Summary

A pathway to zero emission road freight

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Zero emission technologies for heavy-duty freight vehicles can become competitive as a result of increasing returns to scale coupled with high carbon taxes on fossil fuel. Through an integration of models covering, respectively, transportation demand, the vehicle fleet, and the energy system, a pathway toward zero emission road transportation in Norway has been drawn up. By using certain input assumptions underlying this pathway as checkpoints, an assessment can be made of whether we are behind or ahead of schedule toward the 2030 and 2050 greenhouse gas abatement targets.

Greenhouse gas emissions in Norway

Some 17 per cent of all greenhouse gas (GHG) emissions on Norwegian soil is due to road transportation (Figure E.1).

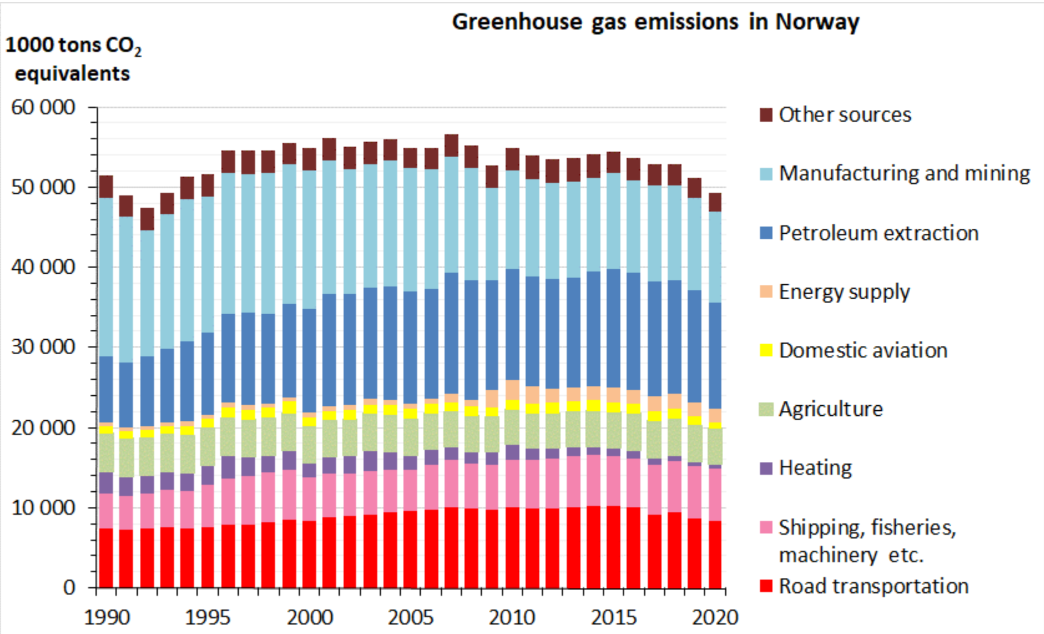

Figure E.1: Greenhouse gas emissions on Norwegian soil 1990–2020, by sector. Source: Statistics Norway.

The emission sources not covered by the European Union's Emissions Trading System (EU ETS) correspond, roughly speaking, to the four lowermost color codes in Figure E.1. Out of these, road transportation emissions constitute approximately 42 per cent.

For the non-ETS sectors, the European Effort Sharing Regulation (ESR) commits Norway to cut at least 40 percent of its emissions between 2005 and 2030. The Norwegian government has signaled even higher ambitions, not unlike the 'Fit for 55' package proposed by the European Commission.

Almost all GHG emissions in Norwegian road transportation consists of carbon dioxide (CO_2). An increasing share of these emissions is due to heavy-duty vehicles, mostly trucks and trailer tractors (Figure E.2).

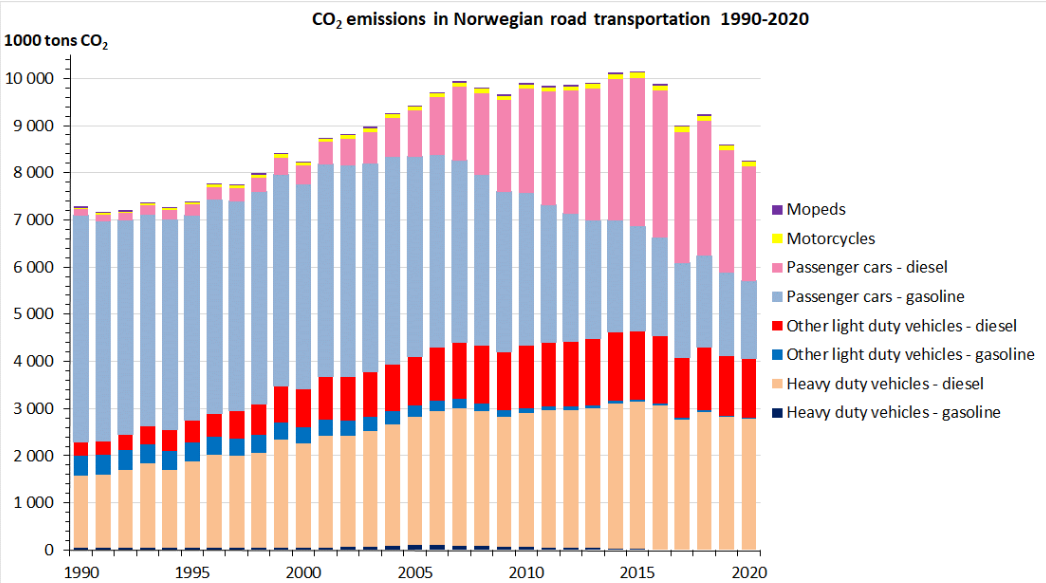

Figure E.2: CO_2 emissions on Norwegian roads 1990–2020, by vehicle class. Source: Statistics Norway.

An integrative modeling approach

To shed light on the policy options and requirements for radically reduced GHG emissions in road transportation at the 2030 and 2050 horizons, a comprehensive quantitative modeling exercise has been carried out. Three different model systems have been calibrated and run in interaction with each other. This includes the National freight transport model (NFM), a national energy system model (IFE-TIMES-Norway), and a vehicle stock-flow projection model (BIG).

The NFM model calculates transportation demand, by mode, commodity group and vehicle size, on a detailed geographical network level, however without differentiating between propulsion technologies. The IFE-TIMES-Norway model is a techno-economic optimization model for energy production and use, however without built-in algorithms reflecting the lags or inertia typical of infrastructure and technology development. The BIG model accurately calculates the time lag between innovations affecting new vehicle acquisitions and their penetration into the vehicle fleet, but does not include relationships that explain or predict technology choices in the market for new freight vehicles.

By soft-linking these models through a short iterative loop, we endeavor to exploit the strengths of the respective models, while alleviating their weaknesses. The NFM model provides input to IFE-TIMES-Norway on aggregate road freight demand until 2050. The latter model provides, in turn, input to the BIG projection model on the economically optimal split between energy technologies, given fuel and vehicle prices etc. BIG then calculates the lag between the market uptake of new technology and the corresponding changes in the vehicle fleet. These lags are then translated into growth constraints in the TIMES model, for more realistic medium and long term projections. This second step optimization in TIMES is used as input for a final vehicle stock-flow projection by means of BIG. Further details are provided in a companion paper by Rosenberg et al. (2022).

A scenario for sustainable road freight

To depict a scenario in which the targets laid down in European and Norwegian climate policy documents are reached, some fairly strong assumptions – some would say draconian – have been made. The price of diesel is assumed to roughly double between 2020 and 2030, due primarily to a surge in the fuel tax (Figure E.3). We assume both national and supranational fiscal incentives to be embedded in the fuel tax, i.e. we interpret the fuel tax to encompass the price of emission allowances following the possible introduction, in 2026, of an EU-wide cap-and-trade system for GHG emissions in buildings and transportation.

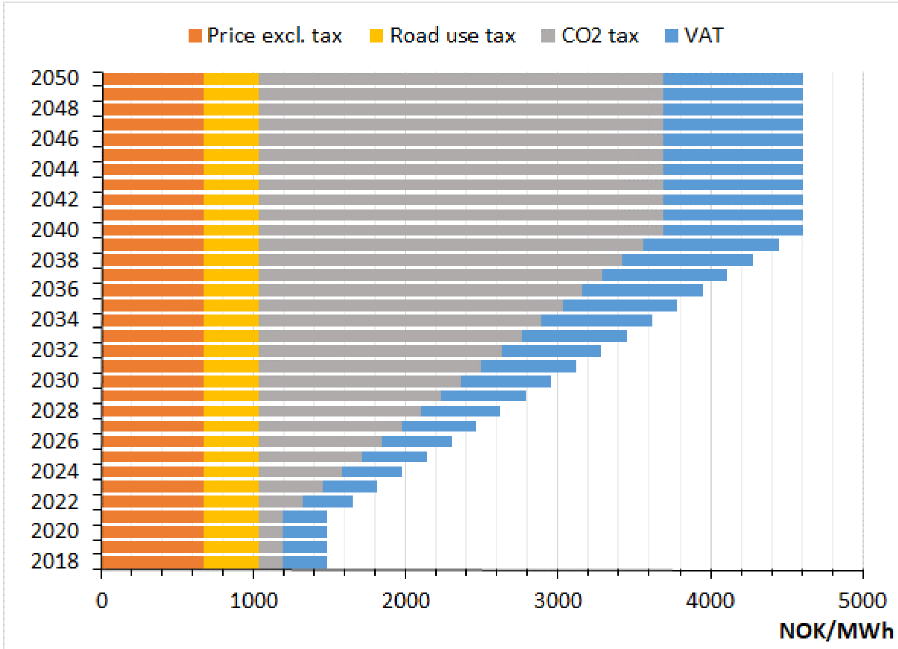

Figure E.3: Assumptions regarding the price and tax on diesel fuel 2018–2050.

The energy content of diesel is almost exactly 10 kWh per liter, and the exchange rate of the Norwegian currency is very close to NOK 10 = € 1. Thus the price per liter of diesel in euros, including value added tax (VAT), can be read off as 1/1000 of the stacked bars shown in the graph, i.e. as approximately € 1.50 in 2020, € 2.95 in 2030 and € 4.60 in 2050.

Such a price hike would affect the total cost of ownership (TCO) of light and heavy-duty commercial vehicles and tilt the competition in favor of zero emission powertrains, such as batteries, biomethane, or hydrogen fuel cells. These technologies are also assumed to benefit from increasing returns to scale at the 2030, 2040 and 2050 horizons. A simplified picture coming out of the TIMES model is shown in Figure E.4.

As of 2020, no powertrain is able to outdo the diesel engine in terms of TCO. But already in 2030, battery electric powertrains are projected to be more economical than diesel engines. From 2040 onwards, even hydrogen fuel cell electric vehicles (FCEVs) are projected to fare better than diesel. Biomethane driven trucks appear to have a window of opportunity between 2020 and 2030, however the supply of this energy carrier is too limited to provide more than a transitory solution. For the heaviest kind of trucks operating in long-haul freight, we assume the battery electric option to be less competitive, opening the field to fuel cell electric vehicles.

Figure E.4: Total costs of ownership per vehicle kilometer, relative to diesel vehicles, for four categories of road freight 2020–2050. Source: IFE-TIMES-Norway.

To support the transition to battery electric road freight, a massive investment in charging infrastructure will be needed. A rough picture of the foreseen aggregate capacity installed is shown in Figure E.5. The capacity will have to increase rapidly between 2025 and 2040.

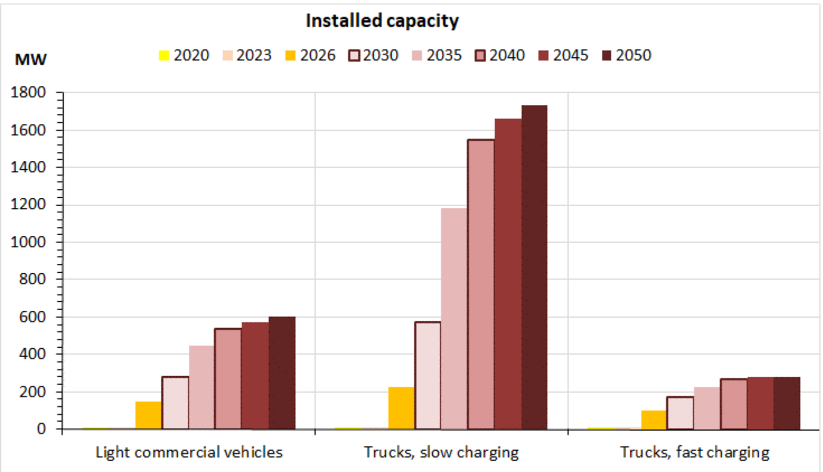

Figure E.5: Aggregate installed recharging capacity for battery electric freight vehicles. Source: IFE-TIMES-Norway.

The projected *flows* (market uptake) of new zero emission vehicles is shown by the dotted lines in Figure E.6. The base year for the projections is 2020, i.e. the values shown for 2021 are predictions rather than observations.

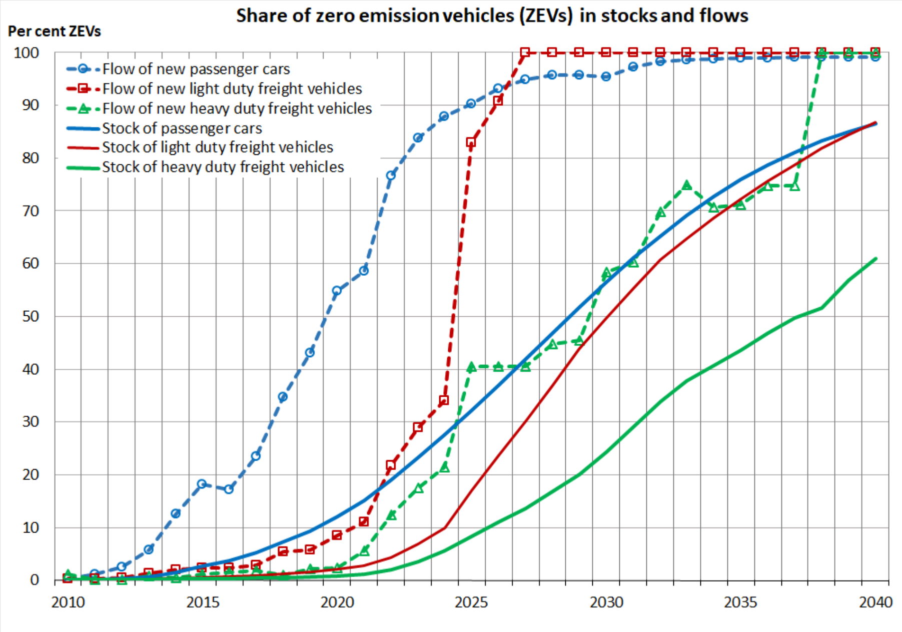

Figure E.6: Share of zero emission technology in vehicle flows and stocks 2010–2040, by vehicle class. Sources: IFE-TIMES-Norway and BIG modeling.

In the passenger car segment, on account of the comprehensive fiscal and regulatory incentives put in place in Norway, electrification is already vigorously underway, the battery electric vehicle (BEV) share reaching 64.5 percent of new vehicles already in 2021, with plug-in hybrid electric vehicles (PHEV) representing another 21.7 percent and ordinary (non-plug-in) hybrids (HEV) accounting for 5.5 percent. In our projections, we have, in line with the national budget white paper for 2021, set the BEV share of new passenger cars at 90 percent in 2025 and 95 percent in 2030.

In the light commercial vehicle (LCV) segment, the BEV share reached 16.1 percent of all new vehicles in 2021 – a bit 'ahead of schedule' compared to the TIMES prediction shown in Figure E.6.

In regard to new heavy-duty trucks, we are, however, behind schedule, the zero emission share being only 1.4 percent in 2021, versus the predicted 5.6 percent. The incidence of new zero emission trucks is projected to rise considerably by 2025, and even more so by 2030, partly on account of the sharpened mandates laid down in EU Regulation 2019/1242, which obliges truck manufacturers to bring down the average CO_2 emission rates of new vehicles brought to the EU market in 2025 and 2030, or else incur considerable 'excess emissions premiums'.

The solid lines in Figure E.6 represent the zero emission vehicle share of the *stock* of vehicles at the end of each year. The lag between new vehicle market uptake and the penetration into the stock can be read off as the horizontal distance between the two identically colored lines. At the 50 percent penetration level, the lag is seen to be 9 years for passenger cars, 6 years for LCVs and 8 years for trucks (including trailer tractors).

Considering these lags, an 'early warning' about the future GHG emissions of the vehicle fleet can be had by calculating the mean emission rates of new vehicles registered in any given year. Such figures are exhibited in Figure E.7. For trucks (and trailer tractors) we count emissions per ton kilometer, while for vans and automobiles the simpler ratio of CO_2 emissions per vehicle kilometer is used.

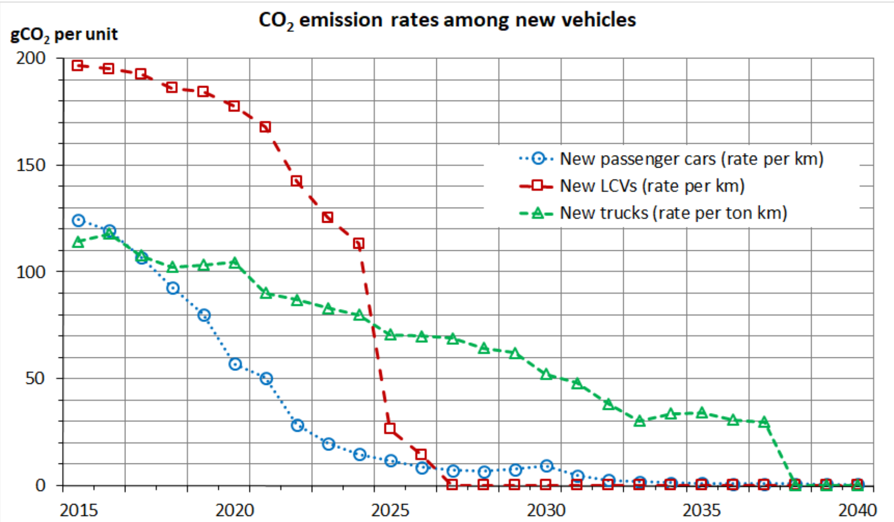

Figure E.7: Mean CO_2 emission rates of new vehicles 2015-2040. Source: IFE-TIMES-Norway and BIG modeling.

The observed and projected stocks of passenger cars, at each year-end from 2010 to 2050, are shown in Figure E.8. From 2029 onwards, the majority of automobiles in Norway are projected to have zero exhaust emissions.

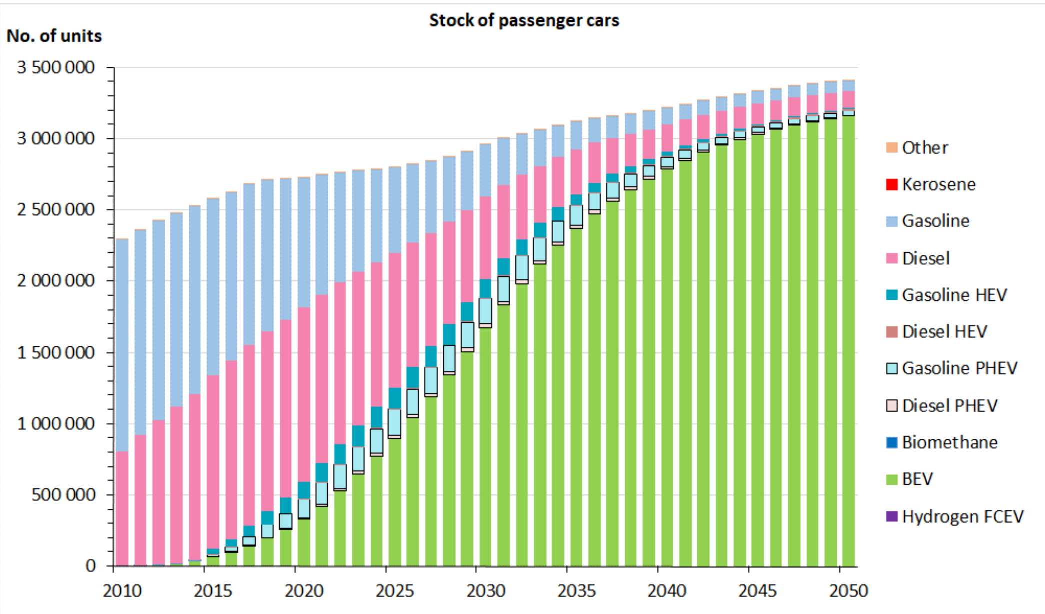

Figure E.8: Stocks of passengers cars at year-end 2010–2050, by powertrain. Source: BIG modeling.

Figure E.9 is a corresponding graph for light commercial vehicles. According to the projection, from 2031 more than half the LCVs will be zero emission vehicles.

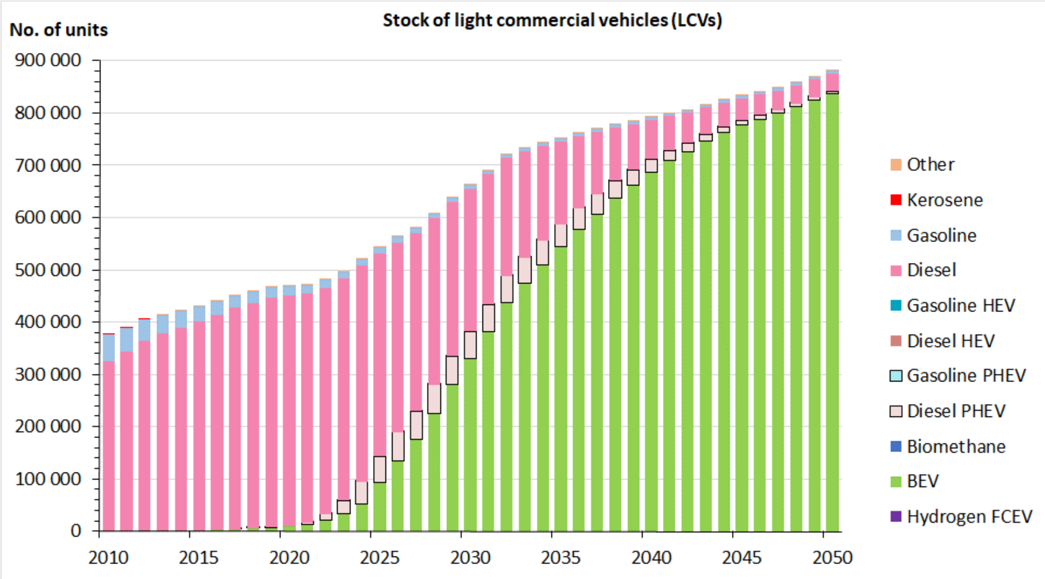

Figure E.9: Stocks of light commercial vehicles at year-end 2010–2050, by powertrain. Source: IFE-TIMES-Norway and BIG modeling.

Among heavy-duty freight vehicles, a similar transition will not take place until 2038 (Figure E.10).

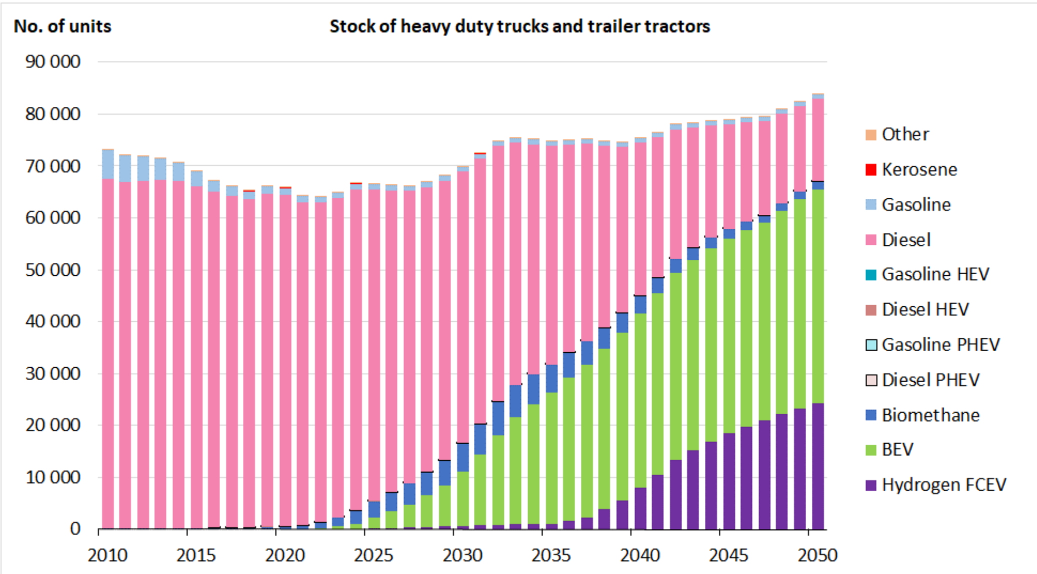

Figure E.10: Stocks of heavy-duty freight vehicles at year-end 2010–2050, by powertrain. Source: IFE-TIMES-Norway and BIG modeling.

The transition to zero emission vehicles will affect energy consumption – in the aggregate as well as broken down by energy carrier. The use of gasoline and diesel for road transportation purposes is projected to decrease by 94 percent between 2020 and 2050 (Figure E.11).

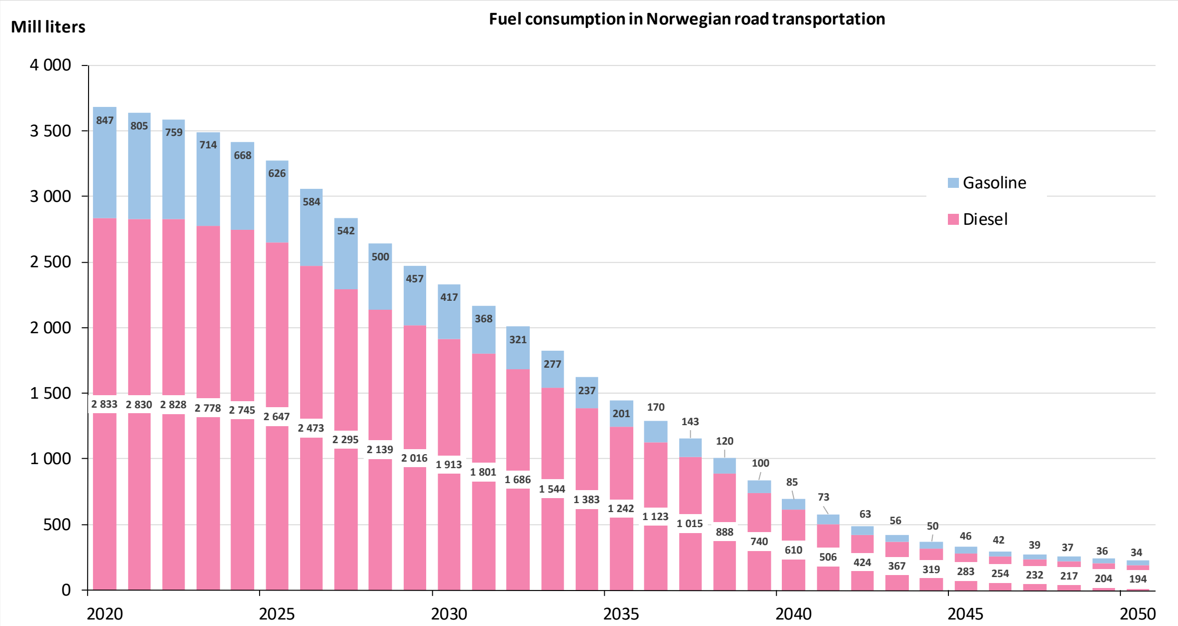

Figure E.11: Gasoline and diesel consumption on Norwegian roads 2020–2050. Source: IFE-TIMES-Norway and BIG modeling.

By 2050, less than 3 percent of the energy consumed by Norwegian freight vehicles will be fossil, according to our projection (Figure E.12). Since battery electric powertrains are more energy efficient than internal combustion engines, the total energy consumption in road transportation will go down.

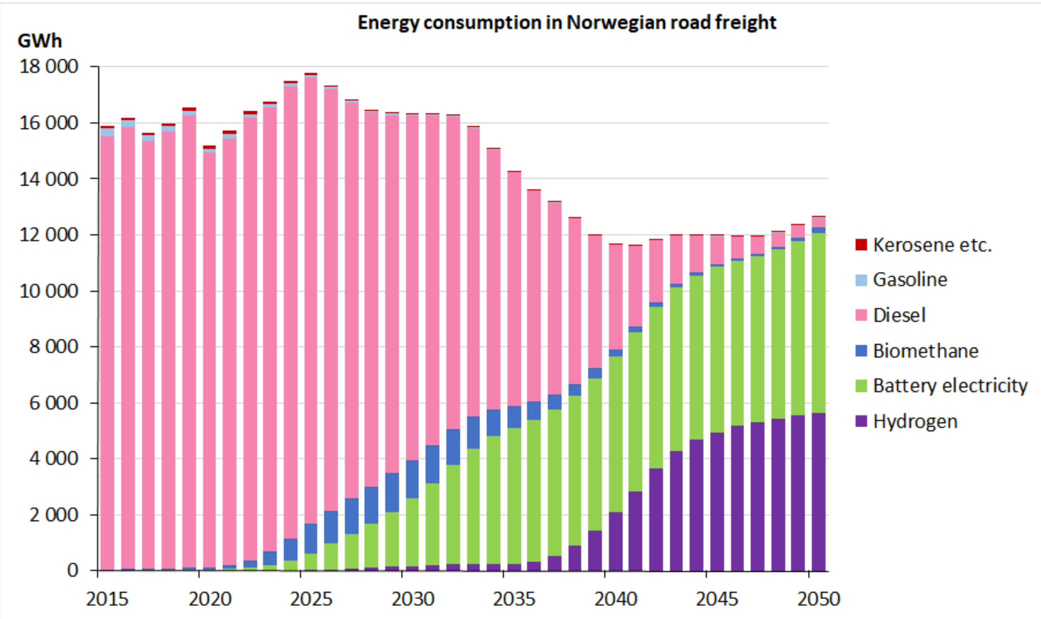

Figure E.12: Energy consumption in Norwegian road freight 2015–2050, by energy carrier. Source: IFE-TIMES-Norway and BIG modeling.

CO_2 emissions will come down, too, by 45 percent compared to the 2005 benchmark in 2030, assuming a constant 15 percent biofuel blend-in (Figure E.13).

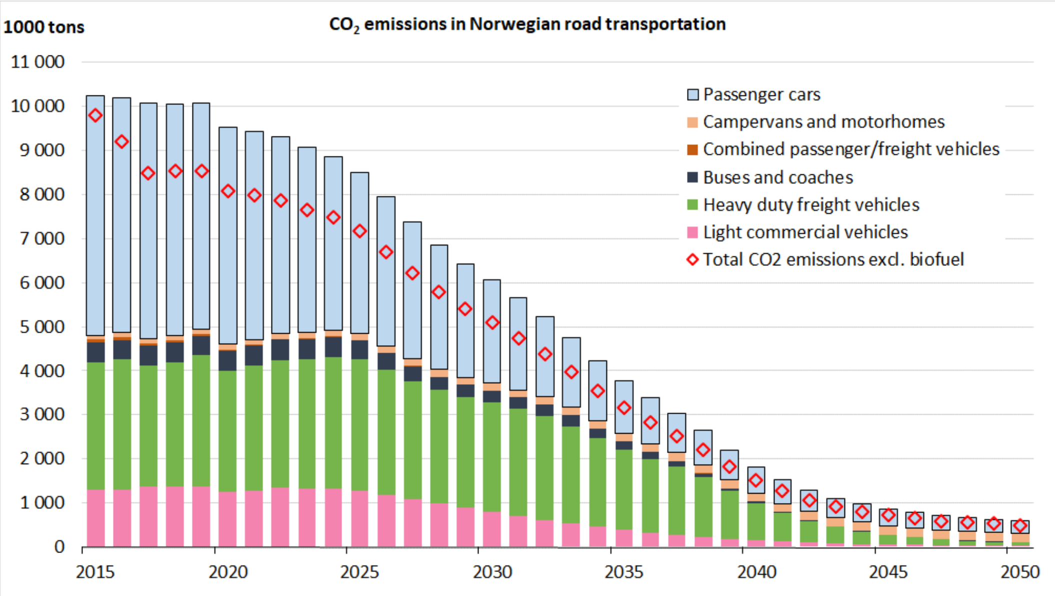

Figure E.13: CO_2 emissions on Norwegian roads 2015–2050, by vehicle class. Source: IFE-TIMES-Norway and BIG modeling.

Checkpoints for early warning

Integrating models for energy systems, transportation demand and stock-flow vehicle projections, we have drawn up a pathway conducive to large GHG emissions cuts in road travel and freight. The fiscal and regulatory policy assumptions forming the pathway are drastic, bordering on draconian. Fossil fuel prices are assumed to double by 2030 and triple by 2040, while zero emission energy technologies for heavy-duty vehicles are assumed to mature and exhibit quickly improving economies of scale at the 2030 and 2040 horizons.

To assess whether the pace of energy transition during the next 10 to 20 years is sufficient to achieve the greenhouse gas abatement goals, many of the assumptions underlying our scenario can be interpreted as checkpoints or early warning indicators. This applies to

- the prices of energy
- the vehicle costs of ownership (TCO)
- the roadside charging infrastructure
- the share of zero emission new vehicles
- the mean CO_2 emissions rate of new vehicles
- the aggregate fuel sales

By comparing, in the years ahead, the observed values of these indicators to the projections published in this report, one might get a clue as to whether greenhouse gas abatement in the road transportation sector is behind or ahead of schedule toward the 2030 and 2050 horizon targets.