2017-2050, with financial support maintained until a stock of 50 000 units is achieved. This calculation is made with reduction factor 1, which is previously explained.

Hydrogen - passenger vehicles, support until 50 000 units. Reduction factor 2																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Fueling stations	-2	-2	-2	-2	-89	-81	-73	-66	-60	-138	-100	-73	-53	-39	-329	-316	-303	-290	-278	-270	-259	-248	-237	-227	-189	-182	-176	-169	-163	-211	-201	-191	-181	-172	0
	Vehicle stock projection		-18	-18	-18	-18	-780	-755	-731	-708	-685	-1959	-1767	-1593	-355																					
Net present value (MNOK)	-9071	-2	-19	-18	-18	-91	-708	-655	-606	-561	-578	-1391	-1195	-1028	-236	-190	-175	-162	-149	-137	-128	-118	-109	-100	-92	-74	-68	-63	-59	-54	-68	-62	-57	-52	-47	0

Table 28: Hydrogen passenger vehicles, support until 50 000 units, reduction factor 2

Table 28 shows the cash flow and NPV of investment into hydrogen passenger vehicles when evaluating over the period 2017-2050, with financial support maintained until a stock of 50 000 units is achieved. This calculation is made with reduction factor 2, which is previously explained.

Hydrogen - passenger vehicles, support until year 2025. Reduction factor 1																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Fueling stations	-2	-2	-2	-2	-80	-65	-53	-44	-36	-59	-31	-17	-9	-5	-3	-97	-78	-63	-51	-42	-34	-27	-22	-18	-13	-11	-9	-7	-6	-6	-5	-4	-3	-2	0
	Vehicle stock projection		-18	-18	-18	-18	-752	-704	-660	-618	-579																									
Net present value (MNOK)	-3153	-2	-19	-18	-18	-83	-672	-599	-534	-478	-448	-21	-11	-5	-3	-2	-54	-42	-33	-25	-20	-15	-12	-9	-7	-5	-4	-3	-3	-2	-2	-2	-1	-1	-1	0

Table 29: Hydrogen passenger vehicles, support until year 2025, reduction factor 1

Table 29 shows the cash flow and NPV of investment into hydrogen passenger vehicles when evaluating over the period 2017-2050, with financial support maintained until year 2025. This calculation is made with reduction factor 1, which is previously explained.

Hydrogen - passenger vehicles, support until year 2025. Reduction factor 2																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Fueling stations	-2	-2	-2	-2	-89	-81	-73	-66	-60	-138	-100	-73	-53	-39	-34	-316	-303	-290	-278	-270	-259	-248	-237	-227	-189	-182	-176	-169	-163	-211	-201	-191	-181	-172	0
	Vehicle stock projection		-18	-18	-18	-18	-780	-755	-731	-708	-685																									
Net present value (MNOK)	-5220	-2	-19	-18	-18	-91	-708	-655	-606	-561	-578	-68	-47	-33	-23	-19	-175	-162	-149	-137	-128	-118	-109	-100	-92	-74	-68	-63	-59	-54	-68	-62	-57	-52	-47	0

Table 30: Hydrogen passenger vehicles, support until year 2025, reduction factor 2

Table 30 shows the cash flow and NPV of investment into hydrogen passenger vehicles when evaluating over the period 2017-2050, with financial support maintained until year 2025. This calculation is made with reduction factor 2, which is previously explained.

Electric passenger vehicles, support until 2020. Reduction factor 1																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	EV charging stations	-185	-136	-100	-73	-82	-41	-21	-11	-5	-3	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	EV stock projection		-5656	-4149	-3044	-2233																														
Net present value (MNOK)	-14499	-185	-5569	-3928	-2771	-1979	-34	-17	-8	-4	-2	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 31: Electric passenger vehicles, support until 2020. Reduction factor 1

Table 31 shows the cash flow and NPV of investment into electric passenger vehicles when evaluating over the period 2017-2050, with financial support maintained until year 2020. This calculation is made with reduction factor 1, which is previously explained.

Electric passenger vehicles, support until 2020. Reduction factor 2																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	EV charging stations	-185	-180	-174	-169	-347	-325	-303	-283	-265	-302	-277	-255	-234	-215	-174	-161	-150	-139	-130	-88	-84	-79	-75	-71	-41	-40	-39	-38	-36	-16	-15	-15	-15	-15	0
	EV stock projection		-7247	-6813	-6404	-6020																														
Net present value (MNOK)	-27503	-185	-7141	-6460	-5843	-5443	-267	-240	-215	-193	-212	-187	-166	-146	-129	-100	-90	-80	-72	-64	-42	-38	-35	-32	-29	-16	-15	-14	-13	-12	-5	-5	-4	-4	-4	0

Table 32: Electric passenger vehicles, support until 2020. Reduction factor 2

Table 32 shows the cash flow and NPV of investment into electric passenger vehicles when evaluating over the period 2017-2050, with financial support maintained until year 2020. This calculation is made with reduction factor 2, which is previously explained.

Status quo prolonged - passenger vehicles, minimum costs (IPCC)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Investment costs	0																																		
	CO_2		-924,5	-914,9	-904,5	-893,4	-879,7	-865,5	-850,7	-835,2	-819,2	-803,3	-786,7	-769,6	-751,8	-733,3	-725,1	-720,4	-715,5	-710,1	-704,4	-698,7	-692,8	-686,6	-680,0	-673,0	-665,3	-657,1	-648,5	-639,6	-630,3	-619,6	-607,9	-595,9	-583,7	-571,3
	CH_4		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N_2O		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SO_2		-0,8	-0,8	-0,8	-0,8	-0,8	-0,8	-0,8	-0,8	-0,7	-0,7	-0,7	-0,7	-0,7	-0,7	-0,7	-0,7	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,5	-0,5	-0,5
	NO_X		-254,1	-251,5	-248,7	-245,8	-242,1	-238,2	-234,2	-230,0	-225,6	-221,3	-216,8	-212,1	-207,2	-202,2	-200,3	-199,0	-197,7	-196,3	-194,7	-193,2	-191,6	-189,9	-188,1	-186,2	-184,1	-181,9	-179,5	-177,1	-174,5	-171,5	-168,3	-165,0	-161,6	-158,2
	nmVOC		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NH_3		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PM2,5		-60,1	-59,6	-58,9	-58,2	-57,4	-56,5	-55,6	-54,6	-53,6	-52,6	-51,5	-50,4	-49,3	-48,1	-47,8	-47,5	-47,2	-46,9	-46,5	-46,2	-45,8	-45,4	-45,0	-44,6	-44,1	-43,5	-43,0	-42,4	-41,8	-41,1	-40,3	-39,5	-38,7	-37,9
Net present value (MNOK)	-19087,4	0	-1191,9	-1134,2	-1078,3	-1024,2	-969,9	-917,5	-867,2	-818,8	-772,3	-728,2	-685,8	-645,0	-605,9	-568,4	-540,7	-516,6	-493,4	-470,9	-449,2	-428,4	-408,5	-389,3	-370,7	-352,8	-335,4	-318,5	-302,3	-286,7	-271,7	-256,8	-242,2	-228,3	-215,1	-202,4

Table 33: Status quo prolonged, passenger vehicles, minimum costs (IPCC)

Table 33 shows the cash flow and NPV of the scenario status quo prolonged when evaluating over the period 2017-2050 and using minimum social costs of emissions based on IPCC's report (97). These values for the social costs of emissions can be seen in Table 8.

Status quo prolonged - passenger vehicles, maximum costs (IPCC)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Investment costs	0																																		
	CO_2		-19035	-18835	-18622	-18394	-18112	-17819	-17513	-17196	-16867	-16539	-16198	-15844	-15477	-15098	-14928	-14833	-14730	-14620	-14503	-14385	-14264	-14136	-13999	-13856	-13698	-13528	-13351	-13167	-12976	-12757	-12515	-12269	-12018	-11761
	CH_4		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N_2O		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SO_2		-2,1	-2,1	-2,0	-2,0	-2,0	-2,0	-1,9	-1,9	-1,8	-1,8	-1,8	-1,7	-1,7	-1,7	-1,6	-1,6	-1,6	-1,6	-1,6	-1,6	-1,6	-1,6	-1,5	-1,5	-1,5	-1,5	-1,5	-1,4	-1,4	-1,4	-1,4	-1,4	-1,3	-1,3
	NO_X		-1270	-1258	-1244	-1229	-1210	-1191	-1171	-1150	-1128	-1106	-1084	-1060	-1036	-1011	-1001	-995	-989	-981	-974	-966	-958	-950	-941	-931	-921	-909	-898	-885	-873	-858	-841	-825	-808	-791
	nmVOC		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NH_3		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PM2,5		-4231	-4190	-4146	-4099	-4038	-3976	-3910	-3841	-3770	-3699	-3625	-3548	-3467	-3384	-3364	-3344	-3323	-3299	-3275	-3250	-3225	-3197	-3168	-3137	-3101	-3064	-3025	-2985	-2943	-2890	-2837	-2782	-2725	-2668
Net present value (MNOK)	-378066	0	-23595	-22453	-21348	-20279	-19203	-18167	-17171	-16213	-15293	-14420	-13581	-12775	-12001	-11258	-10714	-10237	-9776	-9331	-8901	-8490	-8096	-7715	-7347	-6993	-6648	-6313	-5991	-5682	-5385	-5089	-4801	-4526	-4263	-4012

Table 34: Status quo prolonged, passenger vehicles, maximum costs (IPCC)

Table 34 shows the cash flow and NPV of the scenario status quo prolonged when evaluating over the period 2017-2050 and using maximum social costs of emissions based on IPCC's report (97). These values for the social costs of emissions can be seen in Table 8.

Status quo prolonged - passenger vehicles, best guess costs (IPCC & SFT combined)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Investment costs	0																																		
	CO_2		-4895	-4843	-4788	-4730	-4657	-4582	-4503	-4422	-4337	-4253	-4165	-4074	-3980	-3882	-3839	-3814	-3788	-3759	-3729	-3699	-3668	-3635	-3600	-3563	-3522	-3479	-3433	-3386	-3337	-3280	-3218	-3155	-3090	-3024
	CH_4		-1,8	-1,8	-1,8	-1,7	-1,7	-1,7	-1,6	-1,6	-1,6	-1,6	-1,5	-1,5	-1,4	-1,4	-1,4	-1,4	-1,4	-1,4	-1,3	-1,3	-1,3	-1,3	-1,3	-1,3	-1,3	-1,2	-1,2	-1,2	-1,2	-1,2	-1,2	-1,1	-1,1	-1,1
	N_2O		-9,1	-9,0	-8,9	-8,8	-8,7	-8,5	-8,4	-8,2	-8,1	-7,9	-7,8	-7,6	-7,4	-7,2	-7,2	-7,1	-7,1	-7,0	-7,0	-6,9	-6,9	-6,8	-6,7	-6,7	-6,6	-6,5	-6,4	-6,3	-6,2	-6,1	-6,0	-5,9	-5,8	-5,7
	SO_2		-1,5	-1,4	-1,4	-1,4	-1,4	-1,4	-1,3	-1,3	-1,3	-1,3	-1,2	-1,2	-1,2	-1,2	-1,1	-1,1	-1,1	-1,1	-1,1	-1,1	-1,1	-1,1	-1,1	-1,1	-1,1	-1,0	-1,0	-1,0	-1,0	-1,0	-1,0	-0,9	-0,9	-0,9
	NO_X		-762	-755	-746	-737	-726	-715	-702	-690	-677	-664	-650	-636	-622	-607	-601	-597	-593	-589	-584	-580	-575	-570	-564	-559	-552	-546	-539	-531	-524	-515	-505	-495	-485	-475
	nmVOC		-9,2	-9,1	-8,9	-8,8	-8,7	-8,5	-8,4	-8,2	-8,1	-7,9	-7,7	-7,6	-7,4	-7,2	-7,1	-7,0	-7,0	-6,9	-6,9	-6,8	-6,7	-6,7	-6,6	-6,5	-6,5	-6,4	-6,3	-6,2	-6,1	-6,0	-5,9	-5,8	-5,7	-5,5
	NH_3		-3,7	-3,6	-3,6	-3,5	-3,5	-3,4	-3,4	-3,3	-3,2	-3,2	-3,1	-3,0	-3,0	-2,9	-2,8	-2,8	-2,8	-2,8	-2,7	-2,7	-2,7	-2,7	-2,6	-2,6	-2,6	-2,5	-2,5	-2,5	-2,4	-2,4	-2,4	-2,3	-2,3	-2,2
	PM2,5		-2146	-2125	-2103	-2078	-2048	-2016	-1983	-1948	-1912	-1876	-1838	-1799	-1758	-1716	-1706	-1696	-1685	-1673	-1661	-1648	-1635	-1621	-1606	-1591	-1573	-1554	-1534	-1514	-1492	-1466	-1438	-1411	-1382	-1353
	PM10		-1419	-1405	-1390	-1374	-1354	-1332	-1310	-1287	-1263	-1239	-1215	-1189	-1162	-1134	-1126	-1120	-1113	-1105	-1096	-1088	-1080	-1070	-1060	-1050	-1038	-1026	-1013	-999	-985	-968	-949	-931	-912	-893
Net present value (MNOK)	-142723	0	-8891	-8462	-8047	-7645	-7240	-6851	-6476	-6116	-5769	-5441	-5125	-4821	-4530	-4249	-4049	-3869	-3695	-3527	-3365	-3210	-3061	-2918	-2779	-2645	-2515	-2388	-2267	-2150	-2038	-1925	-1817	-1712	-1613	-1518

Table 35: Status quo prolonged, passenger vehicles, best guess costs (IPCC & SFT combined)

Table 35 shows the cash flow and NPV of the scenario status quo prolonged when evaluating over the period 2017-2050 and using best guess social costs of emissions based on IPCC's report (97). These values for the social and abatement costs of emissions can be seen in Table 24.

Projected development - passenger vehicles, best guess costs (IPCC & SFT combined)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	H2 fueling stations	-2,2	-2,2	-2,1	-2,1	-79,8	-65,2	-53,3	-43,5	-35,6	-59,5	-31,3	-16,5	-8,7	-4,6	-2,6	-96,9	-78,3	-63,3	-51,2	-41,8	-33,7	-27,2	-21,9	-17,7	-12,7	-10,5	-8,7	-7,3	-6,0	-6,4	-4,9	-3,8	-3,0	-2,3	0,0
	H2 FCEV stock projection		-17,7	-17,6	-17,6	-17,6	-752,2	-704,5	-659,8	-618,0	-578,8																									
	EV charging stations	-185,4	-136,1	-99,9	-73,3	-81,7	-41,4	-21,0	-10,6	-5,4	-2,9	-1,2	-0,5	-0,2	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	EV stock projection		-5656	-4149	-3044	-2233																														
	CO_2		193	377	551	715	946	1164	1368	1558	1734	1931	2113	2278	2427	2560	2674	2802	2923	3037	3145	3192	3237	3276	3311	3341	3331	3317	3300	3280	3257	3212	3161	3108	3053	2997
	CH_4		0,1	0,3	0,4	0,5	0,6	0,7	0,7	0,8	0,9	0,9	1,0	1,0	1,0	1,1	1,1	1,1	1,1	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,1	1,1	1,1	1,1
	N_2O		0,3	0,5	0,8	1,0	1,4	1,8	2,2	2,6	2,9	3,3	3,7	4,0	4,3	4,6	4,8	5,1	5,3	5,6	5,8	5,9	6,0	6,1	6,1	6,2	6,2	6,2	6,1	6,1	6,1	6,0	5,9	5,8	5,7	5,6
	SO_2		0,0	0,1	0,1	0,2	0,2	0,3	0,4	0,4	0,5	0,5	0,6	0,6	0,7	0,7	0,8	0,8	0,9	0,9	0,9	0,9	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,9	0,9	0,9	0,9
	NO_X		23	44	65	84	120	153	185	214	242	275	306	335	361	384	404	426	447	466	485	493	501	508	514	520	519	517	515	513	509	502	495	487	478	470
	nmVOC		0,6	1,2	1,8	2,3	2,8	3,2	3,6	3,9	4,3	4,5	4,8	5,0	5,2	5,3	5,4	5,6	5,8	5,9	6,1	6,1	6,2	6,2	6,2	6,3	6,2	6,2	6,1	6,1	6,0	5,9	5,8	5,7	5,6	5,5
	NH_3		0,3	0,5	0,8	1,0	1,2	1,4	1,5	1,7	1,8	1,9	2,0	2,1	2,1	2,2	2,2	2,3	2,3	2,4	2,4	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,4	2,4	2,4	2,3	2,3	2,2	2,2
	PM2,5		28	55	81	105	204	298	386	468	545	654	755	848	933	1009	1081	1151	1217	1280	1339	1369	1396	1420	1443	1463	1462	1460	1456	1451	1444	1425	1404	1382	1360	1336
	PM10		22	43	63	81	147	209	267	322	373	443	509	569	624	674	720	765	808	849	888	907	924	940	954	967	967	965	962	959	954	941	927	913	898	882
Net present value (MNOK)	51389	-188	-5331	-3465	-2111	-1216	464	832	1140	1398	1589	2218	2389	2520	2614	2678	2663	2713	2745	2763	2767	2713	2654	2591	2524	2456	2358	2261	2165	2072	1980	1878	1778	1682	1590	1502

Table 36: Projected development, passenger vehicles, best guess costs (IPCC & SFT combined)

Table 36 shows the NPV of projected development of passenger vehicles with best guess social and abatement costs of emissions in the ultra-low emissions path relative to the status quo path. This means that in year 1, being 2017, CO_2-emissions are decreased by an amount worth 193 MNOK compared to what they would be in the reference scenario. Over the evaluated period, the amount of diesel and gasoline passenger vehicles becomes smaller and smaller, increasing the difference between the projected stock's emissions and the emissions of the stock in the status quo scenario and thus similarly decreasing governmental expenses due to social costs of emissions. For hydrogen FCEVs, the scenario of financial support until year 2025 and reduction factor 1 is used. For EVs, reduction factor 1 is used.

Cargo vans

In these calculations, all assumptions equal those of passenger vehicles, with the exception of reduction factor 1 and 2 for electric cargo vans. Here, it is assumed that governmental expenses decrease by a range of 0.1-0.5 % for each thousandth vehicle purchased.

Cargo vans stock development, by fuel																																				
Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Gasoline	29141	25715	22289	18863	15437	12011	10712	9413	8115	6816	5517	4865	4213	3562	2910	2258	1941	1623	1306	988	671	576	480	385	289	194	167	140	113	86	59	49,6	40,2	30,8	21,4	12
Diesel	398845	405710	412576	419441	426307	433172	420374	407576	394778	381980	369182	343328	317473	291619	265764	239910	217526	195142	172758	150374	127990	114217	100444	86670	72897	59124	52818,2	46512,4	40206,6	33900,8	27595	24886,2	22177,4	19468,6	16759,8	14051
BEV	1805	7490	13175	18861	24546	30231	48972	67713	86455	105196	123937	140087	156237	172387	188537	204687	215705	226723	237742	248760	259778	268656	277534	286413	295291	304169	314188,2	324207,4	334226,6	344245,8	354265	366890,6	379516,2	392141,8	404767,4	417393
Hydrogen	0	2	5	7	10	12	3561	7110	10658	14207	17756	35863	53970	72077	90184	108291	127825	147358	166892	186425	205959	217960	229961	241963	253964	265965	269126,4	272287,8	275449,2	278610,6	281772	279707,6	277643,2	275578,8	273514,4	271450

Table 37: Cargo vans stock development, by fuel

Table 26 shows passenger vehicles stock development for the ultra-low emissions scenario. This table is developed by the Norwegian Institute of Transport Economics' report and is used as basis for calculation of EVs and hydrogen FCEV's net present values (68). Linear interpolation is performed as the report only includes estimates for every fifth year (68).

Hydrogen - cargo vans, support until 50 000 units. Reduction factor 1																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Fueling stations	-0,1	-0,1	-0,1	-0,1	-87,6	-70,3	-56,3	-45,2	-36,2	-59,8	-19,4	-6,3	-2,0	-0,7	-119,8	-96,9	-78,3	-63,3	-51,2	-41,8	-33,7	-27,2	-21,9	-17,7	-12,7	-10,5	-8,7	-7,3	-6,0	-6,4	-4,9	-3,8	-3,0	-2,3	0,0
	Vehicle stock projection		-0,6	-0,6	-0,6	-0,6	-824,0	-767,0	-713,9	-664,5	-618,5	-2189,1	-1185,5	0,0	0,0																					
Net present value (MNOK)	-5605,2	0	-0,6	-0,6	-0,6	-75,4	-735,0	-650,7	-576,8	-512,0	-476,6	-1491,9	-774,1	-1,3	-0,4	-69,2	-53,8	-41,8	-32,5	-25,3	-19,9	-15,4	-11,9	-9,3	-7,2	-4,9	-3,9	-3,2	-2,5	-2,0	-2,0	-1,5	-1,1	-0,8	-0,6	0,0

Table 38: Hydrogen cargo vans, support until 50 000 units, reduction factor 1

Table 38 shows the cash flow and NPV of investment into hydrogen cargo vans when evaluating over the period 2017-2050, with financial support maintained until a stock of 50 000 units is achieved. This calculation is made with reduction factor 1, which is previously explained.

Hydrogen - cargo vans, support until 50 000 units. Reduction factor 2																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Fueling stations	0	0	0	0	-98	-88	-79	-70	-63	-184	-105	-60	-34	-19	-329	-316	-303	-290	-278	-270	-259	-248	-237	-227	-189	-182	-176	-169	-163	-211	-201	-191	-181	-172	0
	Vehicle stock projection		-1	-1	-1	-1	-854	-824	-795	-768	-741	-3151	-2050	0	0																					
Net present value (MNOK)	-9056	0	-1	-1	-1	-84	-774	-714	-658	-607	-650	-2199	-1371	-21	-12	-190	-175	-162	-149	-137	-128	-118	-109	-100	-92	-74	-68	-63	-59	-54	-68	-62	-57	-52	-47	0

Table 39: Hydrogen cargo vans, support until 50 000 units, reduction factor 2

Table 39 shows the cash flow and NPV of investment into hydrogen cargo vans when evaluating over the period 2017-2050, with financial support maintained until a stock of 50 000 units is achieved. This calculation is made with reduction factor 2, which is previously explained.

Hydrogen - cargo vans, support until year 2025. Reduction factor 1																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Fueling stations	0	0	0	0	-88	-70	-56	-45	-36	-60	-19	-6	-2	-1	0	-97	-78	-63	-51	-42	-34	-27	-22	-18	-13	-11	-9	-7	-6	-6	-5	-4	-3	-2	0
	Vehicle stock projection		-1	-1	-1	-1	-824	-767	-714	-665	-619																									
Net present value (MNOK)	-3287	0	-1	-1	-1	-75	-735	-651	-577	-512	-477	-13	-4	-1	0	0	-54	-42	-33	-25	-20	-15	-12	-9	-7	-5	-4	-3	-3	-2	-2	-2	-1	-1	-1	0

Table 40: Hydrogen cargo vans, support until year 2025, reduction factor 1

Table 40 shows the cash flow and NPV of investment into hydrogen cargo vans when evaluating over the period 2017-2050, with financial support maintained until year 2025. This calculation is made with reduction factor 1, which is previously explained.

Hydrogen - cargo vans, support until year 2025. Reduction factor 2																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Fueling stations	0	0	0	0	-98	-88	-79	-70	-63	-184	-105	-60	-34	-19	-11	-316	-303	-290	-278	-270	-259	-248	-237	-227	-189	-182	-176	-169	-163	-211	-201	-191	-181	-172	0
	Vehicle stock projection		-1	-1	-1	-1	-854	-824	-795	-768	-741																									
Net present value (MNOK)	-5412	0	-1	-1	-1	-84	-774	-714	-658	-607	-650	-71	-39	-21	-12	-7	-175	-162	-149	-137	-128	-118	-109	-100	-92	-74	-68	-63	-59	-54	-68	-62	-57	-52	-47	0

Table 41: Hydrogen cargo vans, support until year 2025, reduction factor 2

Table 41 shows the cash flow and NPV of investment into hydrogen cargo vans when evaluating over the period 2017-2050, with financial support maintained until year 2025. This calculation is made with reduction factor 2, which is previously explained.

Electric cargo vans, support until 2020. Reduction factor 1																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	EV charging stations	-17	-17	-16	-16	-47	-43	-39	-35	-32	-26	-24	-22	-20	-19	-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	EV stock projection		-689	-670	-651	-633																														
Net present value (MNOK)	-2699	-17	-679	-634	-593	-581	-35	-31	-27	-24	-18	-16	-14	-13	-11	-7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 42: Electric cargo vans, support until 2020. Reduction factor 1

Table 42 shows the cash flow and NPV of investment into electric cargo vans when evaluating over the period 2017-2050, with financial support maintained until year 2020. This calculation is made with reduction factor 1, which is previously explained.

Electric cargo vans, support until 2020. Reduction factor 2																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	EV charging stations	-17	-17	-17	-17	-55	-55	-54	-54	-53	-45	-45	-45	-44	-44	-174	-161	-150	-139	-130	-88	-84	-79	-75	-71	-41	-40	-39	-38	-36	-16	-15	-15	-15	-15	
	EV stock projection		-705	-701	-697	-693																														
Net present value (MNOK)	-3637	-17	-694	-664	-635	-640	-45	-43	-41	-39	-32	-30	-29	-28	-26	-100	-90	-80	-72	-64	-42	-38	-35	-32	-29	-16	-15	-14	-13	-12	-5	-5	-4	-4	-4	0

Table 43: Electric cargo vans, support until 2020. Reduction factor 2

Table 43 shows the cash flow and NPV of investment into electric cargo vans when evaluating over the period 2017-2050, with financial support maintained until year 2020. This calculation is made with reduction factor 2, which is previously explained.

Status quo prolonged - cargo vans, minimum costs (IPCC)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Investment costs	0																																		
	CO_2		-244	-243	-241	-238	-236	-232	-229	-226	-222	-217	-212	-207	-201	-196	-193	-190	-187	-184	-181	-178	-174	-171	-167	-164	-160	-157	-154	-151	-147	-145	-142	-139	-136	-133
	CH_4		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N_2O		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SO_2		-0,3	-0,3	-0,3	-0,3	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1
	NO_X		-102	-101	-100	-99	-98	-96	-95	-93	-91	-89	-87	-85	-83	-80	-79	-78	-77	-75	-74	-73	-71	-70	-68	-67	-66	-64	-63	-62	-60	-59	-58	-57	-55	-54
	nmVOC		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NH_3		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PM2,5		-18,7	-18,5	-18,2	-17,9	-17,6	-17,3	-17,0	-16,7	-16,3	-15,9	-15,5	-15,1	-14,6	-14,2	-14,0	-13,8	-13,5	-13,3	-13,1	-12,8	-12,6	-12,3	-12,0	-11,8	-11,5	-11,3	-11,1	-10,8	-10,6	-10,4	-10,1	-9,9	-9,7	-9,5
Net present value (MNOK)	-5509	0	-351	-335	-319	-304	-289	-274	-259	-245	-232	-218	-204	-192	-180	-168	-159	-150	-142	-135	-127	-120	-113	-107	-100	-95	-89	-84	-79	-74	-70	-66	-62	-59	-55	-52

Table 44: Status quo prolonged, cargo vans, minimum costs (IPCC)

Table 44 shows the cash flow and NPV of the scenario status quo prolonged when evaluating over the period 2017-2050 and using minimum social costs of emissions based on IPCC's report (97). These values for the social costs of emissions can be seen in Table 8.

Status quo prolonged - cargo vans, maximum costs (IPCC)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Investment costs	0																																		
	CO_2		-5032	-4996	-4955	-4910	-4850	-4785	-4717	-4645	-4569	-4468	-4364	-4258	-4148	-4037	-3971	-3910	-3849	-3787	-3724	-3655	-3584	-3512	-3439	-3367	-3299	-3234	-3169	-3103	-3036	-2976	-2920	-2863	-2804	-2744
	CH_4		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N_2O		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SO_2		-0,7	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,5	-0,5	-0,5	-0,5	-0,5	-0,5	-0,5	-0,5	-0,5	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,3	-0,3	-0,3
	NO_X		-510	-506	-500	-495	-488	-481	-473	-465	-457	-446	-436	-425	-413	-402	-395	-389	-383	-376	-370	-363	-356	-349	-342	-334	-328	-321	-314	-308	-301	-295	-289	-283	-277	-271
	nmVOC		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NH_3		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PM2,5		-1316	-1299	-1281	-1262	-1241	-1219	-1196	-1172	-1148	-1119	-1090	-1061	-1031	-1000	-984	-968	-952	-936	-919	-901	-883	-865	-847	-829	-812	-795	-778	-761	-744	-729	-714	-698	-682	-666
Net present value (MNOK)	-103127	0	-6595	-6288	-5989	-5699	-5407	-5125	-4853	-4591	-4338	-4076	-3826	-3587	-3359	-3141	-2971	-2812	-2661	-2517	-2380	-2246	-2117	-1994	-1878	-1767	-1665	-1569	-1478	-1391	-1309	-1233	-1163	-1096	-1032	-970

Table 45: Status quo prolonged, cargo vans, maximum costs (IPCC)

Table 45 shows the cash flow and NPV of the scenario status quo prolonged when evaluating over the period 2017-2050 and using maximum social costs of emissions based on IPCC's report (97). These values for the social costs of emissions can be seen in Table 8.

Status quo prolonged - cargo vans, best guess costs (IPCC & SFT combined)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Investment costs	0																																		
	CO_2		-1294	-1285	-1274	-1263	-1247	-1231	-1213	-1194	-1175	-1149	-1122	-1095	-1067	-1038	-1021	-1005	-990	-974	-958	-940	-921	-903	-884	-866	-848	-832	-815	-798	-781	-765	-751	-736	-721	-706
	CH_4		-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1
	N_2O		-2,3	-2,3	-2,3	-2,3	-2,2	-2,2	-2,2	-2,2	-2,1	-2,1	-2,1	-2,0	-2,0	-1,9	-1,9	-1,9	-1,8	-1,8	-1,8	-1,7	-1,7	-1,7	-1,6	-1,6	-1,6	-1,5	-1,5	-1,5	-1,5	-1,4	-1,4	-1,4	-1,3	-1,3
	SO_2		-0,5	-0,5	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,2	-0,2	-0,2	-0,2
	NO_X		-306	-303	-300	-297	-293	-288	-284	-279	-274	-268	-261	-255	-248	-241	-237	-233	-230	-226	-222	-218	-214	-209	-205	-201	-197	-193	-189	-185	-181	-177	-174	-170	-166	-163
	nmVOC		-0,7	-0,8	-0,8	-0,8	-0,8	-0,9	-0,9	-0,9	-0,9	-0,9	-0,9	-0,9	-0,9	-0,9	-0,9	-0,8	-0,8	-0,8	-0,8	-0,8	-0,8	-0,8	-0,8	-0,8	-0,7	-0,7	-0,7	-0,7	-0,7	-0,7	-0,7	-0,7	-0,7	-0,7
	NH_3		-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1
	PM2,5		-667	-659	-650	-640	-629	-618	-606	-594	-582	-568	-553	-538	-523	-507	-499	-491	-483	-474	-466	-457	-448	-439	-430	-420	-412	-403	-395	-386	-377	-370	-362	-354	-346	-338
	PM10		-1248	-1232	-1216	-1199	-1179	-1158	-1137	-1115	-1093	-1066	-1039	-1011	-982	-954	-938	-923	-908	-892	-877	-860	-843	-825	-808	-791	-775	-759	-743	-727	-710	-696	-682	-667	-652	-637
Net present value (MNOK)	-52264	0	-3384	-3220	-3061	-2908	-2755	-2607	-2465	-2329	-2197	-2063	-1935	-1812	-1696	-1584	-1499	-1418	-1341	-1268	-1199	-1131	-1066	-1004	-945	-890	-838	-790	-743	-700	-658	-620	-584	-550	-517	-486

Table 46: Status quo prolonged, cargo vans, best guess costs (IPCC & SFT combined)

Table 46 shows the cash flow and NPV of the scenario status quo prolonged when evaluating over the period 2017-2050 and using best guess social costs of emissions based on IPCC's report (97). These values for the social and abatement costs of emissions can be seen in Table 24.

Projected development - cargo vans, best guess costs (IPCC & SFT combined)																			
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Cash flow	H2 fueling stations	-0,1	-0,1	-0,1	-0,1	-87,6	-70,3	-56,3	-45,2	-36,2	-59,8	-19,4	-6,3	-2,0	-0,7	-0,2	-96,9	-78,3	-63,3
	H2 FCEV stock projection		-0,6	-0,6	-0,6	-0,6	-824,0	-767,0	-713,9	-664,5	-618,5								
	EV charging stations	-17,1	-16,6	-16,1	-15,7	-47,0	-42,8	-39,0	-35,5	-32,3	-25,7	-23,7	-21,8	-20,2	-18,6	-12,0	0,0	0,0	0,0
	EV stock projection		-689	-670	-651	-633													
	CO_2		10	20	30	38	93	144	193	238	280	344	402	456	505	550	587	623	658
	CH_4		0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
	N_2O		0,0	0,1	0,1	0,2	0,3	0,4	0,5	0,5	0,6	0,7	0,8	0,9	1,0	1,1	1,1	1,2	1,3
	SO_2		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,2	0,2	0,2	0,2	0,2
	NO_X		1,1	2,2	3,1	4,1	16,6	28,3	39,4	49,8	59,5	74,5	88,4	101,3	113,0	123,7	132,7	141,5	149,9
	nmVOC		0,1	0,2	0,3	0,3	0,4	0,4	0,5	0,5	0,6	0,6	0,6	0,7	0,7	0,7	0,7	0,7	0,7
	NH_3		0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
	PM2,5		-3	-6	-9	-11	14	38	61	82	102	135	166	194	220	244	265	285	304
	PM10		-4	-8	-11	-15	34	79	122	162	199	261	318	371	420	464	503	540	575
Net present value (MNOK)	13533	-17	-675	-626	-581	-642	-640	-451	-287	-146	-43	522	616	689	745	792	773	808	834

Projected development - cargo vans, best guess costs (IPCC & SFT combined)																			
Year		18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	
Cash flow	H2 fueling stations	-51,2	-41,8	-33,7	-27,2	-21,9	-17,7	-12,7	-10,5	-8,7	-7,3	-6,0	-6,4	-4,9	-3,8	-3,0	-2,3	0,0	
	H2 FCEV stock projection																		
	EV charging stations	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
	EV stock projection																		
	CO_2	691	722	734	744	753	761	768	763	758	753	747	740	730	720	710	699	688	
	CH_4	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	
	N_2O	1,3	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,3	1,3	1,3	1,3	
	SO_2	0,2	0,2	0,2	0,2	0,2	0,2	0,3	0,3	0,3	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	
	NO_X	157,8	165,4	168,3	170,9	173,2	175,3	177,1	176,1	175,0	173,8	172,4	170,9	168,5	166,2	163,7	161,1	158,4	
	nmVOC	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	
	NH_3	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	
	PM2,5	322	339	346	352	358	363	367	366	364	361	359	356	350	345	340	334	328	
	PM10	608	640	653	664	675	684	693	689	685	681	675	670	660	651	640	630	619	
Net present value (MNOK)		854	867	853	837	818	799	778	745	713	681	650	620	588	558	528	500	473	

Table 47: Projected development, cargo vans, best guess costs (IPCC & SFT combined)

Table 47 shows the NPV of projected development of cargo vans with best guess social and abatement costs of emissions in the ultra-low emissions path relative to the status quo path. This means that in year 1, being 2017, CO_2-emissions are decreased by an amount worth 10 MNOK compared to what they would be in the reference scenario. Over the evaluated period, the amount of diesel and gasoline cargo vans becomes smaller and smaller, increasing the difference between the projected stock's emissions and the emissions of the stock in the status quo scenario and thus similarly decreasing governmental expenses due to social costs of emissions. For hydrogen FCEVs, the scenario of financial support until year 2025 and reduction factor 1 is used. For EVs, reduction factor 1 is used.

Heavy-duty trucks

The following assumptions and values are used in these calculations:

- For hydrogen heavy-duty trucks, the reduction factor is set to 2 %.
- As no electric heavy-duty trucks are purchased in this scenario, no values are set.
- The cost of a hydrogen heavy-duty truck is set to 7 MNOK, based on talks with the industry (35). Governmental expenses due to purchase of hydrogen heavy-duty trucks are given in Table 25.
- Hydrogen consumption of a hydrogen heavy-duty truck is calculated to be 1 635.8 kg H_2/year based on average annual distance driven by diesel heavy-duty trucks from Table 15 and average hydrogen consumption of a Nikola One from Table 4.

Heavy duty trucks and tractor units stock projection, by fuel								
Year	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	2982	1242	901	577	81	5	1	0
Diesel	65809	59360	55627	46883	32313	22398	15407	10382
BEV	2	1	0	0	0	0	0	0
Hydrogen	0	0	60	6757	23163	36321	46825	55895

Table 48: Heavy-duty trucks stock development, by fuel

Table 48 shows passenger vehicles stock development for the ultra-low emissions scenario. This table is developed by the Norwegian Institute of Transport Economics' report and is used as basis for calculation of EVs and hydrogen FCEV's net present values (68). Linear interpolation is performed as the report only includes estimates for every fifth year (68). Note that these values include both heavy-duty trucks and tractor units, but in calculations for this sector made in this thesis all vehicles are assumed to be heavy-duty trucks.

Hydrogen - heavy-duty trucks, support until 50 000 units. FCH																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Fueling stations	0	0	0	0	-4	-4	-4	-4	-4	-174	-70	-28	-11	-5	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Vehicle stock projection		0	0	0	0	-17	-16	-15	-14	-13	-1484	-1469	-1455	-1440	-1425	-3473	-3455	-3437	-3419	-3401	-2713	-2698	-2684	-2669	-2655	-2108	-2096	-2085	-2073	-2061	-1760	-1305			
Net present value (MNOK)	-23889	0	0	0	0	-3	-17	-16	-14	-13	-132	-1050	-973	-916	-867	-824	-1928	-1845	-1764	-1688	-1614	-1238	-1184	-1132	-1083	-1036	-791	-756	-723	-691	-661	-543	-387	0	0	0

Table 49: Hydrogen heavy-duty trucks, support until 50 000 units, FCH

Table 49 shows the cash flow and NPV of investment into hydrogen heavy-duty trucks when evaluating over the period 2017-2050, with financial support maintained until a stock of 50 000 units is achieved. Development of governmental expenses due to purchase of hydrogen heavy-duty trucks are calculated using FCH's estimates, which are previously explained.

Hydrogen - heavy-duty trucks, support until 50 000 units. FCH rapid decrease																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Fueling stations	0,0	0,0	0,0	0,0	-4,0	-4,0	-3,9	-3,9	-3,9	-174,1	-70,1	-28,2	-11,4	-4,6	-1,2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Vehicle stock projection		0,0	0,0	0,0	0,0	-2,1	-1,7	-1,2	-0,8	-0,4	-32,3	-24,2	-16,1	-8,1	0,0																				
Net present value (MNOK)	-271	0	0	0	0	-3	-5	-4	-4	-3	-123	-69	-34	-17	-8	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 50: Hydrogen heavy-duty trucks, support until 50 000 units, FCH rapid decrease

Table 50 shows the cash flow and NPV of investment into hydrogen heavy-duty trucks when evaluating over the period 2017-2050, with financial support maintained until a stock of 50 000 units is achieved. Development of governmental expenses due to purchase of hydrogen heavy-duty trucks are calculated with basis in FCH's estimates, which are previously explained.

Hydrogen - heavy-duty trucks, support until year 2025. FCH																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Fueling stations	0,0	0,0	0,0	0,0	-4,0	-4,0	-3,9	-3,9	-3,9	-174,1	-70,1	-28,2	-11,4	-4,6	-1,2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Vehicle stock projection		0,0	0,0	0,0	0,0	-16,6	-15,8	-15,0	-14,2	-13,4																									
Net present value (MNOK)	-272	0	0	0	0	-3	-17	-16	-14	-13	-132	-47	-18	-7	-3	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 51: Hydrogen heavy-duty trucks, support until year 2025, FCH

Table 51 shows the cash flow and NPV of investment into hydrogen heavy-duty trucks when evaluating over the period 2017-2050, with financial support maintained until year 2025. Development of governmental expenses due to purchase of hydrogen heavy-duty trucks are calculated using FCH's estimates, which are previously explained.

Hydrogen - heavy-duty trucks, support until year 2025. FCH rapid decrease																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Fueling stations	0,0	0,0	0,0	0,0	-4,0	-4,0	-3,9	-3,9	-3,9	-174,1	-70,1	-28,2	-11,4	-4,6	-1,2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Vehicle stock projection		0,0	0,0	0,0	0,0	-2,1	-1,7	-1,2	-0,8	-0,4																									
Net present value (MNOK)	-219	0	0	0	0	-3	-5	-4	-4	-3	-123	-47	-18	-7	-3	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 52: Hydrogen heavy-duty trucks, support until year 2025, FCH rapid decrease

Table 52 shows the cash flow and NPV of investment into hydrogen heavy-duty trucks when evaluating over the period 2017-2050, with financial support maintained until year 2025. Development of governmental expenses due to purchase of hydrogen heavy-duty trucks are calculated with basis in FCH's estimates, which are previously explained.

Status quo prolonged - heavy-duty trucks, minimum costs (IPCC)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Investment costs	0																																		
	CO_2		-594	-570	-546	-522	-506	-490	-474	-459	-443	-428	-414	-399	-385	-371	-419	-412	-405	-398	-391	-384	-376	-368	-361	-353	-346	-339	-332	-324	-317	-311	-304	-298	-291	-284
	CH_4		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N_2O		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SO_2		-0,6	-0,6	-0,6	-0,6	-0,5	-0,5	-0,5	-0,5	-0,5	-0,5	-0,4	-0,4	-0,4	-0,4	-0,5	-0,5	-0,5	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,3	-0,3	-0,3	-0,3	-0,3
	NO_X		-397	-381	-365	-349	-338	-327	-317	-306	-296	-286	-276	-267	-257	-248	-178	-175	-172	-169	-166	-163	-159	-156	-153	-150	-147	-144	-140	-137	-134	-132	-129	-126	-123	-120
	nmVOC		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NH_3		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PM2,5		-5,0	-4,8	-4,6	-4,4	-4,2	-4,1	-4,0	-3,8	-3,7	-3,6	-3,5	-3,3	-3,2	-3,1	-3,0	-3,0	-2,9	-2,9	-2,8	-2,7	-2,7	-2,6	-2,6	-2,5	-2,5	-2,4	-2,3	-2,3	-2,2	-2,2	-2,1	-2,1	-2,0	-2,0
Net present value (MNOK)	-12588	0	-959	-884	-814	-749	-698	-650	-605	-562	-522	-485	-451	-418	-388	-359	-333	-315	-298	-282	-266	-251	-236	-223	-210	-197	-186	-175	-165	-155	-146	-137	-129	-121	-114	-107

Table 53: Status quo prolonged, heavy-duty trucks, minimum costs (IPCC)

Table 53 shows the cash flow and NPV of the scenario status quo prolonged when evaluating over the period 2017-2050 and using minimum social costs of emissions based on IPCC's report (97). These values for the social costs of emissions can be seen in Table 8.

Status quo prolonged - heavy-duty trucks, maximum costs (IPCC)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Investment costs	0																																		
	CO_2		-12237	-11731	-11236	-10751	-10420	-10091	-9765	-9441	-9119	-8819	-8521	-8224	-7927	-7632	-8626	-8485	-8344	-8201	-8058	-7901	-7743	-7585	-7427	-7268	-7121	-6974	-6826	-6677	-6528	-6395	-6262	-6127	-5990	-5851
	CH_4		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N_2O		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SO_2		-1,6	-1,5	-1,5	-1,4	-1,4	-1,3	-1,3	-1,2	-1,2	-1,2	-1,1	-1,1	-1,0	-1,0	-1,2	-1,2	-1,1	-1,1	-1,1	-1,1	-1,1	-1,0	-1,0	-1,0	-1,0	-0,9	-0,9	-0,9	-0,9	-0,9	-0,8	-0,8	-0,8	-0,8
	NO_X		-1985	-1903	-1823	-1744	-1690	-1637	-1584	-1532	-1479	-1431	-1382	-1334	-1286	-1238	-888	-873	-859	-844	-829	-813	-797	-780	-764	-748	-733	-718	-702	-687	-672	-658	-644	-630	-616	-602
	nmVOC		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NH_3		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PM2,5		-349	-334	-320	-306	-297	-288	-278	-269	-260	-251	-243	-234	-226	-218	-213	-209	-205	-201	-197	-193	-189	-185	-181	-177	-173	-169	-165	-161	-157	-154	-150	-146	-142	-139
Net present value (MNOK)	-190436	0	-14012	-12916	-11895	-10944	-10199	-9497	-8837	-8215	-7629	-7095	-6592	-6117	-5670	-5248	-5401	-5109	-4830	-4565	-4312	-4065	-3831	-3608	-3397	-3197	-3011	-2836	-2669	-2510	-2359	-2222	-2092	-1968	-1850	-1737

Table 54: Status quo prolonged, heavy-duty trucks, maximum costs (IPCC)

Table 54 shows the cash flow and NPV of the scenario status quo prolonged when evaluating over the period 2017-2050 and using maximum social costs of emissions based on IPCC's report (97). These values for the social costs of emissions can be seen in Table 8.

Status quo prolonged - heavy-duty trucks, best guess costs (IPCC & SFT combined)																			
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Cash flow	Investment costs	0																	
	CO_2		-3147	-3017	-2889	-2765	-2679	-2595	-2511	-2428	-2345	-2268	-2191	-2115	-2038	-1962	-1925	-1887	-1849
	CH_4		-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	N_2O		-5,9	-5,7	-5,4	-5,2	-5,0	-4,9	-4,7	-4,6	-4,4	-4,3	-4,1	-4,0	-3,8	-3,7	-3,6	-3,5	-3,5
	SO_2		-1,1	-1,1	-1,0	-1,0	-1,0	-0,9	-0,9	-0,9	-0,8	-0,8	-0,8	-0,8	-0,7	-0,7	-0,7	-0,7	-0,7
	NO_X		-1191	-1142	-1094	-1046	-1014	-982	-950	-919	-888	-858	-829	-800	-772	-743	-728	-714	-700
	nmVOC		-0,7	-0,7	-0,7	-0,7	-0,6	-0,6	-0,6	-0,6	-0,6	-0,5	-0,5	-0,5	-0,5	-0,5	-0,5	-0,4	-0,4
	NH_3		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	PM2,5		-177	-170	-162	-155	-151	-146	-141	-136	-132	-127	-123	-119	-115	-110	-108	-106	-104
	PM10		-1166	-1118	-1070	-1024	-993	-961	-930	-899	-869	-840	-812	-783	-755	-727	-713	-699	-685
Net present value (MNOK)	-71816	0	-5469	-5042	-4643	-4272	-3981	-3707	-3449	-3207	-2978	-2770	-2573	-2388	-2213	-2049	-1932	-1821	-1716

Year		18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Investment costs																	
	CO_2	-1811	-1773	-1738	-1702	-1666	-1630	-1594	-1559	-1525	-1490	-1455	-1420	-1386	-1352	-1318	-1284	-1249
	CH_4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	N_2O	-3,4	-3,3	-3,3	-3,2	-3,1	-3,1	-3,0	-2,9	-2,9	-2,8	-2,7	-2,7	-2,6	-2,5	-2,5	-2,4	-2,3
	SO_2	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,5	-0,5	-0,5	-0,5	-0,5	-0,5	-0,5	-0,5	-0,4
	NO_X	-686	-671	-658	-644	-631	-617	-603	-590	-577	-564	-551	-538	-525	-512	-499	-486	-473
	nmVOC	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,4	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3	-0,3
	NH_3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	PM2,5	-102	-100	-98	-96	-94	-92	-90	-88	-86	-84	-82	-80	-78	-76	-74	-72	-70
	PM10	-671	-657	-644	-630	-617	-604	-591	-578	-565	-552	-539	-526	-514	-501	-488	-476	-463
Net present value (MNOK)		-1616	-1522	-1434	-1350	-1271	-1196	-1124	-1057	-994	-934	-877	-823	-773	-725	-679	-636	-595

Table 55: Status quo prolonged, heavy-duty trucks, best guess costs (IPCC & SFT combined)

Table 55 shows the cash flow and NPV of the scenario status quo prolonged when evaluating over the period 2017-2050 and using best guess social costs of emissions based on IPCC's report (97). These values for the social and abatement costs of emissions can be seen in Table 24.

Projected development - heavy duty trucks, best guess costs (IPCC & SFT & FCH)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	H_2 fueling stations	0,0	0,0	0,0	0,0	-4,0	-4,0	-3,9	-3,9	-3,9	-174,1	-70,1	-28,2	-11,4	-4,6	-1,2	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	H_2 FCEV stock projection		0,0	0,0	0,0	0,0	-16,6	-15,8	-15,0	-14,2	-13,4	-1484,2	-1469,4	-1454,6	-1439,9	-1425,1	-3473,0	-3454,9	-3436,8	-3418,7	-3400,6	-2712,8	-2698,3	-2683,8	-2669,3	-2654,8	-2107,7	-2096,1	-2084,5	-2072,9	-2061,3	-1759,9	-1305,4	0,0	0,0	0,0
	EV charging stations	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	EV stock projection		0,0	0,0	0,0	0,0																														
	CO_2		12	23	34	44	66	87	106	124	140	200	255	306	352	395	482	565	645	721	794	837	877	915	951	984	1001	1015	1028	1039	1048	1048	1046	1042	1037	1031
	CH_4		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	N_2O		0,0	0,0	0,1	0,1	0,1	0,2	0,2	0,2	0,3	0,4	0,5	0,6	0,7	0,7	0,9	1,1	1,2	1,4	1,5	1,6	1,6	1,7	1,8	1,8	1,9	1,9	1,9	1,9	2,0	2,0	2,0	2,0	1,9	1,9
	SO_2		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,2	0,2	0,2	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
	NO_X		5	9	13	17	25	33	40	47	53	76	96	116	133	150	182	214	244	273	300	317	332	347	360	373	379	384	389	393	397	397	396	394	393	390
	nmVOC		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,1	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
	NH_3		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	PM2,5		0,7	1,3	1,9	2,5	3,7	4,9	5,9	7,0	7,9	11,2	14,3	17,2	19,8	22,2	27,1	31,8	36,3	40,5	44,6	47,0	49,3	51,5	53,5	55,3	56,3	57,1	57,8	58,4	58,9	58,9	58,8	58,6	58,3	58,0
	PM10		4	9	13	16	24	32	39	46	52	74	94	113	131	146	179	209	239	267	294	310	325	339	352	365	371	376	381	385	388	388	387	386	384	382
Net present value (MNOK)	-8980	0	21	39	55	65	81	108	131	150	47	-806	-674	-571	-485	-411	-1445	-1299	-1166	-1044	-933	-548	-488	-434	-385	-341	-112	-94	-78	-65	-53	41	173	537	514	491

Table 56: Projected development, heavy-duty trucks, best guess costs (IPCC & SFT & FCH)

Table 56 shows the NPV of projected development of heavy-duty trucks with best guess social and abatement costs of emissions in the ultra-low emissions path relative to the status quo path. This means that in year 1, being 2017, CO_2-emissions are decreased by an amount worth 12 MNOK compared to what they would be in the reference scenario. Over the evaluated period, the amount of diesel and gasoline heavy-duty trucks becomes smaller and smaller, increasing the difference between the projected stock's emissions and the emissions of the stock in the status quo scenario and thus similarly decreasing governmental expenses due to social costs of emissions. For hydrogen FCEVs, the scenario of financial support until 50 000 units and FCH is used. EVs have no share in this sector.

Projected development - heavy duty trucks, best guess costs (IPCC & SFT & FCH rapid decrease)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	H2 fueling stations	0,0	0,0	0,0	0,0	-4,0	-4,0	-3,9	-3,9	-3,9	-174,1	-70,1	-28,2	-11,4	-4,6	-1,2	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	H2 FCEV stock projection		0,0	0,0	0,0	0,0	-2,1	-1,7	-1,2	-0,8	-0,4	-32,3	-24,2	-16,1	-8,1	0,0																				
	EV charging stations	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	EV stock projection		0,0	0,0	0,0	0,0																														
	CO_2		12	23	34	44	66	87	106	124	140	200	255	306	352	395	482	565	645	721	794	837	877	915	951	984	1001	1015	1028	1039	1048	1048	1046	1042	1037	1031
	CH_4		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	N_2O		0,0	0,0	0,1	0,1	0,1	0,2	0,2	0,2	0,3	0,4	0,5	0,6	0,7	0,7	0,9	1,1	1,2	1,4	1,5	1,6	1,6	1,7	1,8	1,8	1,9	1,9	1,9	1,9	2,0	2,0	2,0	2,0	1,9	1,9
	SO_2		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,2	0,2	0,2	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
	NO_X		5	9	13	17	25	33	40	47	53	76	96	116	133	150	182	214	244	273	300	317	332	347	360	373	379	384	389	393	397	397	396	394	393	390
	nmVOC		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,1	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
	NH_3		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	PM2,5		0,7	1,3	1,9	2,5	3,7	4,9	5,9	7,0	7,9	11,2	14,3	17,2	19,8	22,2	27,1	31,8	36,3	40,5	44,6	47,0	49,3	51,5	53,5	55,3	56,3	57,1	57,8	58,4	58,9	58,9	58,8	58,6	58,3	58,0
	PM10		4	9	13	16	24	32	39	46	52	74	94	113	131	146	179	209	239	267	294	310	325	339	352	365	371	376	381	385	388	388	387	386	384	382
Net present value (MNOK)	14638	0	21	39	55	65	93	119	141	160	56	175	265	328	375	412	484	546	599	643	681	690	696	698	698	694	679	662	645	626	608	584	560	537	514	491

Table 57: Projected development, heavy-duty trucks, best guess costs (IPCC & SFT & FCH rapid decrease)

Table 57 shows the NPV of projected development of heavy-duty trucks with best guess social and abatement costs of emissions in the ultra-low emissions path relative to the status quo path. For hydrogen FCEVs, the scenario of financial support until 50 000 units and FCH rapid decrease is used. EVs have no share in this sector.

Buses

The following assumptions and values are used in these calculations:

- For hydrogen buses, the reduction factor is set to 2 %.
- For electric buses, the reduction factor is set to 0.1 %.
- Governmental expenses due to purchase of hydrogen buses are given in Table 25. It is assumed that governmental expenses due to purchase of electric buses also equal these values.
- Hydrogen consumption of a hydrogen bus is calculated to be 4 231 kg H_2/year based on average annual distance driven by diesel buses from Table 15 and average hydrogen consumption of a Ruter's hydrogen buses in Oslo from Table 3.
- Support for electric buses is assumed to be maintained until 2025.
- One rapid charging station is established for every 7.1 electric bus.

Bus stock projection, by fuel								
Year	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	297	90	38	21	3	0	0	0
Diesel	15498	12345	7919	3769	1493	639	263	142
BEV	11	171	1281	2429	3186	3741	4350	4725
Hydrogen	5	153	1607	3390	4841	5526	6242	6721

Table 58: Bus stock development, by fuel

Table 58 shows bus stock development for the ultra-low emissions scenario. This table is developed by the Norwegian Institute of Transport Economics' report and is used as basis for calculation of EVs and hydrogen FCEV's net present values (68). Linear interpolation is performed as the report only includes estimates for every fifth year (68).

Hydrogen - buses, support until year 2050. FCH																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Fueling stations	-23,0	-21,8	-20,7	-19,7	-116,0	-69,6	-41,7	-25,1	-15,0	-9,9	-5,3	-2,8	-1,5	-0,8	-0,4	-0,2	-0,1	-0,1	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Vehicle stock projection		-48,2	-44,3	-40,4	-36,6	-342,8	-326,4	-310,0	-293,6	-277,3	-336,7	-333,3	-330,0	-326,6	-323,3	-261,7	-260,3	-259,0	-257,6	-256,2	-120,3	-119,7	-119,0	-118,4	-117,8	-122,4	-121,7	-121,1	-120,4	-119,7	-79,2	-78,3	-77,4	-76,5	-75,6
Net present value (MNOK)	-3924,9	-23	-67,4	-60,2	-53,4	-130,4	-338,9	-290,9	-254,6	-225,6	-201,7	-231,0	-218,3	-207,0	-196,6	-186,9	-145,4	-139,1	-133,0	-127,2	-121,6	-54,9	-52,5	-50,2	-48,0	-45,9	-45,9	-43,9	-42,0	-40,1	-38,4	-24,4	-23,2	-22,1	-21,0	-19,9

Table 59: Hydrogen buses, support until year 2050, FCH

Table 59 shows the cash flow and NPV of investment into hydrogen buses when evaluating over the period 2017-2050, with financial support maintained until year 2050. Development of governmental expenses due to purchase of hydrogen buses are calculated with FCH's estimates, which are previously explained.

Hydrogen - buses, support until year 2050. FCH rapid decrease																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Fueling stations	-23,0	-21,8	-20,7	-19,7	-116,0	-69,6	-41,7	-25,1	-15,0	-9,9	-5,3	-2,8	-1,5	-0,8	-0,4	-0,2	-0,1	-0,1	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Vehicle stock projection		-35,7	-25,6	-15,4	-5,3	-43,2	-34,3	-25,3	-16,4	-7,5	-7,3	-5,5	-3,7	-1,8	0,0																				
Net present value (MNOK)	-501,5	-23	-55,3	-42,8	-31,2	-103,7	-92,7	-60,1	-38,3	-23,0	-12,2	-8,5	-5,4	-3,2	-1,6	-0,2	-0,1	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Table 60: Hydrogen buses, support until year 2050, FCH rapid decrease

Table 60 shows the cash flow and NPV of investment into hydrogen buses when evaluating over the period 2017-2050, with financial support maintained until year 2050. Development of governmental expenses due to purchase of hydrogen buses are calculated with basis in FCH's estimates, which are previously explained.

Hydrogen - buses, support until year 2025. FCH																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Fueling stations	-23,0	-21,8	-20,7	-19,7	-116,0	-69,6	-41,7	-25,1	-15,0	-9,9	-5,3	-2,8	-1,5	-0,8	-0,4	-0,2	-0,1	-0,1	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Vehicle stock projection		-48,2	-44,3	-40,4	-36,6	-342,8	-326,4	-310,0	-293,6	-277,3																									
Net present value (MNOK)	-1653,4	-23	-67,4	-60,2	-53,4	-130,4	-338,9	-290,9	-254,6	-225,6	-201,7	-3,6	-1,8	-0,9	-0,5	-0,2	-0,1	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Table 61: Hydrogen buses, support until year 2025, FCH

Table 61 shows the cash flow and NPV of investment into hydrogen buses when evaluating over the period 2017-2050, with financial support maintained until year 2025. Development of governmental expenses due to purchase of hydrogen buses are calculated with FCH's estimates, which are previously explained.

Hydrogen - buses, support until year 2025. FCH rapid decrease																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Fueling stations	-23,0	-21,8	-20,7	-19,7	-116,0	-69,6	-41,7	-25,1	-15,0	-9,9	-5,3	-2,8	-1,5	-0,8	-0,4	-0,2	-0,1	-0,1	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Vehicle stock projection		-35,7	-25,6	-15,4	-5,3	-43,2	-34,3	-25,3	-16,4	-7,5																									
Net present value (MNOK)	-489,6	-23	-55,3	-42,8	-31,2	-103,7	-92,7	-60,1	-38,3	-23,0	-12,2	-3,6	-1,8	-0,9	-0,5	-0,2	-0,1	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Table 62: Hydrogen buses, support until year 2025, FCH rapid decrease

Table 62 shows the cash flow and NPV of investment into hydrogen buses when evaluating over the period 2017-2050, with financial support maintained until year 2025. Development of governmental expenses due to purchase of hydrogen buses are calculated with basis in FCH's estimates, which are previously explained.

Electric buses, support until 2025. FCH																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	EV charging stations	-2,7	-2,7	-2,7	-2,7	-18,0	-17,4	-16,9	-16,4	-15,8	-15,9	-15,4	-14,9	-14,4	-13,9	-9,0	-8,8	-8,6	-8,4	-8,3	-6,0	-5,9	-5,8	-5,7	-5,6	-6,0	-5,9	-5,8	-5,7	-5,6	-3,4	-3,4	-3,4	-3,3	-3,3	0,0
	EV stock projection		-52,1	-47,9	-43,7	-39,5	-261,7	-249,2	-236,7	-224,2	-211,7																									
Net present value (MNOK)	-1248,6	-3	-52,7	-46,8	-41,2	-49,1	-229,4	-210,3	-192,3	-175,4	-159,9	-10,4	-9,7	-9,0	-8,4	-5,2	-4,9	-4,6	-4,3	-4,1	-2,8	-2,7	-2,5	-2,4	-2,3	-2,4	-2,2	-2,1	-2,0	-1,9	-1,1	-1,0	-1,0	-0,9	-0,9	0,0

Table 63: Electric buses, support until 2025, FCH

Table 63 shows the cash flow and NPV of investment into electric buses when evaluating over the period 2017-2050, with financial support maintained until year 2025. Development of governmental expenses due to purchase of hydrogen buses are calculated with FCH’s estimates, which are previously explained.

Electric buses, support until 2025. FCH rapid decrease																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	EV charging stations	-2,7	-2,7	-2,7	-2,7	-18,0	-17,4	-16,9	-16,4	-15,8	-15,9	-15,4	-14,9	-14,4	-13,9	-9,0	-8,8	-8,6	-8,4	-8,3	-6,0	-5,9	-5,8	-5,7	-5,6	-6,0	-5,9	-5,8	-5,7	-5,6	-3,4	-3,4	-3,4	-3,3	-3,3	0,0
	EV stock projection		-38,6	-27,7	-16,7	-5,7	-33,0	-26,2	-19,3	-12,5	-5,7																									
Net present value (MNOK)	-335,2	-3	-39,7	-28,1	-17,2	-20,3	-41,4	-34,0	-27,1	-20,7	-15,1	-10,4	-9,7	-9,0	-8,4	-5,2	-4,9	-4,6	-4,3	-4,1	-2,8	-2,7	-2,5	-2,4	-2,3	-2,4	-2,2	-2,1	-2,0	-1,9	-1,1	-1,0	-1,0	-0,9	-0,9	0,0

Table 64: Electric buses, support until 2025. FCH rapid decrease

Table 64 shows the cash flow and NPV of investment into electric buses when evaluating over the period 2017-2050, with financial support maintained until year 2020. Development of governmental expenses due to purchase of hydrogen buses are calculated with basis in FCH’s estimates, which are previously explained.

Status quo prolonged - buses, minimum costs (IPCC)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Investment costs	0																																		
	CO_2		-17,7	-16,9	-16,0	-15,1	-14,5	-13,8	-13,1	-12,5	-11,9	-11,3	-10,8	-10,3	-9,9	-9,4	-9,2	-9,0	-8,8	-8,6	-8,4	-8,3	-8,1	-8,0	-7,8	-7,6	-7,5	-7,3	-7,1	-7,0	-6,8	-6,6	-6,5	-6,3	-6,1	-5,9
	CH_4		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N_2O		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SO_2		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	NO_X		-7,5	-7,2	-6,8	-6,5	-6,2	-5,9	-5,6	-5,4	-5,1	-4,9	-4,7	-4,5	-4,3	-4,1	-4,0	-3,9	-3,8	-3,7	-3,6	-3,6	-3,5	-3,4	-3,4	-3,3	-3,2	-3,2	-3,1	-3,0	-2,9	-2,9	-2,8	-2,7	-2,6	-2,6
	nmVOC		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NH_3		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PM2,5		-1,4	-1,4	-1,3	-1,2	-1,2	-1,1	-1,1	-1,0	-1,0	-0,9	-0,9	-0,9	-0,8	-0,8	-0,8	-0,8	-0,7	-0,7	-0,7	-0,7	-0,7	-0,7	-0,7	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,5	-0,5	-0,5	-0,5
Net present value (MNOK)	-307,9	0	-25,7	-23,5	-21,4	-19,5	-18,0	-16,5	-15,1	-13,8	-12,6	-11,6	-10,7	-9,8	-9,0	-8,2	-7,7	-7,3	-6,9	-6,5	-6,1	-5,7	-5,4	-5,1	-4,8	-4,5	-4,3	-4,0	-3,8	-3,5	-3,3	-3,1	-2,9	-2,7	-2,5	-2,4

Table 65: Status quo prolonged, buses, minimum costs (IPCC)

Table 65 shows the cash flow and NPV of the scenario status quo prolonged when evaluating over the period 2017-2050 and using minimum social costs of emissions based on IPCC's report (97). These values for the social costs of emissions can be seen in Table 8.

Status quo prolonged - buses, maximum costs (IPCC)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Investment costs	0																																		
	CO_2		-365	-347	-329	-312	-298	-284	-270	-257	-244	-233	-223	-213	-203	-193	-189	-185	-181	-177	-174	-170	-167	-164	-161	-157	-154	-150	-147	-144	-140	-137	-133	-129	-126	-122
	CH_4		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N_2O		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SO_2		-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	NO_X		-38	-36	-34	-32	-31	-30	-28	-27	-26	-24	-23	-22	-21	-20	-20	-19	-19	-19	-18	-18	-18	-17	-17	-17	-16	-16	-15	-15	-15	-14	-14	-14	-13	-13
	nmVOC		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NH_3		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PM2,5		-100	-96	-91	-87	-83	-80	-76	-73	-69	-67	-64	-61	-58	-56	-54	-53	-52	-51	-50	-49	-48	-47	-46	-45	-44	-43	-42	-41	-40	-39	-38	-37	-36	-35
Net present value (MNOK)	-5810	0	-484	-443	-404	-369	-339	-311	-285	-261	-238	-219	-201	-185	-170	-155	-146	-138	-130	-122	-115	-108	-102	-96	-91	-85	-80	-76	-71	-67	-63	-59	-55	-51	-48	-45

Table 66: Status quo prolonged, buses, maximum costs (IPCC)

Table 66 shows the cash flow and NPV of the scenario status quo prolonged when evaluating over the period 2017-2050 and using maximum social costs of emissions based on IPCC's report (97). These values for the social costs of emissions can be seen in Table 8.

Status quo prolonged - buses, best guess costs (IPCC & SFT combined)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Investment costs	0																																		
	CO_2		-94	-89	-85	-80	-77	-73	-69	-66	-63	-60	-57	-55	-52	-50	-49	-48	-47	-46	-45	-44	-43	-42	-41	-40	-40	-39	-38	-37	-36	-35	-34	-33	-32	-31
	CH_4		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	N_2O		-0,2	-0,2	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1
	SO_2		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	NO_X		-22,6	-21,5	-20,5	-19,4	-18,6	-17,7	-16,9	-16,1	-15,3	-14,7	-14,0	-13,4	-12,8	-12,2	-11,9	-11,7	-11,4	-11,2	-10,9	-10,7	-10,5	-10,3	-10,1	-9,9	-9,7	-9,5	-9,3	-9,0	-8,8	-8,6	-8,4	-8,2	-7,9	-7,7
	nmVOC		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	NH_3		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	PM2,5		-50,9	-48,6	-46,3	-44,1	-42,2	-40,4	-38,6	-36,9	-35,2	-33,7	-32,3	-30,9	-29,5	-28,2	-27,6	-27,1	-26,5	-25,9	-25,4	-24,9	-24,4	-23,9	-23,5	-23,0	-22,5	-22,0	-21,5	-21,0	-20,5	-19,9	-19,4	-18,9	-18,4	-17,8
	PM10		-94,7	-90,3	-86,1	-81,9	-78,4	-75,0	-71,7	-68,4	-65,2	-62,5	-59,9	-57,3	-54,7	-52,2	-51,1	-50,1	-49,0	-48,0	-47,0	-46,1	-45,2	-44,3	-43,4	-42,5	-41,6	-40,7	-39,7	-38,8	-37,9	-36,9	-35,9	-34,9	-34,0	-33,0
Net present value (MNOK)	-3056	0	-252	-231	-211	-193	-177	-163	-150	-137	-125	-116	-106	-98	-90	-82	-77	-73	-69	-65	-61	-57	-54	-51	-48	-45	-43	-40	-38	-35	-33	-31	-29	-27	-25	-24

Table 67: Status quo prolonged, buses, best guess costs (IPCC & SFT combined)

Table 67 shows the cash flow and NPV of the scenario status quo prolonged when evaluating over the period 2017-2050 and using best guess social costs of emissions based on IPCC's report (97). These values for the social and abatement costs of emissions can be seen in Table 24.

Projected development - buses, best guess costs (IPCC & SFT & FCH)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	H_2 fueling stations	-23,0	-21,8	-20,7	-19,7	-116,0	-69,6	-41,7	-25,1	-15,0	-9,9	-5,3	-2,8	-1,5	-0,8	-0,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	H_2 FCEV stock projection		-48,2	-44,3	-40,4	-36,6	-342,8	-326,4	-310,0	-293,6	-277,3																									
	EV charging stations	-2,7	-2,7	-2,7	-2,7	-18,0	-17,4	-16,9	-16,4	-15,8	-15,9	-15,4	-14,9	-14,4	-13,9	-9,0	-8,8	-8,6	-8,4	-8,3	-6,0	-5,9	-5,8	-5,7	-5,6	-6,0	-5,9	-5,8	-5,7	-5,6	-3,4	-3,4	-3,4	-3,3	-3,3	0,0
	EV stock projection		-52,1	-47,9	-43,7	-39,5	-261,7	-249,2	-236,7	-224,2	-211,7																									
	CO_2		1,7	3,3	4,9	6,3	9,8	13,1	16,2	19,1	21,8	24,5	27,0	29,3	31,4	33,2	34,4	35,6	36,7	37,8	38,7	38,7	38,6	38,5	38,3	38,2	37,6	37,0	36,4	35,8	35,2	34,4	33,6	32,7	31,9	31,0
	CH_4		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	N_2O		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
	SO_2		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	NO_X		0,4	0,9	1,3	1,6	2,5	3,3	4,1	4,8	5,4	6,1	6,7	7,3	7,8	8,2	8,5	8,8	9,0	9,3	9,5	9,5	9,5	9,4	9,4	9,4	9,2	9,1	8,9	8,8	8,6	8,4	8,2	8,0	7,8	7,6
	nmVOC		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	NH_3		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	PM2,5		1,1	2,2	3,2	4,1	6,1	8,0	9,8	11,5	13,0	14,5	15,9	17,1	18,3	19,3	19,9	20,6	21,1	21,7	22,2	22,1	22,1	22,0	21,9	21,7	21,4	21,1	20,7	20,4	20,0	19,5	19,1	18,6	18,1	17,6
	PM10		2,0	4,0	5,8	7,6	11,3	14,8	18,1	21,1	24,0	26,8	29,3	31,6	33,7	35,6	36,8	38,0	39,1	40,1	41,0	40,9	40,8	40,6	40,5	40,2	39,6	39,0	38,4	37,7	37,0	36,2	35,3	34,4	33,5	32,6
Net present value (MNOK)	-1593,4	-26	-115,0	-97,4	-81,2	-162,7	-543,8	-470,2	-410,3	-359,6	-316,4	34,7	39,8	43,4	45,9	50,2	50,5	50,4	50,1	49,7	50,1	48,1	46,2	44,3	42,4	40,4	38,3	36,2	34,3	32,4	31,3	29,3	27,5	25,8	24,1	23,4

Table 68: Projected development, buses, best guess costs (IPCC & SFT & FCH)

Table 68 shows the NPV of projected development of buses with best guess social and abatement costs of emissions in the ultra-low emissions path relative to the status quo path. This means that in year 1, being 2017, CO_2-emissions are decreased by an amount worth 1.7 MNOK compared to what they would be in the reference scenario. Over the evaluated period, the amount of diesel and gasoline buses becomes smaller and smaller, increasing the difference between the projected stock's emissions and the emissions of the stock in the status quo scenario and thus similarly decreasing governmental expenses due to social costs of emissions. For hydrogen FCEVs and EVs, the scenario of financial support until year 2025 and FCH is used.

Projected development - buses, best guess costs (IPCC & SFT & FCH rapid decrease)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	H_2 fueling stations	-23,0	-21,8	-20,7	-19,7	-116,0	-69,6	-41,7	-25,1	-15,0	-9,9	-5,3	-2,8	-1,5	-0,8	-0,4	-0,2	-0,1	-0,1	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	H_2 FCEV stock projection		-35,7	-25,6	-15,4	-5,3	-43,2	-34,3	-25,3	-16,4	-7,5																									
	EV charging stations	-2,7	-2,7	-2,7	-2,7	-18,0	-17,4	-16,9	-16,4	-15,8	-15,9	-15,4	-14,9	-14,4	-13,9	-9,0	-8,8	-8,6	-8,4	-8,3	-6,0	-5,9	-5,8	-5,7	-5,6	-6,0	-5,9	-5,8	-5,7	-5,6	-3,4	-3,4	-3,4	-3,3	-3,3	0,0
	EV stock projection		-38,6	-27,7	-16,7	-5,7	-33,0	-26,2	-19,3	-12,5	-5,7																									
	CO_2		1,7	3,3	4,9	6,3	9,8	13,1	16,2	19,1	21,8	24,5	27,0	29,3	31,4	33,2	34,4	35,6	36,7	37,8	38,7	38,7	38,6	38,5	38,3	38,2	37,6	37,0	36,4	35,8	35,2	34,4	33,6	32,7	31,9	31,0
	CH_4		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	N_2O		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
	SO_2		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	NO_X		0,4	0,9	1,3	1,6	2,5	3,3	4,1	4,8	5,4	6,1	6,7	7,3	7,8	8,2	8,5	8,8	9,0	9,3	9,5	9,5	9,5	9,4	9,4	9,4	9,2	9,1	8,9	8,8	8,6	8,4	8,2	8,0	7,8	7,6
	nmVOC		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	NH_3		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	PM2,5		1,1	2,2	3,2	4,1	6,1	8,0	9,8	11,5	13,0	14,5	15,9	17,1	18,3	19,3	19,9	20,6	21,1	21,7	22,2	22,1	22,1	22,0	21,9	21,7	21,4	21,1	20,7	20,4	20,0	19,5	19,1	18,6	18,1	17,6
	PM10		2,0	4,0	5,8	7,6	11,3	14,8	18,1	21,1	24,0	26,8	29,3	31,6	33,7	35,6	36,8	38,0	39,1	40,1	41,0	40,9	40,8	40,6	40,5	40,2	39,6	39,0	38,4	37,7	37,0	36,2	35,3	34,4	33,5	32,6
Net present value (MNOK)	483,6	-26	-90,0	-61,3	-35,0	-107,1	-109,6	-63,0	-28,8	-2,4	17,9	34,7	39,8	43,4	45,9	50,2	50,4	50,3	50,1	49,7	50,1	48,1	46,2	44,3	42,4	40,4	38,3	36,2	34,3	32,4	31,3	29,3	27,5	25,8	24,1	23,4

Table 69: Projected development, buses, best guess costs (IPCC & SFT & FCH rapid decrease)

Table 69 shows the NPV of projected development of buses with best guess social and abatement costs of emissions in the ultra-low emissions path relative to the status quo path. For hydrogen FCEVs and EVs, the scenario of financial support until year 2025 and FCH rapid decrease is used.

The whole transport sector combined

The following assumption is used in these calculations other than the ones stated in the respective sectors:

- The amount of established hydrogen fueling stations equals the theoretically necessary number due to synergy effects of hydrogen usage in all sectors.

Hydrogen - all combined, support until 50 000 units/year 2050 & reduction factor 1 & FCH rapid decrease																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Fueling stations	-17,2	-16,6	-15,9	-15,4	-136,5	-72,8	-38,9	-20,7	-11,1	-4,3	-0,5	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Vehicle stock projection		-54,0	-43,8	-33,7	-23,5	-1621,5	-1507,4	-1400,3	-1299,7	-1205,1	-3720,1	-2426,7	-1003,9	-207,4	0,0																				
Net present value (MNOK)	-10663,9	-17	-67,8	-55,3	-43,6	-136,7	-1392,6	-1222,0	-1079,9	-957,7	-849,7	-2513,5	-1576,4	-627,1	-124,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Table 70: Hydrogen all combined, support until 50 000 units/year 2050, reduction factor 1, FCH rapid decrease

Table 70 shows the cash flow and NPV of investment into all hydrogen vehicles when evaluating over the period 2017-2050, with financial support for passenger vehicles and cargo vans maintained until a stock of 50 000 units is achieved for each sector. For heavy-duty trucks and buses, financial support is maintained until year 2050. However, FCH rapid decrease causes this to reach zero in year 2030.

Hydrogen - all combined, support until 50 000 units/year 2050 & reduction factor 2 & FCH																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Fueling stations	-17,9	-17,6	-17,3	-16,9	-206,4	-151,0	-110,5	-80,9	-59,2	-69,4	-23,2	-7,8	-2,6	-0,9	-0,3	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Vehicle stock projection		-67	-63	-59	-55	-1994	-1922	-1852	-1783	-1716	-6931	-5620	-3378	-2121	-1748	-3735	-3715	-3696	-3676	-3657	-2833	-2818	-2803	-2788	-2773	-2230	-2218	-2206	-2193	-2181	-1839	-1384	-77	-76	-76
Net present value (MNOK)	-40954	-18	-81	-74	-67	-223	-1763	-1606	-1469	-1346	-1255	-4698	-3656	-2111	-1275	-1010	-2074	-1984	-1897	-1815	-1736	-1293	-1237	-1183	-1131	-1082	-837	-800	-765	-731	-699	-567	-410	-22	-21	-20

Table 71: Hydrogen all combined, support until 50 000 units/year 2050, reduction factor 2, FCH

Table 71 shows the cash flow and NPV of investment into hydrogen passenger vehicles when evaluating over the period 2017-2050, with financial support for passenger vehicles and cargo vans maintained until a stock of 50 000 units is achieved for each sector. For heavy-duty trucks and buses, financial support is maintained until year 2050.

Hydrogen - all combined, support until 2025 & reduction factor 1 & FCH rapid decrease																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Fueling stations	-17,2	-16,6	-15,9	-15,4	-136,5	-72,8	-38,9	-20,7	-11,1	-4,3	-0,5	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Vehicle stock projection		-54,0	-43,8	-33,7	-23,5	-1621,5	-1507,4	-1400,3	-1299,7	-1205,1																									
Net present value (MNOK)	-5822,9	-17	-67,8	-55,3	-43,6	-136,7	-1392,6	-1222,0	-1079,9	-957,7	-849,7	-0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Table 72: Hydrogen all combined, support until year 2025, reduction factor 1, FCH rapid decrease

Table 72 shows the cash flow and NPV of investment into hydrogen passenger vehicles when evaluating over the period 2017-2050, with financial support maintained until year 2025.

Hydrogen - all combined, support until 2025 & reduction factor 2 & FCH																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Fueling stations	-17,9	-17,6	-17,3	-16,9	-206,4	-151,0	-110,5	-80,9	-59,2	-69,4	-23,2	-7,8	-2,6	-0,9	-0,3	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Vehicle stock projection		-66,5	-62,6	-58,7	-54,8	-1994,0	-1921,9	-1851,6	-1783,1	-1716,4																									
Net present value (MNOK)	-7924,7	-18	-80,9	-73,8	-67,2	-223,3	-1763,0	-1606,2	-1468,5	-1346,1	-1254,6	-15,7	-5,0	-1,6	-0,5	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Table 73: Hydrogen all combined, support until year 2025, reduction factor 2, FCH

Table 73 shows the cash flow and NPV of investment into hydrogen passenger vehicles when evaluating over the period 2017-2050, with financial support maintained until year 2025.

Electric - all combined, support until 2020 + Reduction factor 1 & support until 2025 + FCH rapid decrease																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	EV charging stations	-205,2	-155,4	-118,7	-91,7	-146,7	-101,6	-76,8	-62,4	-53,5	-44,4	-40,3	-37,2	-34,8	-32,6	-21,0	-20,2	-19,4	-18,6	-17,9	-13,4	-13,0	-12,6	-12,2	-11,8	-12,7	-12,3	-11,9	-11,5	-11,1	-9,9	-9,5	-9,1	-8,7	-8,3	0,0
	EV stock projection		-6383,7	-4846,7	-3711,7	-2871,6	-33,0	-26,2	-19,3	-12,5	-5,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Net present value (MNOK)	-17589,9	-205	-6287,5	-4590,8	-3381,2	-2580,1	-110,6	-81,4	-62,2	-48,3	-35,2	-27,2	-24,2	-21,7	-19,6	-12,1	-11,2	-10,3	-9,6	-8,8	-6,4	-5,9	-5,5	-5,1	-4,8	-5,0	-4,6	-4,3	-4,0	-3,7	-3,2	-2,9	-2,7	-2,5	-2,3	0,0

Table 74: Electric all combined, support until year 2020 + reduction factor 1 & support until year 2025 & FCH rapid decrease

Table 74 shows the cash flow and NPV of investment into all electric vehicles when evaluating over the period 2017-2050, with financial support maintained until year 2020 for passenger vehicles and cargo vans, where also reduction factor 1 is used. For buses, financial support is maintained until year 2025, where also FCH rapid decrease is used.

Electric - all combined, support until 2020 + Reduction factor 2 & support until 2025 & FCH																																				
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	EV charging stations	-205	-199	-194	-189	-421	-397	-374	-353	-334	-363	-338	-315	-293	-273	-213	-200	-188	-177	-167	-118	-113	-108	-104	-100	-73	-72	-70	-69	-67	-51	-50	-50	-49	-49	0
	EV stock projection		-8004	-7562	-7145	-6753	-262	-249	-237	-224	-212	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net present value (MNOK)	-31938	-205	-7888	-7171	-6520	-6132	-541	-493	-448	-408	-404	-228	-204	-183	-164	-123	-111	-100	-91	-82	-56	-51	-48	-44	-41	-29	-27	-25	-24	-22	-16	-15	-15	-14	-13	0

Table 75: Electric all combined, support until year 2020 + reduction factor 2 & support until year 2025 & FCH

Table 75 shows the cash flow and NPV of investment into all electric vehicles when evaluating over the period 2017-2050, with financial support maintained until year 2020 for passenger vehicles and cargo vans, where also reduction factor 2 is used. For buses, financial support is maintained until year 2025, where also FCH is used.

Status quo prolonged - all combined, minimum costs (IPCC)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Investment costs	0																																		
	CO_2		-1781	-1744	-1707	-1669	-1636	-1602	-1567	-1532	-1496	-1460	-1423	-1386	-1348	-1309	-1346	-1331	-1316	-1301	-1285	-1268	-1251	-1234	-1216	-1197	-1179	-1160	-1141	-1122	-1102	-1081	-1060	-1039	-1017	-995
	CH_4		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N_2O		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SO_2		-1,8	-1,7	-1,7	-1,6	-1,6	-1,6	-1,5	-1,5	-1,5	-1,4	-1,4	-1,3	-1,3	-1,3	-1,3	-1,3	-1,3	-1,3	-1,3	-1,3	-1,2	-1,2	-1,2	-1,2	-1,2	-1,1	-1,1	-1,1	-1,1	-1,1	-1,0	-1,0	-1,0	-1,0
	NO_X		-761	-740	-720	-700	-684	-668	-651	-635	-618	-602	-585	-568	-551	-534	-461	-455	-450	-444	-438	-432	-426	-419	-413	-406	-399	-393	-386	-379	-372	-365	-358	-350	-343	-335
	nmVOC		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NH_3		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PM2,5		-85,2	-84,1	-83,0	-81,8	-80,4	-79,0	-77,6	-76,1	-74,6	-73,0	-71,4	-69,7	-68,0	-66,2	-65,6	-65,0	-64,4	-63,8	-63,1	-62,4	-61,7	-61,0	-60,3	-59,5	-58,7	-57,9	-57,0	-56,1	-55,2	-54,2	-53,1	-52,1	-51,0	-49,9
Net present value (MNOK)	-37492	0	-2528	-2376	-2233	-2097	-1974	-1857	-1746	-1640	-1539	-1443	-1352	-1265	-1182	-1104	-1040	-989	-940	-894	-849	-805	-763	-724	-686	-649	-615	-581	-550	-519	-491	-463	-436	-411	-387	-364

Table 76: Status quo prolonged, all combined, minimum costs (IPCC)

Table 76 shows the cash flow and NPV of the scenario status quo prolonged when evaluating over the period 2017-2050 and using minimum social costs of emissions based on IPCC's report (97). These values for the social costs of emissions can be seen in Table 8.

Status quo prolonged - all combined, maximum costs (IPCC)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Investment costs	0																																		
	CO_2		-36668	-35909	-35142	-34366	-33680	-32979	-32266	-31538	-30798	-30059	-29306	-28538	-27756	-26959	-27714	-27413	-27103	-26785	-26459	-26112	-25758	-25396	-25026	-24648	-24272	-23887	-23493	-23091	-22680	-22265	-21831	-21388	-20938	-20479
	CH_4		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N_2O		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SO_2		-4,4	-4,3	-4,2	-4,1	-4,0	-3,9	-3,8	-3,7	-3,6	-3,6	-3,5	-3,4	-3,3	-3,2	-3,3	-3,3	-3,3	-3,2	-3,2	-3,1	-3,1	-3,0	-3,0	-2,9	-2,9	-2,9	-2,8	-2,8	-2,7	-2,7	-2,6	-2,5	-2,5	-2,4
	NO_X		-3804	-3702	-3601	-3500	-3420	-3338	-3256	-3173	-3090	-3008	-2925	-2841	-2757	-2671	-2304	-2277	-2249	-2220	-2191	-2160	-2128	-2096	-2063	-2030	-1997	-1964	-1930	-1895	-1860	-1825	-1789	-1752	-1715	-1677
	nmVOC		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NH_3		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PM2,5		-5997	-5920	-5839	-5754	-5659	-5561	-5460	-5355	-5247	-5136	-5021	-4904	-4782	-4658	-4616	-4575	-4532	-4487	-4440	-4393	-4345	-4294	-4242	-4188	-4131	-4072	-4011	-3949	-3885	-3812	-3738	-3663	-3586	-3508
Net present value (MNOK)	-677439	0	-44686	-42100	-39637	-37291	-35148	-33101	-31146	-29279	-27498	-25811	-24201	-22664	-21199	-19802	-19233	-18296	-17397	-16534	-15708	-14910	-14145	-13414	-12713	-12042	-11405	-10794	-10209	-9650	-9115	-8604	-8111	-7641	-7193	-6764

Table 77: Status quo prolonged, all combined, maximum costs (IPCC)

Table 77 shows the cash flow and NPV of the scenario status quo prolonged when evaluating over the period 2017-2050 and using maximum social costs of emissions based on IPCC's report (97). These values for the social costs of emissions can be seen in Table 8.

Status quo prolonged - all combined, best guess costs (IPCC & SFT combined)																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	Investment costs	0																																		
	CO_2		-9429	-9234	-9036	-8837	-8660	-8480	-8297	-8110	-7919	-7729	-7536	-7338	-7137	-6932	-6833	-6754	-6673	-6590	-6505	-6420	-6334	-6246	-6156	-6063	-5970	-5874	-5776	-5676	-5574	-5467	-5356	-5242	-5128	-5011
	CH_4		-2,0	-2,0	-1,9	-1,9	-1,9	-1,9	-1,8	-1,8	-1,8	-1,7	-1,7	-1,7	-1,6	-1,6	-1,6	-1,6	-1,5	-1,5	-1,5	-1,5	-1,5	-1,5	-1,5	-1,4	-1,4	-1,4	-1,4	-1,4	-1,3	-1,3	-1,3	-1,3	-1,2	-1,2
	N_2O		-17,4	-17,1	-16,7	-16,4	-16,1	-15,7	-15,4	-15,1	-14,7	-14,4	-14,0	-13,7	-13,3	-12,9	-12,7	-12,6	-12,4	-12,3	-12,1	-12,0	-11,8	-11,7	-11,5	-11,3	-11,1	-11,0	-10,8	-10,6	-10,4	-10,2	-10,0	-9,8	-9,6	-9,4
	SO_2		-3,1	-3,0	-2,9	-2,9	-2,8	-2,7	-2,7	-2,6	-2,6	-2,5	-2,4	-2,4	-2,3	-2,2	-2,2	-2,2	-2,1	-2,1	-2,1	-2,1	-2,0	-2,0	-2,0	-1,9	-1,9	-1,9	-1,8	-1,8	-1,8	-1,7	-1,7	-1,7	-1,6	-1,6
	NO_X		-2282	-2221	-2161	-2100	-2052	-2003	-1954	-1904	-1854	-1805	-1755	-1705	-1654	-1603	-1578	-1556	-1534	-1511	-1489	-1466	-1443	-1420	-1396	-1373	-1349	-1325	-1300	-1276	-1251	-1225	-1199	-1172	-1145	-1118
	nmVOC		-10,7	-10,6	-10,5	-10,3	-10,2	-10,0	-9,9	-9,7	-9,5	-9,3	-9,2	-9,0	-8,7	-8,5	-8,4	-8,3	-8,2	-8,2	-8,1	-8,0	-7,9	-7,8	-7,8	-7,7	-7,6	-7,5	-7,4	-7,2	-7,1	-7,0	-6,9	-6,8	-6,6	-6,5
	NH_3		-3,8	-3,8	-3,7	-3,7	-3,6	-3,6	-3,5	-3,5	-3,4	-3,3	-3,3	-3,2	-3,1	-3,0	-3,0	-3,0	-2,9	-2,9	-2,9	-2,9	-2,8	-2,8	-2,8	-2,8	-2,7	-2,7	-2,6	-2,6	-2,6	-2,5	-2,5	-2,4	-2,4	-2,3
	PM2,5		-3041	-3002	-2961	-2918	-2870	-2820	-2769	-2716	-2661	-2604	-2546	-2487	-2425	-2362	-2341	-2320	-2298	-2275	-2252	-2228	-2203	-2178	-2151	-2124	-2095	-2065	-2034	-2002	-1970	-1933	-1896	-1858	-1819	-1779
	PM10		-3927	-3845	-3762	-3679	-3604	-3527	-3450	-3370	-3290	-3208	-3125	-3040	-2954	-2867	-2829	-2792	-2754	-2716	-2677	-2638	-2598	-2557	-2516	-2474	-2432	-2390	-2347	-2304	-2259	-2214	-2168	-2121	-2074	-2026
Net present value (MNOK)	-269860	0	-17996	-16955	-15963	-15018	-14154	-13329	-12540	-11788	-11070	-10389	-9739	-9119	-8528	-7965	-7557	-7181	-6821	-6476	-6146	-5832	-5531	-5243	-4968	-4704	-4453	-4212	-3982	-3762	-3552	-3349	-3154	-2969	-2792	-2624

Table 78: Status quo prolonged, all combined, best guess costs (IPCC & SFT combined)

Table 78 shows the cash flow and NPV of the scenario status quo prolonged when evaluating over the period 2017-2050 and using best guess social costs of emissions based on SFT and IPCC's report (64, 97). These values for the social and abatement costs of emissions can be seen in Table 24.

Projected development - all combined, best guess costs (IPCC & SFT combined) & maximum hydrogen FCEV and EV costs																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	H2 fueling stations	-17,9	-17,6	-17,3	-16,9	-206,4	-151,0	-110,5	-80,9	-59,2	-69,4	-23,2	-7,8	-2,6	-0,9	-0,3	-0,1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	H2 FCEV stock projection		-67	-63	-59	-55	-1994	-1922	-1852	-1783	-1716	-6931	-5620	-3378	-2121	-1748	-3735	-3715	-3696	-3676	-3657	-2833	-2818	-2803	-2788	-2773	-2230	-2218	-2206	-2193	-2181	-1839	-1384	-77	-76	-76
	EV charging stations	-205	-199	-194	-189	-421	-397	-374	-353	-334	-363	-338	-315	-293	-273	-356	-332	-309	-287	-267	-182	-173	-164	-156	-148	-89	-86	-83	-81	-79	-34	-34	-34	-33	-33	0
	EV stock projection		-8004	-7562	-7145	-6753	-262	-249	-237	-224	-212	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	CO_2		217	424	619	804	1115	1408	1683	1939	2176	2499	2797	3069	3316	3538	3777	4026	4263	4487	4699	4802	4897	4983	5062	5132	5133	5128	5117	5102	5081	5024	4960	4892	4821	4747
	CH_4		0,1	0,3	0,4	0,6	0,6	0,7	0,8	0,9	1,0	1,0	1,1	1,1	1,2	1,2	1,2	1,3	1,3	1,3	1,3	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,3	1,3	1,3	1,3	1,3	1,3	1,2	1,2
	N_2O		0,3	0,7	1,0	1,3	1,8	2,4	2,9	3,4	3,8	4,4	5,0	5,5	6,0	6,5	6,9	7,4	7,9	8,3	8,7	8,9	9,1	9,3	9,4	9,6	9,6	9,6	9,5	9,5	9,5	9,4	9,3	9,1	9,0	8,9
	SO_2		0,0	0,1	0,1	0,2	0,3	0,4	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,1	1,1	1,2	1,3	1,4	1,5	1,5	1,5	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,5	1,5	1,5
	NO_X		29	56	82	106	164	218	268	316	360	431	498	559	615	665	728	790	850	906	960	988	1013	1037	1059	1079	1083	1086	1087	1087	1086	1076	1065	1053	1040	1026
	nmVOC		0,7	1,4	2,1	2,7	3,2	3,7	4,1	4,5	4,9	5,2	5,5	5,7	5,9	6,1	6,3	6,5	6,7	6,8	7,0	7,1	7,1	7,2	7,2	7,2	7,2	7,1	7,1	7,0	6,9	6,9	6,7	6,6	6,5	6,4
	NH_3		0,3	0,6	0,8	1,1	1,3	1,4	1,6	1,8	1,9	2,0	2,1	2,2	2,3	2,3	2,3	2,4	2,5	2,5	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,5	2,5	2,5	2,4	2,4	2,3
	PM2,5		27	53	77	101	229	349	463	569	668	815	951	1077	1191	1295	1393	1488	1578	1664	1745	1783	1819	1852	1881	1907	1906	1902	1896	1888	1879	1854	1827	1799	1770	1740
	PM10		25	48	70	91	216	335	446	551	648	805	951	1085	1208	1320	1438	1552	1661	1765	1863	1910	1954	1995	2031	2065	2066	2065	2062	2057	2049	2026	2000	1974	1945	1916
Net present value (MNOK)	31436	-223	-7682	-6705	-5829	-5409	-881	-266	264	720	1056	-1843	-475	1332	2373	2731	1825	2056	2253	2418	2586	2966	2950	2924	2889	2865	2961	2850	2739	2629	2533	2506	2507	2745	2601	2470

Table 79: Projected development, all vehicles, best guess costs (IPCC & SFT combined) & maximum hydrogen FCEV and EV costs

Table 79 shows the NPV of projected development of all vehicles with best guess social and abatement costs of emissions in the ultra-low emissions path relative to the status quo path with maximum hydrogen FCEV and EV costs. This means that in year 1, being 2017, CO_2-emissions are decreased by an amount worth 217 MNOK compared to what they would be in the reference scenario. Over the evaluated period, the amount of diesel and gasoline vehicles becomes smaller and smaller, increasing the difference between the projected stock's emissions and the emissions of the stock in the status quo scenario and thus similarly decreasing governmental expenses due to social costs of emissions. Thusly, Table 79 combines Table 78, Table 75 and Table 71 along with the actual emissions in the ultra-low emissions path.

Projected development - all combined, best guess costs (IPCC & SFT combined) & minimum hydrogen FCEV and EV costs																																				
Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cash flow	H2 fueling stations	-17,2	-16,6	-15,9	-15,4	-136,5	-72,8	-38,9	-20,7	-11,1	-4,3	-0,5	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	H2 FCEV stock projection		-54,0	-43,8	-33,7	-23,5	-1621,5	-1507,4	-1400,3	-1299,7	-1205,1	-3720,1	-2426,7	-1003,9	-207,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	EV charging stations	-205,2	-155,4	-118,7	-91,7	-146,7	-101,6	-76,8	-62,4	-53,5	-44,4	-40,3	-37,2	-34,8	-32,6	-21,0	-8,8	-8,6	-8,4	-8,3	-6,0	-5,9	-5,8	-5,7	-5,6	-6,0	-5,9	-5,8	-5,7	-5,6	-3,4	-3,4	-3,4	-3,3	-3,3	0,0
	EV stock projection		-6383,7	-4846,7	-3711,7	-2871,6	-33,0	-26,2	-19,3	-12,5	-5,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	CO_2		217	424	619	804	1115	1408	1683	1939	2176	2499	2797	3069	3316	3538	3777	4026	4263	4487	4699	4802	4897	4983	5062	5132	5133	5128	5117	5102	5081	5024	4960	4892	4821	4747
	CH_4		0,1	0,3	0,4	0,6	0,6	0,7	0,8	0,9	1,0	1,0	1,1	1,1	1,2	1,2	1,2	1,3	1,3	1,3	1,3	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,3	1,3	1,3	1,3	1,3	1,3	1,2	1,2
	N_2O		0,3	0,7	1,0	1,3	1,8	2,4	2,9	3,4	3,8	4,4	5,0	5,5	6,0	6,5	6,9	7,4	7,9	8,3	8,7	8,9	9,1	9,3	9,4	9,6	9,6	9,6	9,5	9,5	9,5	9,4	9,3	9,1	9,0	8,9
	SO_2		0,0	0,1	0,1	0,2	0,3	0,4	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,1	1,1	1,2	1,3	1,4	1,5	1,5	1,5	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,5	1,5	1,5
	NO_X		29	56	82	106	164	218	268	316	360	431	498	559	615	665	728	790	850	906	960	988	1013	1037	1059	1079	1083	1086	1087	1087	1086	1076	1065	1053	1040	1026
	nmVOC		0,7	1,4	2,1	2,7	3,2	3,7	4,1	4,5	4,9	5,2	5,5	5,7	5,9	6,1	6,3	6,5	6,7	6,8	7,0	7,1	7,1	7,2	7,2	7,2	7,2	7,1	7,1	7,0	6,9	6,9	6,7	6,6	6,5	6,4
	NH_3		0,3	0,6	0,8	1,1	1,3	1,4	1,6	1,8	1,9	2,0	2,1	2,2	2,3	2,3	2,3	2,4	2,5	2,5	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,5	2,5	2,5	2,4	2,4	2,3
	PM2,5		27	53	77	101	229	349	463	569	668	815	951	1077	1191	1295	1393	1488	1578	1664	1745	1783	1819	1852	1881	1907	1906	1902	1896	1888	1879	1854	1827	1799	1770	1740
	PM10		25	48	70	91	216	335	446	551	648	805	951	1085	1208	1320	1438	1552	1661	1765	1863	1910	1954	1995	2031	2065	2066	2065	2062	2057	2049	2026	2000	1974	1945	1916
Net present value (MNOK)	76581	-222	-6068	-4107	-2667	-1771	-80	529	1039	1468	1830	543	1785	2977	3667	3935	4079	4200	4293	4361	4405	4335	4256	4170	4078	3979	3828	3678	3530	3385	3243	3082	2926	2775	2630	2490

Table 80: Projected development, all vehicles, best guess costs (IPCC & SFT combined) & minimum hydrogen FCEV and EV costs

Table 80 shows the NPV of projected development of all vehicles with best guess social and abatement costs of emissions in the ultra-low emissions path relative to the status quo path with minimum hydrogen FCEV and EV costs. Thusly, Table 80 combines Table 78, Table 74 and Table 70 along with the actual emissions in the ultra-low emissions path.

Cost and NPV comparisons																
Vehicle type	Fuel type	Factors of impact	Annual GHG reduction in 2030 [tonnes CO_2-equivalents]	GHG reduction cost 2017-2030 [NOK/tonne CO_2-equivalent]	Accumulated GHG reduction 2017-2030 [tonnes CO_2-equivalents]	Accumulated GHG reduction cost 2017-2030 [NOK/tonne CO_2-equivalent]	Annual GHG reduction in 2050 [tonnes CO_2-equivalents]	GHG reduction cost 2017-2050 [NOK/tonne CO_2-equivalent]	Accumulated GHG reduction 2017-2050 [tonnes CO_2-equivalents]	Accumulated GHG reduction cost 2017-2050 [NOK/tonne CO_2-equivalent]	NPV based on Minimum SCC 2030 [MNOK]	Best guess SCC 2030 [MNOK]	Maximum SCC 2030 [MNOK]	Minimum SCC 2050 [MNOK]	Best guess SCC 2050 [MNOK]	Maximum SCC 2050 [MNOK]
Passenger vehicles	Fossil	Status quo prolonged	850739	-	4055707	-	1715853	-	28626287	-	-12008	-89663	-237757	-19087	-142723	-378066
	Electric	RF 1	3273977	4428	20448275	709	6426935	2256	128291403	113	-7070	40975	132600	3817	122457	348288
		RF 2	3273977	8225	20448275	1317	6426935	4279	128291403	214	-19500	28544	120169	-9187	109452	335284
	Hydrogen	RF 1, 50 000 units	125601	43319	531678	10233	644257	8922	8350600	688	-5175	-3456	-179	-3978	7486	29309
		RF 1, 2025	125601	23193	531678	5479	644257	4894	8350600	378	-2647	-929	2349	-1383	10082	31905
		RF 2, 50 000 units	125601	56739	531678	13404	644257	14080	8350600	1086	-6861	-5142	-1864	-7301	4164	25987
		RF 2, 2025	125601	27442	531678	6483	644257	8103	8350600	625	-3181	-1462	1815	-3450	8014	29837
Cargo vans	Fossil	Status quo prolonged	251704	-	1235720	-	585778	-	9822728	-	-3570	-34016	-66876	-5509	-52264	-103127
	Electric	RF 1	571299	4725	3697156	730	1187529	2321	21377597	129	-1352	10144	22550	1135	34157	70081
		RF 2	571299	5217	3697156	806	1187529	2683	21377597	149	-1633	9863	22269	704	33727	69650
	Hydrogen	RF 1, 50 000 units	313723	16882	1198463	4419	786411	6735	15102695	351	-4583	1499	8062	-2766	18710	42073
		RF 1, 2025	313723	9714	1198463	2543	786411	3875	15102695	202	-2334	3747	10311	-517	20959	44322
		RF 2, 50 000 units	313723	22626	1198463	5923	786411	9036	15102695	470	-6385	-304	6260	-4575	16901	40263
		RF 2, 2025	313723	11596	1198463	3036	786411	4635	15102695	241	-2925	3157	9721	-1115	20361	43724
Heavy duty trucks	Fossil	Status quo prolonged	1198969	-	9142578	-	1927967	-	40928672	-	-8543	-48741	-124866	-12588	-71816	-190436
	Electric	2025, FCH	-98	0	-983	0	-98	0	-2949	0	0	0	0	0	0	0
		2025, FCH rapid decrease	-98	0	-983	0	-98	0	-2949	0	0	0	0	0	0	0
	Hydrogen	50 000 units, FCH	368961	13077	1123266	4295	3052109	7827	40042179	597	-3631	3903	12628	-9676	57195	191124
		50 000 units, FCH rapid decrease	368961	736	1123266	242	3052109	89	40042179	7	923	8456	17181	13941	80813	214741
		2025, FCH	368961	735	1123266	242	3052109	89	40042179	7	923	8456	17181	13941	80813	214741
		2025, FCH rapid decrease	368961	593	1123266	195	3052109	72	40042179	5	975	8509	17234	13994	80865	214793
Buses	Fossil	Status quo prolonged	44739	-	352460	-	63752	-	1448985	-	-215	-2132	-4062	-308	-3056	-5810
	Electric	2025, FCH	14470	83096	84441	14239	28394	43973	536594	2327	-1153	-713	-270	-1112	103	1320
		2025, FCH rapid decrease	14470	19973	84441	3423	28394	11805	536594	625	-240	200	643	-199	1016	2234
	Hydrogen	50 000 units, FCH	20349	131999	111956	23992	40549	96794	774776	5066	-2617	-2003	-1385	-3731	-2003	-271
		50 000 units, FCH rapid decrease	20349	81240	111956	14766	40549	40776	774776	2134	-1584	-971	-352	-1460	268	2000
		2025, FCH	20349	24628	111956	4476	40549	12367	774776	647	-432	181	800	-308	1420	3152
		2025, FCH rapid decrease	20349	24044	111956	4370	40549	12073	774776	632	-420	193	812	-296	1432	3164
All combined	Fossil	Status quo prolonged	2346152	0	14786464	0	4293350	0	80826672	0	-24335	-174551	-433561	-37492	-269860	-677439
	Electric	2020 + RF 2 & 2025 + FCH	3859647	92250	24228890	15678	7642760	48550	150202645	2569	-22286	37694	142168	-9595	143282	406254
		2020 + RF 1 & 2025 + FCH rapid decrease	3859647	33415	24228890	5546	7642760	18767	150202645	988	-8661	51319	155794	4753	157630	420602
	Hydrogen	50 000 units/year 2050 FCH rapid decrease & RF 1	828634	12869	2965363	3596	4523326	2358	64270250	166	-10420	5528	24713	5737	107278	288123
		2025 FCH rapid decrease & RF 1	828634	7027	2965363	1964	4523326	1287	64270250	91	-4427	11521	30706	11798	113338	294184
		50 000 units/year 2050 FCH & RF 2	828634	24922	2965363	6964	4523326	9054	64270250	637	-19494	-3546	15639	-25284	76257	257102
		2025 FCH & RF 2	828634	9564	2965363	2672	4523326	1752	64270250	123	-5616	10332	29517	9068	110609	291454

Table 81: Costs of GHG reductions and NPV comparisons of all scenarios

Important note: The values for this table are tailored for comparison with GHG emission statistics for Norway made by Statistics Norway, in which only the emissions CO_2, CH_4 and N_2O are accounted for (5), while this thesis includes CO_2, CH_4, N_2O, SO_2, NO_X, nmVOC, NH_3, PM2,5 and PM10. As such, annual GHG reduction in 2030 and 2050 only accounts for those which Statistics Norway also account for.

Table 81 shows:

- Annual GHG reduction in 2030 in tons CO_2-equivalents. Meaning, by investment made into a certain scenario, how many tons CO_2-equivalents can be expected to be reduced in 2030 from the start of 2017. This is calculated due to Norway's climate goals being a GHG reduction of 40 % by 2030 when comparing with 1990-levels.
- GHG reduction cost 2017-2030 in NOK per ton CO_2-equivalent. Meaning, how much do the GHG reductions one can expect in 2030 cost per ton CO_2-equivalents for a certain scenario.
- Accumulated GHG reduction 2017-2030 in tons CO_2-equivalents. This is included because it is not enough to the carbon budget to see how many tons CO_2-equivalents are decreased by 2030, rather the accumulated CO_2-equivalents.
- Accumulated GHG reduction cost 2017-2030 in NOK per ton CO_2-equivalent. Meaning, how much do the accumulated GHG reductions cost per ton CO_2-equivalents for a certain scenario.
- Annual GHG reduction in 2050 in tons CO_2-equivalents. This is calculated because at 2050 Norway should be getting close to a zero-emission transport sector.
- GHG reduction cost 2017-2050 in NOK per ton CO_2-equivalent. Meaning, how much do the GHG reductions one can expect in 2050 cost per ton CO_2-equivalents for a certain scenario.
- Accumulated GHG reduction 2017-2050 in tons CO_2-equivalents. This is included because it is not enough to the carbon budget to see how many tons CO_2-equivalents are decreased by 2050, rather the accumulated CO_2-equivalents.
- Accumulated GHG reduction cost 2017-2050 in NOK per ton CO_2-equivalent. Meaning, how much do the accumulated GHG reductions cost per ton CO_2-equivalents for a certain scenario.

- NPV based on minimum SCC 2030 in MNOK. Meaning, what is the net present value of investment in a certain scenario when evaluating over 2017-2030 when using the minimum social costs of emissions.
- NPV based on best guess SCC 2030 in MNOK. Meaning, what is the net present value of investment in a certain scenario when evaluating over 2017-2030 when using the best guess social costs of emissions.
- NPV based on maximum SCC 2030 in MNOK. Meaning, what is the net present value of investment in a certain scenario when evaluating over 2017-2030 when using the maximum social costs of emissions.
- NPV based on minimum SCC 2050 in MNOK. Meaning, what is the net present value of investment in a certain scenario when evaluating over 2017-2050 when using the minimum social costs of emissions.
- NPV based on best guess SCC 2050 in MNOK. Meaning, what is the net present value of investment in a certain scenario when evaluating over 2017-2050 when using the best guess social costs of emissions.
- NPV based on maximum SCC 2050 in MNOK. Meaning, what is the net present value of investment in a certain scenario when evaluating over 2017-2050 when using the maximum social costs of emissions.