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Abstract

Emissions from heavy trucks constitute a large and increasing share of Norwegian CO_2-emissions. The Norwegian Green Tax Commission recently presented recommendations for emission reductions, largely confined to 'sticks', in the form of taxes and levies. Another way to reduce emissions and to force the phase-in of alternative propulsion systems on heavy trucks, is the use of more positive measures for the industry. In Norway, establishment of a CO_2-fund for the industry, modelled after the existing Norwegian NOx-fund, has been proposed. Rather than paying a levy on every litre fuel consumed, participants to the fund will pay a (lower) participation fee in exchange for committing to emission reducing measures. The fund's proceeds will then be used on (partial) subsidies towards the additional investment costs for renewable-based rolling stock and infrastructure. The analysis in this study shows that it is most cost-effective to direct the fund's subsidies towards biodiesel alternatives, but that the availability of sustainable fuel might become a challenge. A fund should therefore also consider subsidizing more expensive renewable technologies based on biogas, electricity, or hydrogen. Although some of these alternative technologies still face several techno-economic barriers, a CO_2-fund can contribute to increasing market demand and to achieving critical masses.

1. Introduction

Norway has committed to cutting greenhouse gas (GHG) emissions by 40 percent in 2030, relative to its 1990 level. Although the transport sector currently falls outside the scope of the Emissions Trading Scheme (ETS), demanding emission targets are expected to be implemented in line with the European Union (EU). At the EU-level, emissions from sectors outside the ETS in 2030 are to be reduced by 30 percent relative to 2005, with targets for individual countries varying between 0 and 40 percent (Norwegian Environment Agency, 2015).

With transport making up over 30 percent of Norwegian national emissions, and transport demand set to increase, these targets imply that measures are needed to keep emissions in check. This particularly applies to emissions from heavy trucks, which constitute a large share, and keep rising. The present study therefore focuses on (heavy) trucks that are used for long-haul transport and local distribution.

Generally, measures to curb emissions from road transport aim at reducing transport demand and/or increasing the use of renewable technologies (e.g. Callan & Thomas, 2010), of which biofuels, hydrogen and electricity are deemed the most promising (e.g. Connolly et al., 2014). These measures often take the form of levies or duties ('sticks') that make (conventional) transport more expensive. Such approaches are also recommended in a recent report by the Norwegian Green Tax Commission (2015).

In this study, we assess a proposal for a CO_2-fund for the industry, which instead uses 'carrots' to incentivize the phase-in of renewable technologies. We contribute to the existing literature by quantifying the emission reduction effect of measures financed within the current Norwegian framework on CO_2-levies for trucks, under different scenarios. In addition, we do this for a scheme which combines positive and negative measures, where these are often assessed in isolation. Particularly the direct 'refunding' of levies to finance subsidies has received little attention before (Hagem et al., 2015). Although our study primarily focuses on emissions from Norwegian heavy truck transport, similar measures can be applied to different sectors and in other countries as well.

Norwegian agents currently pay a CO_2-levy for every litre fuel used. In return for mandatory emission reductions, participants to a CO_2-fund would be exempt from this CO_2-levy and instead pay a (lower) per litre participation fee into the fund. The fund's proceeds are then used on partial subsidies towards the additional investment costs of renewable-based propulsion systems and infrastructure, such as filling stations and charging points. By stimulating and speeding up the adoption of renewable technologies for road transport, a CO_2-fund intends to achieve emission reductions in the years going forward.

This study first discusses the methodology, assumptions, and scenarios of our analysis in section 2. In section 3, we discuss the development of CO_2-emissions, provide a survey of measures and instruments and alternative technologies, and discuss the NOx-fund after which the proposed CO2-fund is modelled. Section 4 presents the results of a scenario analysis in terms of fund proceeds, cost effectiveness, and the potential for CO_2-reductions from Norwegian road transport. In section 5, we discuss the strengths and challenges of a CO_2-fund and our analyses. Section 6 concludes and identifies avenues for further research.

2. Methodology and assumptions

In this section, we will first address the calculation of our emission forecasts under 'business as usual'. We then discuss the underlying assumptions, considerations, values, data sources, and scenarios used in our calculations. Finally, we explain how this information is combined to assess the possible effects of a CO_2-fund, where we distinguish between effects from subsidies to rolling stock and subsidies to infrastructure.

2.1 Emission forecasts

Forecasts on the development of CO_2-emissions under 'business-as-usual' form the reference for an assessment of a CO_2-fund, and are presented in section 3.1. Our forecasts distinguish between vans, heavy trucks, buses, construction equipment, coastal shipping, and fishery, and are largely in line with projections by NEA, the Norwegian Environment Agency (2015).

For heavy trucks, we decided to use forecasts based on transport demand projections (Hovi et al, 2015) developed for the National Transport Plan, rather than NEA's general assumptions about the number of vehicles and driving distances between 2020-2030. We then derived emission factors from data on GHG-emissions from heavy vehicles (Statistics Norway, 2016) and used transport volumes and driving distances for buses and heavy trucks (Farstad, 2015) to calculate and distinguish separate emission paths. We further related historical emissions to transport performance in order to develop a time series of emissions per ton-km. Finally, we took into account that the biodiesel content in regular diesel is legally prescribed to increase from the current 5.5 percent to 7 percent from 2017 (NEA, 2015, p.152). The resulting forecasts are similar to NEA's for 2020, and only somewhat higher for 2030 (5 percent in total for heavy trucks).

2.2 The fund's set-up

The proposed CO_2-fund receives proceeds, and uses these on subsidies. The fund's proceeds are a function of the per litre participant levy, the participation rate, and the yearly diesel sales accounted for by the fund's participants. To provide a sufficient participation incentive, the participant levy is proposed to be set at NOK 0.80 (EUR 0.085/USD 0.095) per litre diesel, which is 70 percent of the current CO_2-levy. The fund is proposed to operate for ten years, starting in 2018. Based on discussions with the NOx-fund, participation is assumed to increase from 25 percent in the first year to 80 percent in the fund's final year. Estimates on the yearly diesel use by participants are derived from the projected CO_2-emissions in section 3.1, while accounting for the downward pressure that the fund's subsidies put on fossil fuel consumption, relative to 'business as usual'

Subsidies from the fund are intended to (partially) cover the additional costs of renewable-based rolling stock and infrastructure, compared to conventional combustion technologies. For investments in rolling stock, the fund provides subsidies of 80 percent of additional investment costs, while infrastructure is subsidized up to 50 percent. Subsidies are only given for investments in new vehicles, as modifying existing vehicles is more expensive, and therefore less cost-effective. Subsidized vehicles are further assumed to fully replace existing vehicles running on fossil diesel with a biodiesel content of 7% (B7). In our analysis, subsidies do not cover the potentially higher operating expenses for renewable-based rolling stock or infrastructure. This is, however, an area worth exploring.

2.3 Vehicle characteristics

The average per kilometer fuel consumption at average loads was calculated based on the model from the Handbook Emission Factors for Road Transport (HBEFA, 2014). This method is consistent with approaches used by Statistics Norway (SSB) and NEA. The results in table 2.1 also correspond well with data from a large Norwegian transport firm.

Table 2.1. Average diesel consumption in litres per km for different vehicle types. Calculation based on HBEFA-model, consistent with approaches by SSB and NEA.

Vehicle types (aggregated)	Litres/km
Vans	0.08
Distribution trucks (gross weight 3.5-12 tons)	0.34
Long-haul trucks (gross weight >12 tons)	0.40
Tractor units	0.40

Given that subsidized measures result in larger CO_2-reductions, the longer the driving distance of replaced vehicles, we also took into account the distribution of driving distances over lifetime. Data was based on periodical vehicle assessments by the Norwegian Public Roads Administration. For vehicles with a gross weight over 7.5 tons, we extrapolated data from the Norwegian Road Traffic Information Council (Opplysningsrådet for Veitrafikken) and checked the resulting estimates against data collected from two large Norwegian transport firms; see table 2.2. As the remainder of this study focuses on alternative technologies on distribution trucks and long-haul trucks, other categories are only depicted as illustration.

Table 2.2. Assumptions on vehicle lifetimes and total driving distances during average lifetimes. Source: periodical vehicle assessment data by the Norwegian Public Roads Administration (gross weight ≤7.5 tons); extrapolation of data from the Norwegian Road Traffic Information Council, checked against data from two large Norwegian transport firms (gross weight >7.5 tons).

	Assumed lifetime (years)	Driving distance over average lifetime (in 1000 km's)
Vans	17	280
Distribution trucks (gross weight 3.5-12 tons)	21	350
Long-haul trucks (gross weight >12 tons)	10	475
Tractor units	10	750

2.4 Additional investment costs

To estimate the additional costs of different types of renewable-based vehicles, we collected data from several vehicle manufacturers, transport firms, and other firms using own vehicles running on biofuels, electricity or hydrogen. As these data were collected confidentially, figure 2.1 presents index numbers, where fossil diesel with a biodiesel content of 7% (B7) = 100. Compared to conventional fossil-based vehicles, additional investment costs are lowest for biofuels, while hydrogen and electric vehicles are currently still expensive due to small-scale production, individual orders, and the lack of a critical mass. However, these costs are expected to fall throughout the fund's lifetime (Anandarajah et al., 2013) and technologies are expected to become ready for use on heavy trucks. In our analysis, we therefore estimated the additional costs at a stage of serial production, based on current price differentials between conventional and electric passenger cars, taxes excluded. As a result, additional costs for electric and hydrogen vehicles are assumed to decrease by roughly 70 percent from today's level, by the fund's last year.

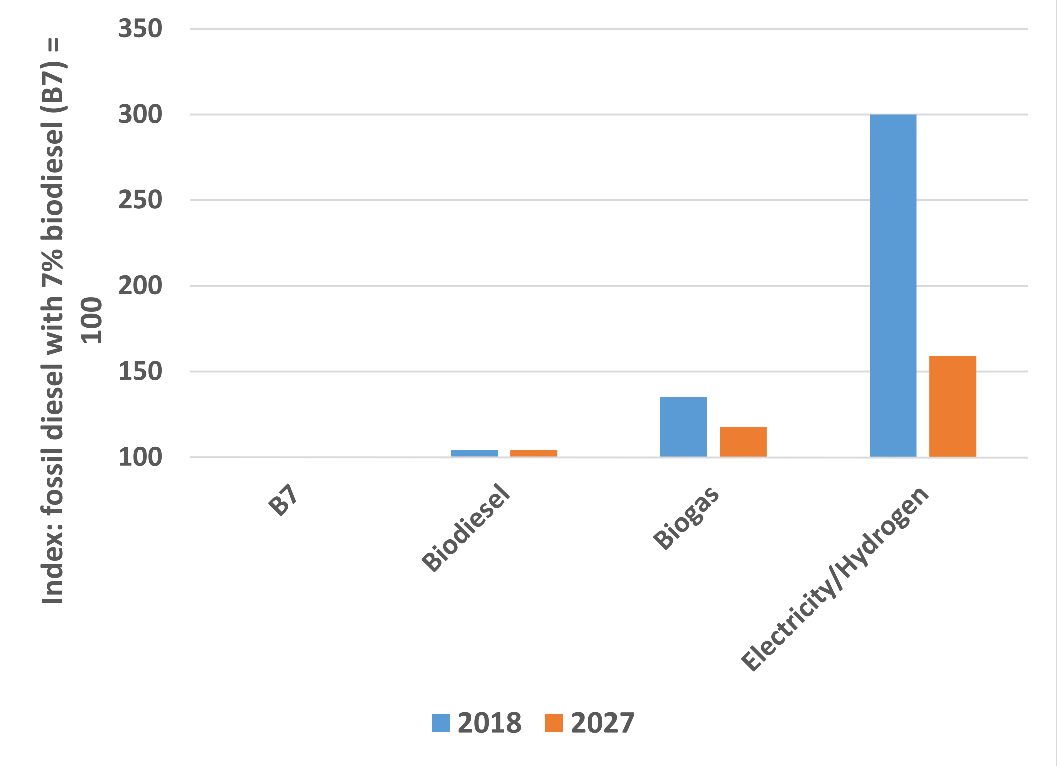

Figure 2.1. Additional investment costs for alternative technologies in 2018 and 2027 (in index numbers with diesel containing 7% biodiesel (B7) =100).

Figure 2.2, in turn, illustrates the cost efficiency of the different technological alternatives over time, given our assumptions. This is done by looking at the number of index points above 100 (as measure for additional investment costs), required for a one-ton reduction in CO_2-emissions. Despite cost efficiency improvements for electricity and hydrogen, biodiesel (and to a lesser extent biogas) remain more cost effective throughout the fund's entire lifetime.

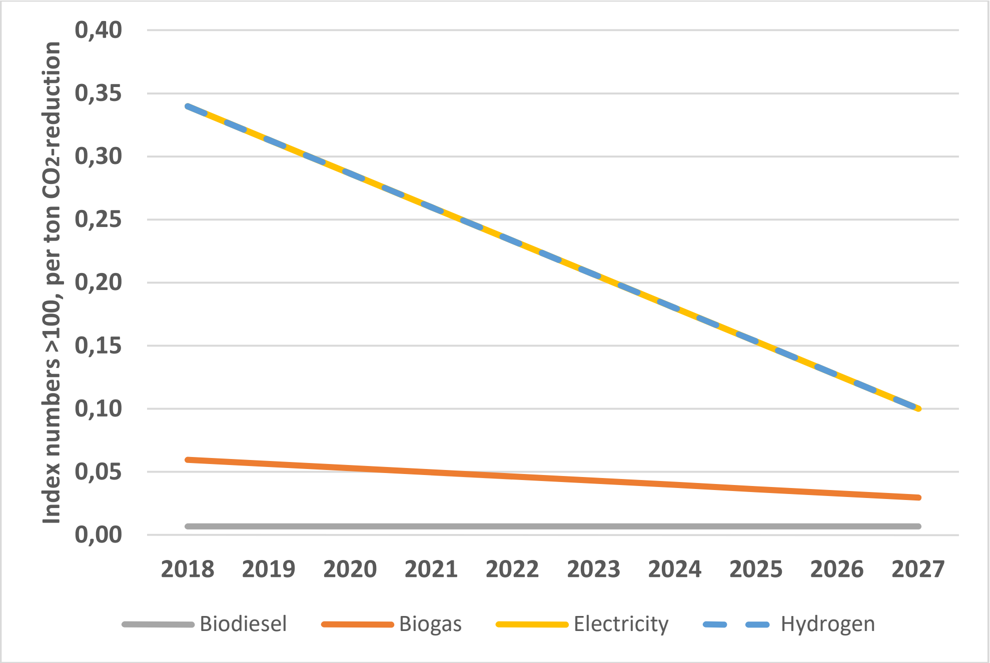

Figure 2.2. Developments in cost efficiency: number of index points above the 100 baseline (i.e. index of additional costs), that are required for a one-ton reduction in CO_2-emissions.

2.5 Emissions and climate accounting

The adoption of biofuels is surrounded by controversy. Besides ethical concerns (e.g. food security, biodiversity reduction, employment, consequences for subsistence farming), the total lifecycle of some biofuels involves higher, rather than lower global CO_2-emissions, compared to fossil counterparts (e.g. Pimentel & Burgess, 2014). The climate impact of biofuels will primarily depend on the type of biomass used, its sourcing and production, and the distribution of the fuel. In this study, we assume the use of biodiesel for which total lifecycle CO_2-reductions are more generally accepted (see e.g. Weber & Amundsen, 2016).

To calculate emissions for different vehicles, we considered the fuel consumption per kilometer and the CO_2-intensities per energy unit for both the conventional fuel and the alternative energy source $(in\ {}^{l}/_{km} * {}^{MJ}/_{l} * {}^{CO_2}/_{MJ})$. To the extent feasible, we used emission factors from a European standard for CO_2-emissions from renewable fuel sources (NEN-EN 16258; Nederlandse norm, 2012), which accounts for cultivation, processing, transport, and distribution. As this standard does not distinguish between different types of biodiesels, we further used the same assumptions as the Norwegian Environment Agency in its climate measures evaluations and emission projections towards 2030 (NEA, 2015).

According to NEA, the production of biofuels currently largely takes place abroad. From a climate accounting perspective, replacing fossil fuels with imported biofuels therefore results in Norwegian emission reductions of almost 100 percent. Although our main analysis will follow this reasoning, we also carried out more conservative analyses assuming that biofuels only reduce emissions by 60 percent globally (over the full life-cycle). This is based on prescriptions (NEA, 2015) that biofuels only qualify as 'sustainable' if they reduce emissions by at least 50% for 2017, and 60% for 2018, the fund's first year, and on the European Renewables Directive (European Parliament, 2009).

Emissions from electric or hydrogen vehicles, in turn, are also considered to be zero – again in line with NEN-EN 16258. During the production phase of these fuels, the use of hydropower implies that Norwegian emissions are zero from a climate accounting perspective, while during the use phase, CO_2-emissions are also zero. Table 2.3 summarizes the CO_2-emissions per kilometer for alternative fuel types and vehicles.

Table 2.3. CO_2-emissions (kg) per kilometer for different fuel types and vehicle categories. For biofuels, we show emissions under both the climate neutrality assumption and the more conservative 60%-reduction assumption. Sources: European standard NEN-EN 16258 and assumptions NEA (2015).

	B7	**Biodiesel**	**Biogas**	**Electric**	**Hydrogen**
Vans	0.25	0 / 0.10	0 / 0.10	0	0
Distribution trucks	1.06	0 / 0.44	0 / 0.44	0	0
Long-haul trucks	1.24	0 / 0.52	0 / 0.52	0	0
Tractor units	1.23	0 / 0.52	0 / 0.52	0	0

Climate change is, however, a global problem, for which it does not matter whether emission reductions take place in Norway or elsewhere. A rising domestic electricity demand for powering transport may, for example, reduce the export of 'clean' Norwegian electricity to other European countries, which in turn could increase fossil fuel use and CO_2-emissions in those countries. Assuming that the use of hydropower or imported biofuels results in zero emissions does therefore not account for the full global climate effects. It is, however, the leading approach in per country climate accounting and political discussions, and therefore the method presented in this paper.

2.6 Infrastructure

Estimates on the costs of developing and constructing different types of filling stations were based on information from suppliers of different fuel types and information from Enova (in: Norwegian Public Roads Administration, 2013). Given the characteristics of the different technologies, filling stations, and use patterns, we assumed that a sufficient infrastructure for heavy vehicles in Norway consists of:

- Ca. 60 hydrogen stations
- Ca. 140 biogas stations
- Ca. 700 biodiesel stations
- Ca. 500 electrical fast-charging points, suitable for trucks

Unlike electric passenger cars, which can typically be charged overnight, restrictions posed by operation schedules for trucks will generally require special, fast chargers. Such charging networks should not be confined to larger urban areas, but also cover locations in between, at rest areas, etc. This critical need is reinforced by the (currently) relatively short driving ranges for trucks with electrical propulsion.

2.7 Biofuel availability

Our analysis presupposes that sufficient sustainable biofuels are available to accommodate the subsidies under each of the scenarios in the following paragraph. This assumption may be critical, as the potential for emission reductions will in many cases be driven by the availability of biofuels (which is restricted by the area of cropland that is available for biomass production, without leading to adverse land-use impacts).

Campbell et al. (2009), for example, carry out life-cycle assessments for bioethanol and bioelectricity, and find that bioelectricity yields considerably higher CO2-offsets than cellulosic ethanol, for several types of biomass, production technologies, and vehicles. Given the limited area for producing this biomass, the authors therefore argue that efficiency should be maximized by choosing bioelectricity applications, rather than bio-combustion fuels. Our analysis facilitates this line of thought by allowing scenarios in which electricity and hydrogen applications gradually receive larger subsidy shares, once they have become techno-economically viable for larger-scale use on freight vehicles.

2.8 Scenarios

We constructed six scenarios to analyze the costs and effects of a possible CO_2-fund. Four of the scenarios were based on 'extremes' with full reliance on either biodiesel, biogas, electricity or hydrogen. In the fifth scenario ('Combined 1') we allocated the share of the subsidies going to rolling stock as follows: 50% to biodiesel vehicles, and the remaining part equally dispersed with 16.7% to hydrogen, electricity and biogas respectively.

In the last scenario ('Combined 2'), we took into account the maturity of electric and hydrogen technology: During the first years of the fund, most emphasis is put on subsidizing biodiesel vehicles and infrastructure, with some of the fund's proceeds going to investments in electric and hydrogen infrastructure. After a few years, emphasis shifts from biodiesel to electric and hydrogen; first to lighter distribution trucks, later also to heavier trucks, facilitating the argument by Campbell et al. (2009).

In addition, the shares of the fund's proceeds going to infrastructure are chosen such that in all scenarios, sufficient infrastructure is constructed for all applicable technologies. This assumption is important for our results: in the four 'extreme' scenarios, only infrastructure for one technology is constructed. This leaves a larger share of proceeds available for subsidies to rolling stock. In the fifth and sixth scenario, a larger share of the fund's proceeds is required for subsidizing the construction of several types of infrastructure.

2.9 Results calculation for rolling stock

Above assumptions, data, and scenarios are used to assess the effects of a CO_2-fund in chapter 4. We started out with the projections for emissions and diesel sales given 'business as usual'. Using the fund's assumed participation rate, we then calculated the fund's proceeds in year 1 by multiplying the fuel consumption of the fund's participants with the per litre participation fee.

The allocation of these proceeds and the costs of different measures then determines the number and types of subsidies in the different scenarios. The fuel and vehicle characteristics described above were used to calculate the corresponding reductions in emissions and diesel sales. We then corrected the projected diesel sales (being the proceed basis) under 'business as usual' for year 2, for the downward effect of previously awarded subsidies. This process was reiterated until the fund's last year. Although no more subsidies are given after this last year, previously awarded subsidies continue to have an effect until the last subsidized vehicle reaches the end of its lifetime.

2.10 Results calculation for infrastructure

Because effects from the construction of infrastructure are difficult to estimate and more uncertain than for rolling stock, results for infrastructure are calculated separately. The development of infrastructure results in CO_2-reductions if expanded distribution networks for alternative fuels are also used by passenger cars or other vehicles not subsidized by the fund (CO_2-reductions from vehicles that have received subsidies are already included in our calculations).

To arrive at CO_2-reduction estimates, we assume that hydrogen, biodiesel and biogas stations reduce the use of regular diesel (B7) by respectively 500,000, 1,500,000 and 2,000,000 litres yearly. For hydrogen and biogas, these assumptions are based on information from suppliers of hydrogen and biogas for fuelling purposes, while estimates for biodiesel are based on sales volumes for different types of filling stations from Madslien et al. (2013).

For hydrogen stations, we assume that 75% of the reduction in regular diesel sales can be attributed to unsubsidized vehicles, and therefore regarded as additional CO_2-reduction. For biogas- and biodiesel stations, we used shares of 50% and 25% respectively. Although these shares are based on judgement, hydrogen stations are expected to cover the passenger car market to a larger extent, as hydrogen is a less mature technology for heavy vehicles than biofuels.

For electrical charging points, it is difficult to estimate the additional CO_2-reductions resulting from constructing public fast charging points. Figenbaum et al. (2013) point out that new charging points do not necessarily result in more people using electric cars, but that owners of electric cars will be able to use their cars for longer trips. As we lack data on the number of users per charging point, we have not included electric infrastructure in our calculations.

In order to estimate additional CO_2-reductions from the construction of infrastructure, we took into account the allocation of proceeds in the different scenarios. Here too, it should be emphasized that filling stations result in CO_2-reductions beyond the year they are built, and after the fund's lifetime.

3. CO_2-emissions, measures, and technology for reducing emissions

3.1 Emission developments and forecasts

Given existing measures and policies, Norwegian CO_2-emissions from transport are expected to increase considerably towards 2030. Based on forecasts for transport demand for the Norwegian National Transport Plan 2017-2029 (Hovi et al, 2015) and the Norwegian Environment Agency's projections[1] (NEA, 2015), emissions from the industry's transport will rise from roughly 9 million tons CO_2 in 2014 to almost 10.6 million tons in 2030. Figure 3.1 shows these projections, divided over different transport segments. Although emissions from coastal shipping might be somewhat underestimated (DNV GL, 2015), the figure illustrates that particularly road transport is a driving force behind emission increases. For heavy trucks, which are the primary focus of this study, emissions are expected to rise from 2.4 million tons CO_2 in 2014 to 2.9 million tons in 2030.

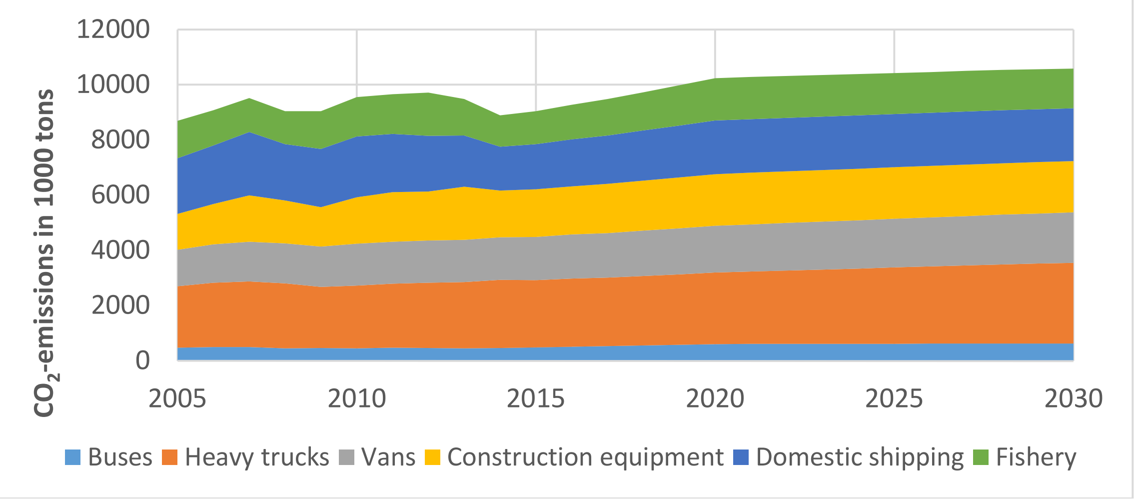

Figure 3.1. Emissions in CO_2-equivalents from the industry's domestic transport. Figures up to 2014 come from Statistics Norway (SSB); figures for 2020 and 2030 are projected by Hovi et al. (2015) for heavy trucks, and the Norwegian Environment Agency (other categories). Figures in 1,000 tons.

3.2 Current measures and instruments

The rising emissions illustrated above illustrate the need for additional measures and instruments. At present, Norway employs a range of measures and instruments aimed at influencing infrastructure usage, vehicle fleet composition, and negative external effects from road transport. The most important ones are summarized from Hovi et al. (2014), and described below.

The first measure is a road use levy, which is differentiated by fuel type, and collected at the point of sale. For diesel, this levy is 3.44 NOK (ca. EUR 0.37/USD 0.41) per litre for 2016. In addition, fuel is charged with a per litre CO_2-levy, again dependent on the fuel type. For diesel, this levy currently amounts to 1.12 NOK (ca. EUR 0.12/USD 0.13) per litre. These measures provide incentives for reductions in the consumption of fuel, by driving less, choosing technologies that use less fuel, and/or choosing fuel technologies that produce fewer negative externalities, and hence face a lower levy rate (Bragadóttir et al., 2015).

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[1] After pointing out that some of their original numbers were incorrect, we received corrected numbers from NEA.

In addition, vehicles over 7,500 kg are charged a yearly weight levy, divided into two parts. The first part is differentiated by weight and number of axels, whilst the second part is differentiated based on the vehicle's environmental characteristics (euro-class).

Besides these taxes and levies, Norway has a range of toll roads, concentrated around large(r) cities and on the major roads network. Heavier vehicles pay higher toll charges, and in some cities an additional rush-hour levy, which disadvantages transport by road. Switches to other modes are also incentivized with a strategy that recently passed Norwegian Parliament. This strategy aims at transferring 30% of (primarily longer-distance) goods transport by road, to transport by ships and trains. This will be done by implementing subsidies for ship transport, and also by prioritizing these transport modes in other ways (Stortinget, 2016).

3.3 Use of alternative technologies

Despite the measures and instruments described above, the adoption of alternative technologies remains slow. For heavy trucks, diesel remains the dominant choice. Of the ca. 66,000 trucks registered in Norway in 2014, over 93% used diesel, while virtually all remaining trucks relied on gasoline (Opplysningsrådet for veitrafikken, 2015).[2] Additional data from Statistics Norway (2015) indicates that new truck sales, including 2015, are also still directed at diesel-technology, and that only a negligible number of new trucks employs alternative technologies.

To illustrate, the diesel share for vans is also very high, with over 92% in 2014 (OFV, 2015), but the number of electric vans has recently shown a clear upward trend following incentives and improved maturity. At the same time, the number of electric passenger cars has also shown a marked increase (Statistics Norway, 2015). Fully electric passenger cars are exempt from toll charges, registration tax, annual taxes and VAT on their purchase. Combined with several practical advantages, this has made Norway Europe's market leader for electric vehicle adoption in both market share and absolute numbers. An evaluation of the contribution and importance of different electric vehicle incentives by Fearnley et al. (2015), suggests that attractive incentive structures can considerably contribute to the adoption of alternative technologies, given that their technologies have sufficiently advanced for practical use.

3.4 'Carrots' and 'sticks'

As described earlier, the Norwegian Green Tax Comission (2015) identifies taxes and levies as the primary means to reduce emissions from transport. At the same time, little to none attention is given to more positive instruments, such as subsidies for stimulating research, development, and the adoption of new technologies. In theory, axes and levies could be cost-effective instruments for reducing emissions (Musso & Rothengatter, 2013). However, in practice, environmental taxes and levies are often set at levels that do not result in socially optimal outcomes, for example because they are also motivated by fiscal or other reasons (e.g. Carlén (2014), and often attract resistance.

One way of making taxes or levies more politically acceptable, is to earmark or 'refund' the proceeds towards publicly desirable objectives, as is done in the proposed CO_2-fund. Hagem et al. (2015) describe three of the few real-life examples where (NOx)-

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[2] The diesel share for the ca. 8,600 tractor units was 99.9%.

levies and subsidies are combined. While combinations of taxes and subsidies are addressed in a number of papers, the authors point out that set-ups like for the Norwegian NOx-fund, where tax proceeds on emissions are refunded through direct subsidies on abatement measures, have hardly been analyzed before. One of the contributions of the present assessment is therefore the quantification of the environmental effects of a CO_2-fund, which allows for comparisons with other measures aimed at emission reductions.

3.5 The NOx-fund in practice

The NOx-fund was established in 2008 and consists of an agreement between the Norwegian Ministry of the Environment[3] and a consortium of industry organizations on the reduction of NOx-emissions. Industry actors who join the NOx-fund see their NOx-levies reduced in exchange for concrete emission reduction measures. After a slow start, the fund has so far helped reduce Norway's NOx-emissions by 30,000 tons, with a side effect of also reducing CO_2-emissions by half a million tons (NHO, 2015).

Although it can be argued that NOx-emissions have been going down in Europe regardless of method, this is different for Norway, where marked NOx-reductions only picked up around the establishment of the NOx-fund in 2008 (see figure 3.2). Norway's oil & gas and domestic shipping & fishery industries together made up between 52-56% of domestic NOx-emissions in the years 2008-2014 (Statistics Norway, 2016). Although contributions to the NOx-fund have to a large extent come from the oil & gas-sector, subsidies have primarily been aimed at domestic shipping & fishery, for which emission reductions of over fifty percent were achieved during this period. Meanwhile, NOx-emissions from the oil & gas industry have remained relatively stable (Hagem et al., 2014 & Eurostat, 2016).

Regarding NOx-emissions from road transport, Norway did largely follow the European downward trend (figure 3.2). A driving force behind particularly these reductions in NOx-emissions is the Euro Directive (see also Caspersen and Hovi, 2015).

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[3] Now the Ministry of Climate and Environment

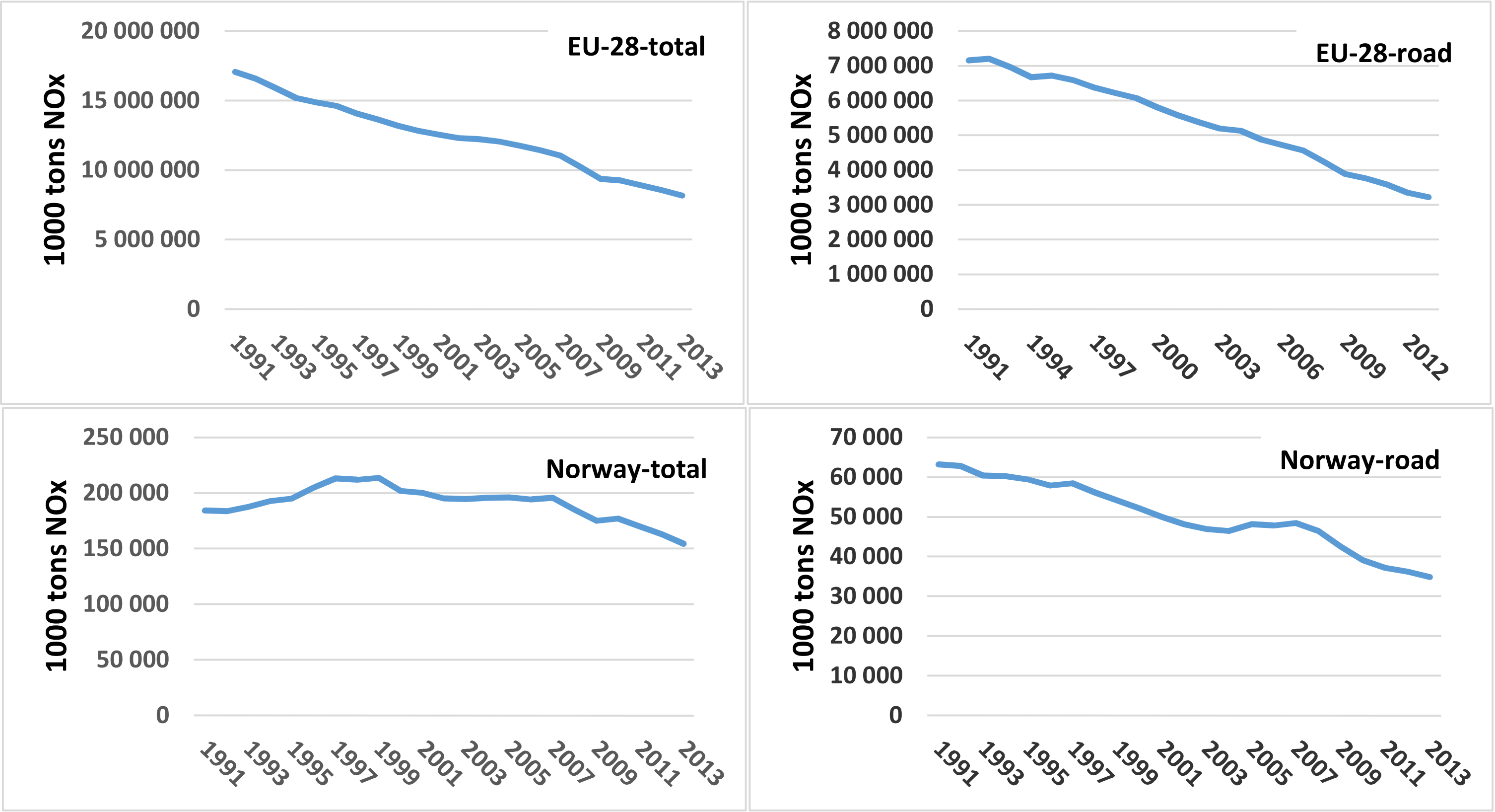

Figure 3.2. Yearly NOx emissions between 1991-2013 in total (upper left: EU-28, lower left: Norway), and confined to road transport (upper right: EU-28, lower right: Norway). Figures in 1000 tons. Source: Eurostat and Statistics Norway data on NOx emissions divided by source.

3.6 Challenges of a CO_2-fund

The proposed CO_2-fund works on a similar premise as the NOx-fund: it accommodates and speeds up the adoption of alternative technologies that result in lower emissions. Instead of a CO_2-levy, industry actors joining the fund pay a (lower) participation fee in return for committing to a plan for taking emission reducing measures. The fund's proceeds are returned through subsidies towards the additional costs of renewable-based rolling stock and infrastructure. As a result, important cost-barriers for the transition to alternative technologies are greatly reduced.

An important difference between the NOx-fund and a CO_2-fund is that the NOx-fund has 900 members and a participation rate of almost 100% within its relevant sectors. In addition, two thirds of its proceeds come from the oil- and gas industry. A CO_2-fund for the private sector for heavy truck transport would require a considerably higher number of members, which could make controlling and enforcing commitments by participants more difficult. According to Statistics Norway, there are about 9,200 firms within road transport, of which 15%, or some 3,400 firms, are responsible for 70% of employment. These numbers should be reasonably good proxies for the share of transport these firms are responsible for. Additionally, several large firms that manage their own transport solutions could also be potential participants of a CO_2-fund.

Other differential factors that may affect the success of a CO_2-fund are mostly of a techno-economic nature. Technological alternatives that result in lower CO_2-emissions for example require relatively large changes to vehicles and infrastructure, compared to the NOx-fund case. In addition, these technologies are still expensive, result in higher depreciation rates, and may not yet be practically viable. Electric trucks, for example, currently still face short driving ranges, which, combined with an underdeveloped infrastructure for fast chargers, does not make the technology practicable for use by most firms. Despite abovementioned differences, the primary reasoning behind the NOx-fund can also be applied to the transport sector.

3.7 Alternative technologies

When it comes to transitions to alternative technologies for road transport, biofuels (e.g. biodiesel or biogas), hydrogen, and electricity are considered most promising (Connolly et al., 2014). The extent to which these alternative technologies result in emission reductions depends on the production methods and raw materials used.

Biodiesel, for example, exists in several varieties and generations and can, amongst others, be based on reactions between vegetable oils and methanol, the hydro treatment of vegetable oils, or raw materials from forests. Biogas can also be produced using many sources, such as sewage sludge or food waste, or livestock manure. In Oslo, biogas from sewage sludge is for example used for waste disposal trucks.

Hydrogen can be produced by splitting water into hydrogen and oxygen through electrolysis. Hydrogen produced in this way is climate neutral if produced from non-fossil sources, and can potentially be produced by many power producers around Norway. On an industrial scale, hydrogen is currently often produced using natural gas. Unless combined with carbon capture and storage, such hydrogen is not climate neutral.

Some types of pure biodiesel can directly replace fossil fuels in newer combustion engines, and adaptation costs or additional costs for new vehicles are relatively low. Using biogas, in turn, usually requires larger and considerably more expensive vehicle adaptations.

Hydrogen requires even larger and more expensive adaptations. Although hydrogen use is still in an early stage, Toyota is expected to introduce a passenger car onto the Norwegian market this year, and several other car manufacturers are also working on hydrogen cars. Public transport company Ruter currently runs a pilot project in Oslo, where 5-8 hydrogen buses are operated at relatively high capacity. This indicates that hydrogen technology can also be feasible for use on heavy vehicles.

For heavy vehicles running on electricity, range limitations are still a pressing issue (Pelletier et al., 2016). While smaller electrical trucks are gaining some market share, larger trucks are still only built on a small scale or individual orders. Although this currently leads to high additional costs, these costs are expected to decrease as market demand increases following technological progress (e.g. Anandarajah et al., 2013).

3.8 Infrastructure

In addition to cost issues and technological limitations, insufficient distribution networks and infrastructure may also pose a barrier for the adoption of above technologies. Although driving ranges for biofuels and their fossil counterparts are similar, there are about 1,600 regular filling stations in Norway (Norwegian Petroleum Institute, 2016), but currently only 5-6 filling stations for pure biodiesel. For biogas, AGA (a large supplier) has only established 15 stations in Norway so far (Melby, 2015).

Although hydrogen vehicles generally have larger driving ranges, there are still only 5 hydrogen stations in Norway, concentrated around greater Oslo. However, there are indications of developments: a hydrogen supplier announced plans to construct 20 more stations by 2020, and hydrogen infrastructure has in recent years seen large expansions in amongst others Germany (Ehret and Bonhoff, 2015). For electric vehicles, the current electric infrastructure consists of 1,875 charging stations with about 7,700 charging points (about 720 non-specialized fast-chargers of ≥43 kW (NOBIL, 2016), and is almost exclusively catering the passenger car market.

A large-scale adoption of electric trucks will therefore particularly require the expansion of networks for fast charging and locations for induction charging. Due to trucks' use patterns and the driving range of electric trucks, these fast chargers need to be built also outside of urban areas, e.g. at resting points.

The expansion of some or all of these infrastructure types entails large costs. At the same time, the construction of distribution networks may also speed up the adoption of alternative technologies by other vehicles, like passenger cars, and contribute to breaking barriers and achieving critical masses.

4. Results

4.1. Rolling stock

Previously, we saw that yearly emissions from heavy truck transport are expected to rise from 2.4 million tons CO_2 in 2014 to 2.9 million tons yearly by 2030, given current developments and instruments.

The potential emission reductions resulting from a CO_2-fund depend on the type and number of measures implemented, and at which segments of the transport market these subsidies are directed. Subsidies to long-haul trucks will for example result in larger CO_2-reductions than subsidies to local distribution vehicles.

Table 4.1 illustrates how subsidies are allocated in every scenario, over the fund's entire lifetime. As explained earlier, the 'combined' scenarios require a considerably larger share of proceeds going to infrastructure than the 'extreme' scenarios. In the 'extreme' scenarios, proceeds are allocated such that sufficient distribution networks will have been established after 6-7 years. In the combined scenarios, the construction of (a higher number of) filling stations is more spread out over the entire fund's existence.

Other noteworthy results include the number of different types of vehicles that can receive subsidies in the different scenarios. In the biodiesel 'extreme', the total number of subsidized vehicles is for example much higher than in the hydrogen scenario. These differences are largely due to the cost differences between investments in different alternative technologies. For all scenarios, subsidies were allocated such that the total number of subsidized vehicles would remain plausible relative to the total number of registered vehicles.

Table 4.1. Number of subsidies in each scenario over the fund's entire lifetime, as well as the distribution of the fund's revenues over infrastructure and rolling stock.

	Number of subsidies, filling stations					Number of subsidies, rolling stock		Share of revenues to		Of which	
	Hydrogen	Biogas	Biodiesel	EL	**TOTAL**	Long-haul	Local distribution	Infra-structure	Rolling stock	Long-haul	Local distribution
Hydrogen	51				51	1,610	4,277	12%	88%	29%	59%
Biogas		110			110	6,452	12,905	10%	90%	30%	60%
Biodiesel			536		536	13,255	26,510	17%	83%	28%	55%
Electricity				425	425	1,686	4,482	8%	92%	31%	62%
Combined 1	38	118	544	399	1,099	12,092	12,204	48%	52%	26%	26%
Combined 2	67		675	449	1,191	7,278	13,211	36%	64%	29%	35%

With above allocations, the following results are obtained:

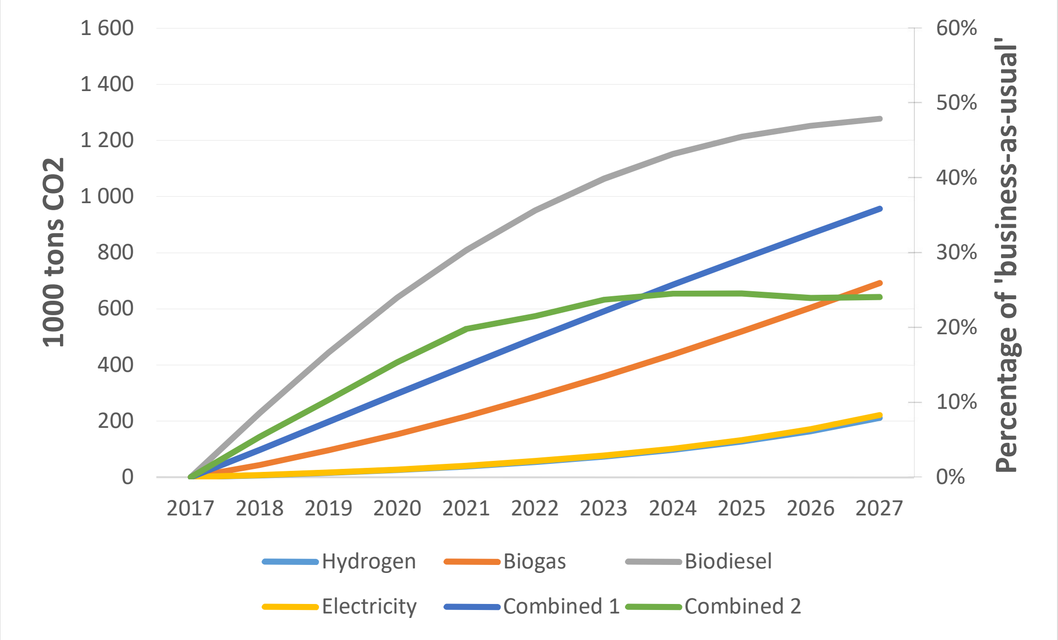

Figure 4.1. Yearly CO_2-reduction in each scenario from subsidized rolling stock, relative to 'business as usual'. Figures in 1,000 tons CO_2 (left axis), and as percentage of 'business as usual' (right axis).

Figure 4.1 shows the yearly CO_2-reductions resulting from a CO_2-fund, relative to 'business as usual'. The left axis shows CO_2-reductions in thousand tons, while the right axis expresses reductions as a percentage of emissions under 'business as usual'. Emission reductions are largest when all of the fund's proceeds are used for subsidies towards biodiesel technology, and amount to 48% in the fund's last year. This is due to biodiesel adaptations being relatively cheap, which makes these subsidies relatively cost-effective. In the two 'combined' scenarios, a considerable share of subsidies goes to biodiesel vehicles as well. This explains why the 'combined' scenarios also yield larger emission reductions than full reliance on biogas, electricity or hydrogen vehicles. In 'Combined 2', yearly emission reductions start to fall during the last years of the fund. This is due to more cost-effective subsidies to biodiesel slowly being replaced by less cost-effective subsidies to electric and hydrogen vehicles in later years.

Figure 4.2., in turn, shows the development of the fund's yearly proceeds, which are determined by the participation rate, the per litre participation fee, and the fuel consumption by the fund's members.

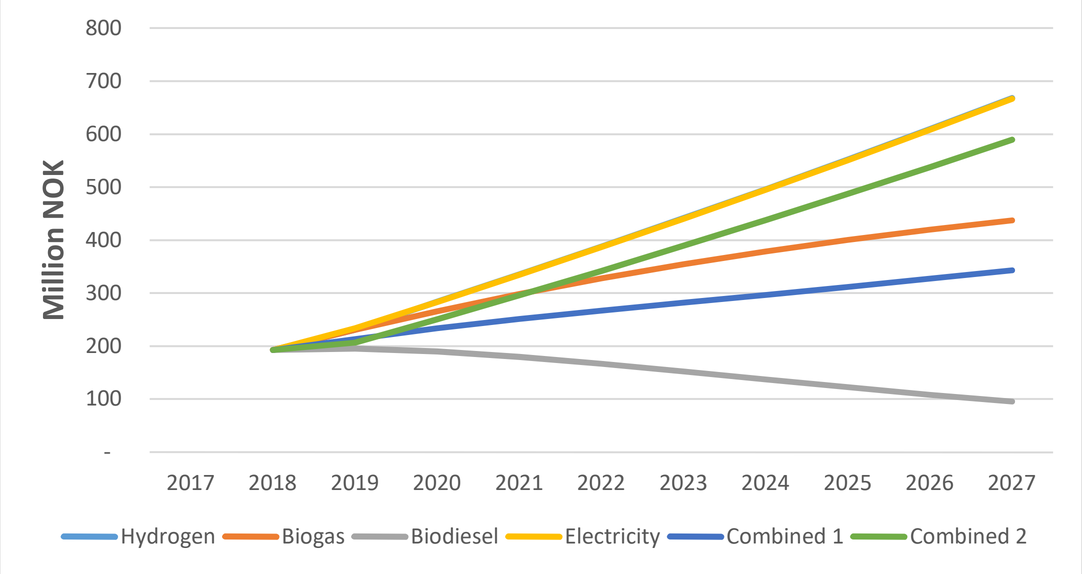

Figure 4.2. The fund's yearly revenues in each scenario. Figures in million NOK.

The figure illustrates that yearly proceeds decrease rapidly in the biodiesel scenario, while proceeds increase for all other scenarios. As biodiesel adaptations are relatively cheap, the number of conventional vehicles replaced in the fund's early years is relatively large. This leads to a reduction in the consumption of (fossil) fuels that are subject to a levy. As a consequence, the proceed basis for the fund diminishes faster than the participation rate increases. The opposite is true for the hydrogen and electricity scenarios; here, the fund's proceeds increase steadily, driven by increasing participation rates and relatively small reductions in diesel sales.

After the fund's final year, annual CO_2-reductions start to decrease year by year until 2048, when the last vehicles that received subsidies reach the end of their lifetime. Annual CO_2-reductions decrease because the driving distance of a vehicle is generally highest in the first year of its use, and then decreases over time. Nevertheless, the fund still achieves CO_2-reductions in the 20 years after its final year: figure 4.3 shows that the accumulated CO_2-reduction in the scenario with full reliance on biodiesel is 13 million tons in 2027, but 18 million tons in total. In other words, almost a third of the CO_2-reduction materializes after the fund's final year. Similar results are found for the other scenarios.

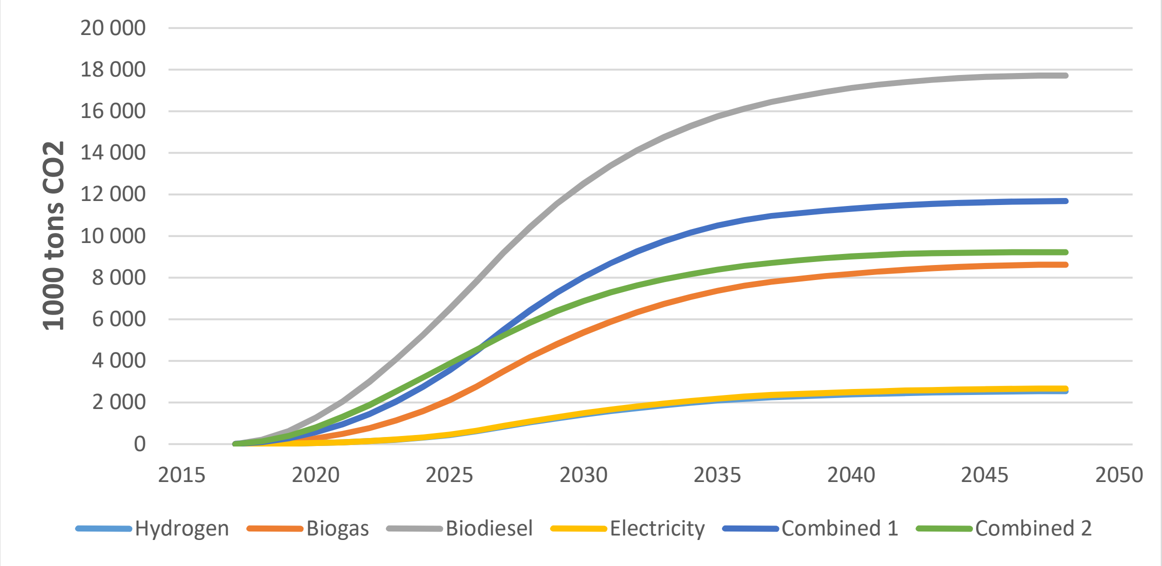

Figure 4.3. Accumulated CO_2-reduction in each scenario from subsidized rolling stock, relative to 'business as usual'. Figures in 1,000 tons CO_2.

4.2. Infrastructure

The previous section discussed CO_2-reductions from subsidies to rolling stock, relative to 'business as usual'. In addition, the construction of corresponding infrastructure is not only necessary for the use of vehicles with alternative technologies, but it also yields additional (indirect) CO_2-reductions. Ideally, one would compare different scenario results based on CO_2-reductions from both rolling stock and infrastructure. As estimates for infrastructure are more uncertain than for rolling stock, and as we lack estimates on electric infrastructure, we chose to separate these results.

Figure 4.4 shows the yearly additional CO_2-reduction resulting from subsidizing investments in infrastructure, based on assumptions described earlier. CO_2-reductions are highest in the two combined scenarios, amounting to between 0.73 and 0.88 million tons CO_2 in the fund's last year. These results are not surprising: as the combined scenarios require sufficient distribution networks for several technologies, a larger share of the fund's revenues is allocated to infrastructure, resulting in much higher numbers of filling stations than in the 'extreme' scenarios.

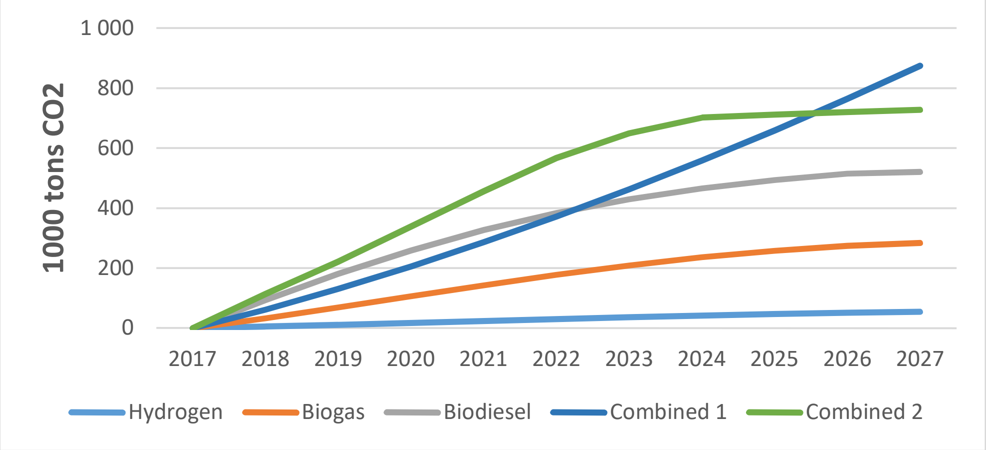

Figure 4.4. Yearly CO_2-reduction in each scenario from subsidized infrastructure, relative to 'business as usual'. Electrical infrastructure not included. Figures in 1000 tons CO_2.

Figure 4.5 shows the accumulated CO_2-reduction during the fund's lifetime. Due to its large number of filling stations, the biodiesel 'extreme' also yields considerable additional CO_2-reductions behind the two 'combined' scenarios. Given unchanged use, the yearly additional CO_2-reduction per station after the fund's last year is equal to the reduction in this last year, until the last life year of the infrastructure. The accumulated additional CO_2-reduction therefore continues to rise after the fund's resolution.

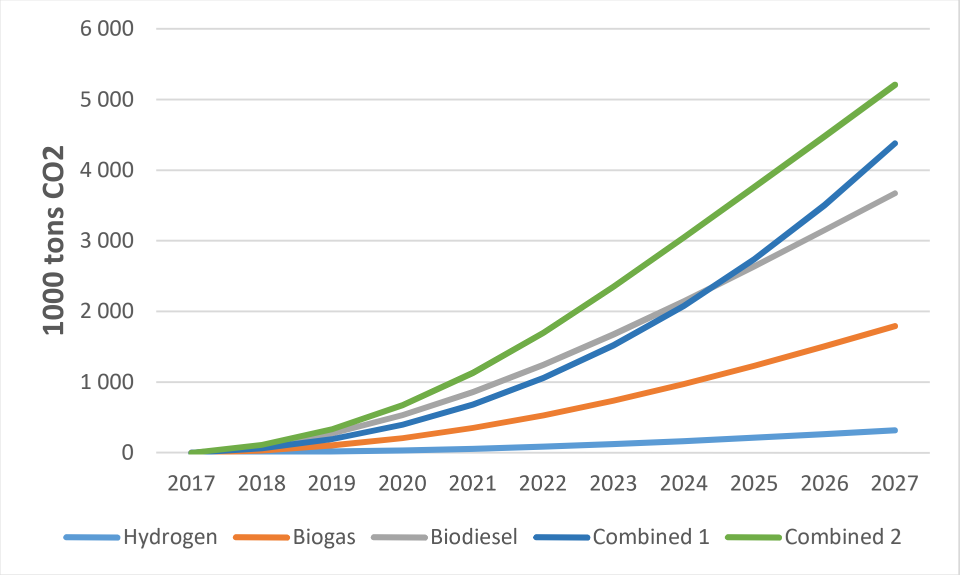

Figure 4.5. Accumulated CO_2-reduction in each scenario from subsidized infrastructure, relative to 'business as usual'. Electrical infrastructure not included. Figures in 1000 tons CO_2.

It remains important to emphasize that no potential additional CO_2-reductions from electric infrastructure were included. Results might therefore underestimate the CO_2-reduction in the full electric 'extreme' and the combined scenarios.

5. Discussion

The idea of a CO_2-fund is not new, and has both upsides and downsides. By employing 'carrots' in the form of reduced CO_2-levies, implementation will likely meet less resistance from the industry and public than when only 'sticks' or stringent command-and-control regulation are used. An additional advantage of a centralized fund is that it can be used to coordinate individual action, build up expertise, and possibly to use its scale to improve bargaining power. Together, these aspects may increase cost-effectiveness and contribute to achieving critical masses.

A CO_2-fund like the one analyzed in this study, however, also faces several downsides. Firstly, participation makes transport cheaper, as the participation fee is set below the prevailing CO_2-levy. Although this provides an incentive to participate, it does not provide participants an incentive to follow through with their mandatory plans for emission reducing measures. The fund will therefore need effective enforcement mechanisms in order to achieve actual emission reductions, particularly given the high number of participants. These challenges are aggravated if reduced driving costs results in higher transport demand than under 'business as usual', resulting in a 'leakage'.

Secondly, the analyzed fund only (partially) covers additional investment costs. Besides higher investment costs, renewable-based propulsion systems and infrastructure often face higher operating and maintenance costs, and currently face several techno-economic barriers. In addition, the lack of a developed second-hand market results in low residual values and higher depreciation rates for vehicles with alternative technologies. Altogether, these factors make investing in alternative vehicles less attractive. It might therefore be worth considering including such factors when awarding subsidies, and performing further analyses, taking into account the sum of investment and operating costs over a vehicle's lifetime.

A third downside to the fund is that it reduces the proceeds from CO_2-levies, implying that more government income will have to be sourced elsewhere.

An alternative could be to earmark current CO_2-levies for use towards subsidies, without first giving a participation 'discount'. This way, per litre proceeds are higher than is the case for the fund, and a larger number of subsidies can be awarded. In addition, there would be no 'leakage' from increases in (cheaper) transport demand, and no incentive to 'free-ride' without intention to act.

However, giving no (or smaller) 'discounts' on current CO_2-levies provides a lesser incentive to participate. In the end, a balance will probably have to be found between participation incentives, financial consequences, and effectively reducing emissions.

Our calculations, in turn, are based on thorough analyses on the development of transport demand, and in addition on real-life experiences from the NOx-fund. For many aspects, we were able to use actual data and educated estimates (e.g. distribution of driving distances over lifetime). Nevertheless, we were also forced to make several important assumptions. Particularly the estimates on CO_2-reductions from infrastructure investments are more uncertain, and subject to assumptions. This uncertainty, combined with lacking data for estimating the effects from constructing electrical infrastructure, made us unable to compare the total effects of every scenario.

6. Conclusions and final remarks

Given current measures and policies, Norwegian emissions from transport are expected to rise from almost 9 million tons CO_2 to 10.6 million tons in 2030. The largest drivers behind this increase are road transport, and in particular heavy truck transport. For heavy trucks, emissions are expected to rise from 2.4 million tons CO_2 in 2014 to 2.9 million tons CO_2 in 2030 under 'business as usual'. This implies that there is a considerable reduction potential for emissions from transport by heavy trucks.

While the Norwegian Green Tax Commission recently confined itself to recommending 'sticks' to achieve emission reductions, our study assesses a CO_2-fund using both 'sticks' and 'carrots'. The fund is modelled after the Norwegian NOx-fund, and rewards participants by charging a lower fee per litre fuel than the current CO_2-levy. In return, participants commit to emission reducing measures that can (partially) be subsidized using the fund's proceeds.

This study analyzed the effects of a CO_2-fund using four 'extreme' scenarios with full reliance on either hydrogen, biogas, biodiesel, or electricity, and two 'combined' scenarios, in which the implementation of different technologies is pursued alongside.

Looking only at the effects of subsidies to rolling stock, full reliance on biodiesel results in the largest CO_2-reductions in the fund's last year (1.4 million tons annually or 48% of the emissions under 'business as usual'). This is due to the relatively low costs for adapting vehicles for the use of biodiesel. The two combined scenarios also achieve considerable CO_2-reductions, which, again, is driven by large shares of (cost-effective) subsidies directed at biodiesel adoption. At the same time, full reliance on biogas results in a CO_2-reduction of about 24% of emissions under 'business as usual', while both hydrogen and electricity achieve reductions of some 8% in the fund's last year. However, the fund's effects don't cease after its last year; in most scenarios, about a third of total CO_2-reductions materializes thereafter.

Ideally, one would compare the different scenarios based on CO_2-reductions resulting from both subsidies to rolling stock and subsidies to infrastructure. This distinction is important, as in the 'extreme' scenarios a considerably larger share of proceeds is allocated to infrastructure. However, as estimates on CO_2-reductions from the construction of infrastructure are more uncertain, these should be interpreted with more caution. Particularly for electrical infrastructure, it is uncertain to what extent the development of infrastructure can or will lead to additional CO_2-reductions. We therefore refrained from adding up CO_2-reductions from subsidies to both rolling stock and infrastructure.

Altogether, our analysis indicates that it is most cost effective to allocate subsidies to vehicles using biodiesel, but that the availability of sustainable biofuels may pose a challenge. This is, however, a critical assumption on which the potential for emission reductions in many cases will depend. A potential CO_2-fund should therefore also consider allocating subsidies to more expensive technologies based on biogas, electricity, and hydrogen. Technologies for the latter two options are still immature for use on heavier trucks, but a CO_2-fund may contribute to increasing demand for these technologies and speed up the achievement of a critical mass. There are also indications that the limited area of available cropland for biomass production, warrants a pathway towards bioelectricity, rather than bio-combustion fuels.

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