Institute of Transport Economics
Norwegian Centre for Transport Research

Summary

Slow, fast or extra fast

Exploring decarbonization pathways for road transportation in Norway

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Relying on a stock-flow projection model of the Norwegian motor vehicle fleet, we explore certain pathways for decarbonization of domestic road transportation. In our most optimistic scenario, CO_2 emissions on the road will come down by 36 percent between 2005 and 2030, before taking account of biofuel use. To achieve a 50 per cent reduction, a biofuel blend-in of 27 percent in 2030 will suffice. The most pessimistic scenario suggests a mere 20 percent emissions cut between 2005 and 2030. In this case, to halve emissions, the biofuel blend-in would have to increase to 47 percent in 2030. A most important incentive is the exemption from value added tax (VAT) for battery electric vehicles (BEVs). Reintroducing VAT on BEVs will reduce their sales by an estimated 30 to 40 percent in 2030.

Supranational Climate Regulations Affect Road Transportation in Norway

Through its Sixth Assessment Report, the United Nations' Intergovernmental Panel on Climate Change (IPCC 2021) has substantiated our scientific knowledge about the ongoing anthropogenic global warming and climate change. By the Paris agreement (United Nations 2015), all nations have expressed their commitment to limit the increase in the global average temperature to less than 2 °C above pre-industrial levels, preferably to not more than 1.5 °C. The signatories have been invited to present, enforce and gradually reinforce their Intended Nationally Determined Contributions (INDC) towards the 1.5 °C target. On February 7, 2020, the Norwegian government announced its intention to reduce greenhouse gas (GHG) emissions by at least 50 to 55 percent between 1990 and 2030.

The European Union (EU) has implemented a cap-and-trade system for GHG emissions, known as the European Union Emissions Trading System (EU ETS). The system applies in the entire European Economic Area (EEA), thus covering Norway, Iceland and Liechtenstein in addition to EU Member States. It covers somewhere in excess of 40 percent of all GHG emissions on EEA soil, including intra-EEA aviation, most of the manufacturing industry and all power plants with an installed effect of at least 20 megawatts.

The sectors not covered by EU ETS are encompassed by the European Effort Sharing Regulation (EU 2018), including transportation, buildings, agriculture, non-ETS manufacturing, and waste. Of these, transportation is the largest in terms of GHG emissions. An estimated 25 percent of all GHG emissions in the EU originate from transportation. Close to one half of these emissions come from private cars.

The emissions targets in force for the various EU Member States follow from decision 2020/2126 of the European Commission. Emission "allowances" under the Effort Sharing Regulation are, to some extent, tradable among the Member States and also, within certain limits, transferable between the ETS and the non-ETS sector.

The Effort Sharing Regulation applies even in Norway and Iceland. In these countries, the regulation is enforced by the EFTA Surveillance Authority, which, in its decision of July

21, 2021, compels the two countries to cut their non-ETS emissions in 2030 by 40 and 29 percent, respectively, as compared to the 2005 level.

Also, to curb GHG emissions in transportation, the EU has mandated, since 2015, quantitative CO_2 emissions targets for new light-duty vehicles sold in EU Member States. For each calendar year from 2020 to 2030, EU Regulation 2019/631 (EU 2019a) specifies target CO_2 emission rates for each pool of manufacturers bringing new passenger cars or light commercial vehicles (LCVs, or vans) to the EEA market. The target for passenger cars in 2020 and 2021 is 95 gCO_2/km, as weighed together over all manufacturers selling cars in the EEA. For LCVs, the mean emissions target in 2021 is 147 gCO_2/km.

More lenient targets are set for manufacturers producing heavier than average vehicles. For passenger cars, the 2020/2021 target increases by 1 gCO_2/km for every 30 kilogram vehicle weight above the reference mass of 1379.88 kg. For each car and each gCO_2/km in excess of the target value (as evened out over all cars sold in a given calendar year), the manufacturer incurs an "excess emissions premium" of € 95. As a matter of phase-in, automakers were allowed to keep 5 percent of their cars out of the calculation in 2020. From 2021 onwards, every car sold counts towards the manufacturer's target.

Cars emitting less than 50 gCO_2/km by the NEDC[1] type approval test give rise to "supercredits", meaning that in 2020, each of these cars is counted twice. The supercredit multiplicator reduces from 2 to 1.67 cars in 2021 and to 1.33 cars in 2022. From 2023 onwards, each zero or low emission car is counted as one.

For LCVs, the reference mass is 1766.4 kg. For each individual manufacturer, the emissions target increases by 0.096 gCO_2/km with each kilogram higher mass.

For heavy-duty vehicles, EU Regulation 2019/1242 (EU 2019b) applies. The aim is to reduce the mean CO_2 emissions rate of new heavy-duty vehicles by 15 percent between 2019 and 2025, and by another 15 percent in 2030. For each manufacturer, targets are defined in terms of grams of CO_2 per payload ton kilometer (gCO_2/tkm), the payload and annual mileage being set in accordance with standardized values defined for the various subgroups of heavy-duty vehicles. The excess emissions premium for heavy-duty trucks has been set at € 4250 per gCO_2/tkm during 2025–2029 and at € 6800 from 2030 onwards.

National Norwegian Regulations and Incentives

In the years to come, the EU regulations are likely to substantially alter the supply of passenger cars, vans and trucks in the EEA, in terms, primarily, of its split between energy technologies (powertrains). Until 2019, however, the automobile markets of the various EEA countries have been affected first and foremost by the respective national taxation systems and fiscal incentives. A wide variety of automobile taxation systems is in place in Europe (Dineen et al. 2018, Hauff et al. 2018, Wappelhorst et al. 2018). Many EEA Member States levy some kind of registration or circulation tax; their structures and levels differ considerably. Some countries grant subsidies and bonuses to buyers of battery, fuel cell or hybrid electric cars. Other countries apply CO_2-graduated purchase or ownership taxes. Some, like France and Sweden (D'Haultfoeuille et al. 2014, Østli et al. 2021), practice feebates, i.e. bonus-malus systems, to enhance the market uptake of zero and low emission vehicles and discourage the acquisition of high emission cars.

[1] New European Driving Cycle – the type approval test procedure in use until 2019 in the European Union.

As of 2021 in Norway, there are a dozen different taxes, subsidies and regulations with a bearing on automobile technology choice and climate footprint:

- VAT, with exemptions for zero exhaust emission vehicles (ZEVs), i.e. battery and fuel cell electric cars (BEVs, FCEVs)
- One-off registration tax, calculated as the sum of three variable components, based on curb weight, CO_2 and NO_X emissions, with ZEVs totally exempt and plug-in hybrid electric vehicles (PHEVs) subject to a reduced weight component
- Annual ownership (circulation) tax, with lower rates for ZEVs
- Fuel tax, calculated as the sum of a CO_2 component and a road use component
- Road toll, with ZEVs exempt or enjoying at least 50 percent discount
- Reregistration tax on used vehicle transactions, with ZEVs exempt
- Ferry fares, differentiated between ZEVs and internal combustion engine (ICE) vehicles
- Parking fees, likewise differentiated
- Income tax on private use of company cars, likewise differentiated
- Government support for fast charging and hydrogen refueling facilities
- Free parking and recharging for BEVs in public parking lots
- Bus lanes open to ZEVs, with some exceptions

The VAT exemption for ZEVs is, along with certain less important tax breaks, contingent upon notification to the EFTA Surveillance Authority. In its decision of December 16, 2020, the Authority approved the prolongation of the zero VAT rating for ZEVs until December 31, 2022.

For LCVs, the same type of fiscal incentives applies, however with much lower rates. The zero VAT rating is of little consequence for LCVs, since most buyers are tax registered companies for which input VAT is deductible.

Heavy-duty trucks, buses and coaches are, apart from fuel tax and toll, subject to comparatively few and minor taxes.

The price of carbon

In a recent analysis by Fridstrøm (2021b), the carbon price implicit in the most important fiscal incentives for new passenger cars registered in Norway, coinciding with the first seven bullet points above, was assessed at somewhere in excess of € 1370 per ton CO_2 as of 2019. For LCVs and heavy-duty trucks, the corresponding carbon prices have been conservatively calculated at € 640 and € 300 per ton CO_2, respectively. Updated figures are presented in Fig. E.1. Note that to convert Norwegian kroner (NOK) into euros, one might, roughly speaking, divide by 10 (NOK 1 = ca. € 0.10).

To calculate the total price of carbon incurred by vehicle owners, one has to add the effects of EU Regulations 2019/631 and 2019/1242. Light-duty vehicle manufacturers that fail to reach their target will incur excess emissions premiums which translate into a carbon price of € 340 per ton CO_2, assuming a 200 000 km lifetime vehicle mileage and a 40 percent discrepancy between the real on-the-road rate of emissions and the NEDC laboratory measurements (Tietge et al. 2019).

For a representative long haul truck running 107 000 km per annum during 10 years with a payload of 26.5 tons, the premiums applicable in 2025 and 2030 translate into carbon prices of € 150 and € 240 per ton CO_2, respectively.

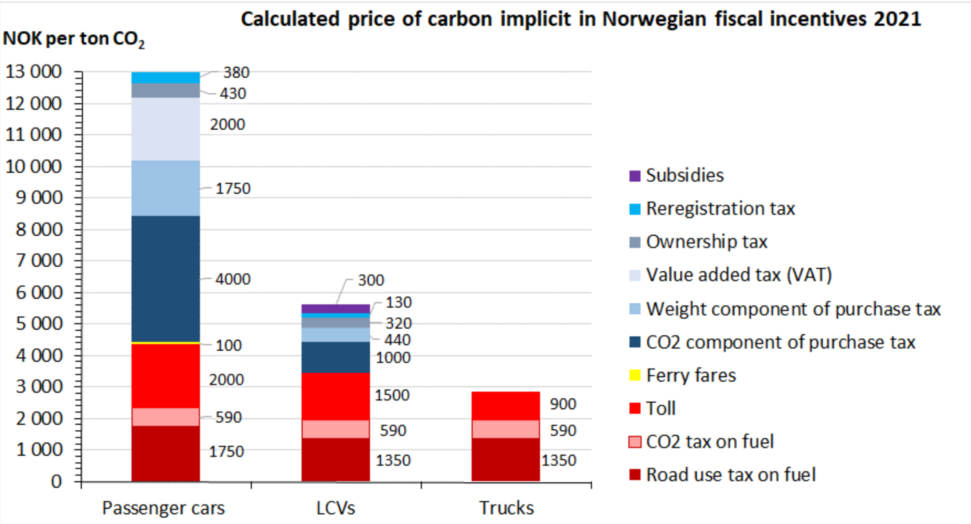

Figure E.1: Calculated carbon prices implicit Norwegian fiscal incentives for zero and low emission vehicles. As of September 1, 2021, € 1 = NOK 10.27.

Three Scenarios for Vehicle Decarbonization

To explore the prerequisites and potential for greenhouse gas mitigation in Norwegian road transportation, a set of scenario projections have been developed, relying on the BIG stock-flow vehicle fleet model developed by Fridstrøm & Østli (2016, 2021)[2].

A total of three main scenarios, set out in Table E.1, have been defined.

Table E.1: Main scenario projections.

Label/pace	**New passenger cars**	**New light commercial vehicles (LCVs)**	**New heavy-duty freight vehicles**	**Carbon price in 2030, 2040 (Euros/tCO_2)**
Slow decarbonization	Technology driven market, constant tax rates	Sales trend extrapolated	Modest innovation	Ca. 200, Ca. 300
Fast decarbonization	Increased CO_2 taxes on fuel and ICE vehicles	Reaching targets in EU-regulation 2019/631	Reaching targets in EU-regulation 2019/1242	Ca. 500, Ca. 1000
Extra fast decarbonization	90 % zero emission new cars in 2025, 95% i 2030	45 % zero emission new vans in 2025, 78 % in 2030	Ca. 50 % zero emission new trucks in 2030	Unspecified

The first two of these scenarios have been developed in two versions – one in which the VAT exemption for ZEVs is prolonged indefinitely, and one in which VAT is imposed gradually during 2023–2027, being augmented by 5 percentage point each year. A full 25 percent VAT is, in other words, assumed to apply from 2027 onwards.

[2] See also Østli et al. (2017, 2021), Fridstrøm et al. (2016) and Fridstrøm (2017).

Passenger cars

Figures E.2 through E.5 show the observed and projected composition of new automobile acquisitions during 2010–2050, according to the slow or fast decarbonization scenarios with or without VAT exemption for ZEVs. In Fig. E.6, the extra fast decarbonization scenario is shown.

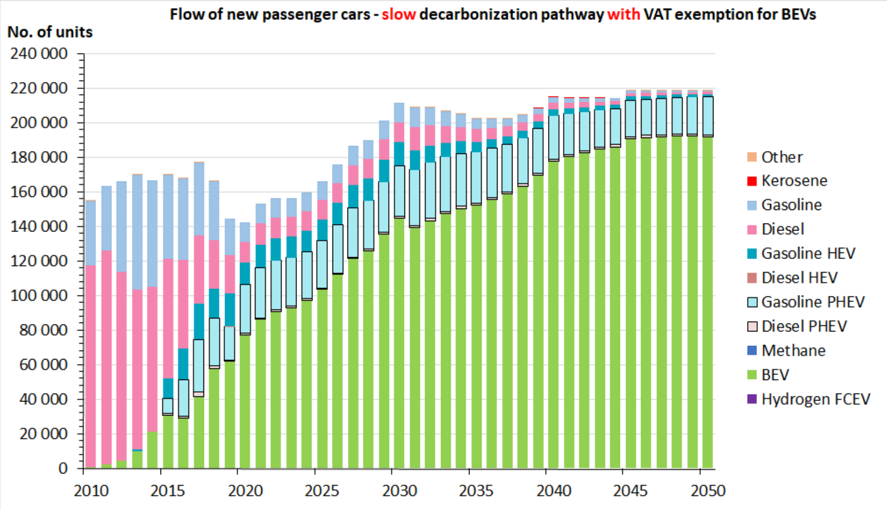

Figure E.2: Annual flows of new passenger cars registered 2010–2050, according to ***slow*** *decarbonization pathway* ***with*** *VAT exemption for ZEVs.*

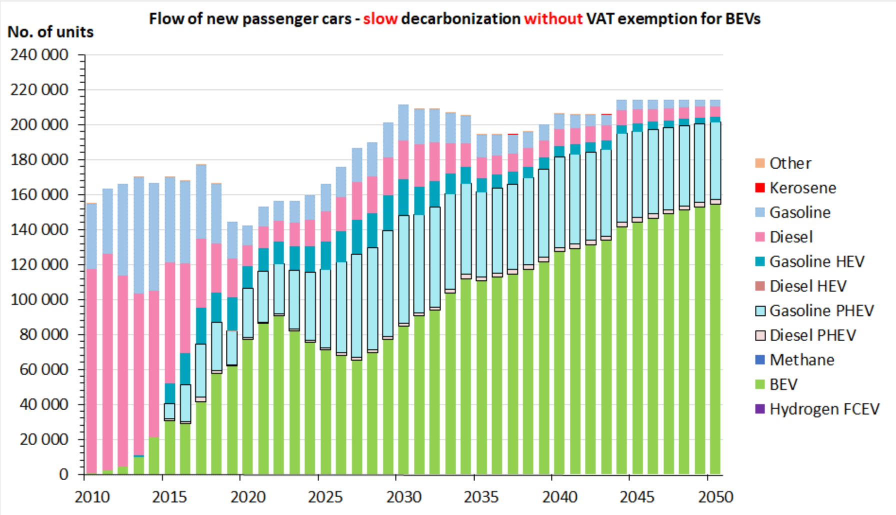

Figure E.3: Annual flows of new passenger cars registered 2010–2050, according to ***slow*** *decarbonization pathway* ***without*** *VAT exemption for ZEVs.*

The slow decarbonization pathway with continued VAT exemption for battery and fuel cell electric cars, shown in Fig. E.2, is our "business-as-usual" scenario. As far as fiscal incentives are concerned, nothing much changes. The market share of battery electric vehicles (BEVs) does, however, continue to grow at a moderate pace, in response to an assumed 3 percent annual decline in the real price of BEVs and an assumed 3 percent general improvement in range. With this input, the BEV market share reaches almost 69 percent in 2030, while plug-in hybrid electric vehicles (PHEVs) constitute 14 percent, according to our generic discrete choice model of automobile purchase (Fridstrøm & Østli 2021).

The gradual introduction of VAT on BEVs will, however, according to the same nested logit model, lead to a slump in demand between 2022 and 2027 (Fig. E.3). In this case, no more than 40 percent of all new cars registered in 2030 will be BEVs.

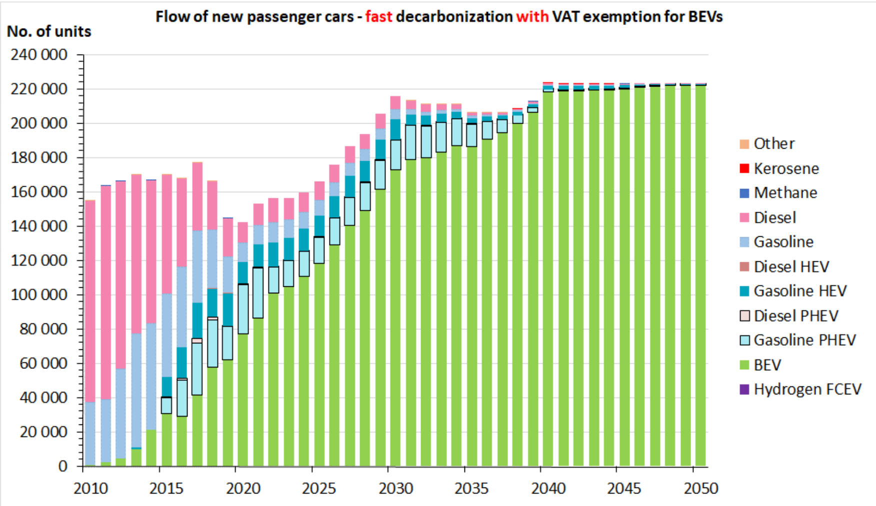

Figure E.4: Annual flows of new passenger cars registered 2010–2050, according to ***fast*** *decarbonization pathway* ***with*** *VAT exemption for ZEVs.*

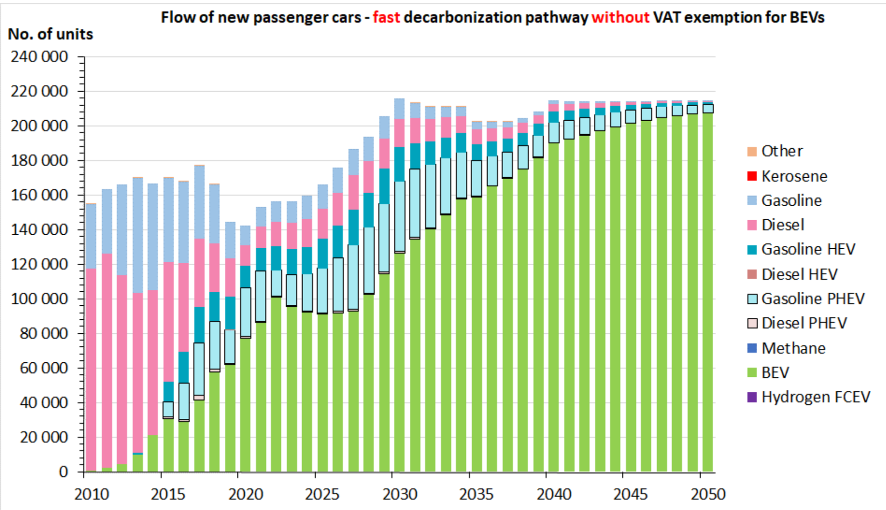

Figure E.5: Annual flows of new passenger cars registered 2010–2050, according to ***fast*** *decarbonization pathway* ***without*** *VAT exemption for ZEVs.*

In the fast decarbonization pathway, strengthened incentives apply. From 2022 onwards, the special tax advantage of PHEVs is called off, thus halving their market share while enhancing that of BEVs. Also, during 2023–2030, the CO_2 component of the one-off registration tax is increased by 10 percent each year. Finally, the fuel price is assumed to grow by around 28 percent between 2019 and 2030, in response to a higher CO_2 tax. Taken together, these fiscal measures lead to an estimated 80 percent BEV market share in 2030, presuming that the VAT exemption be prolonged (Fig. E.4).

In the case, however, where BEVs become subject to VAT, their market share in 2030 is projected to reach 58.5 percent only (Fig. E.5).

Finally, the extra fast decarbonization pathway is depicted in Fig. E.6. In this scenario, BEV market shares have been fixed exogenously, so as to coincide with the assumptions used in the Norwegian government's white paper on the National Budget 2021. Here, the BEV market share is set at 90 percent in 2025 and at 95 percent in 2030.

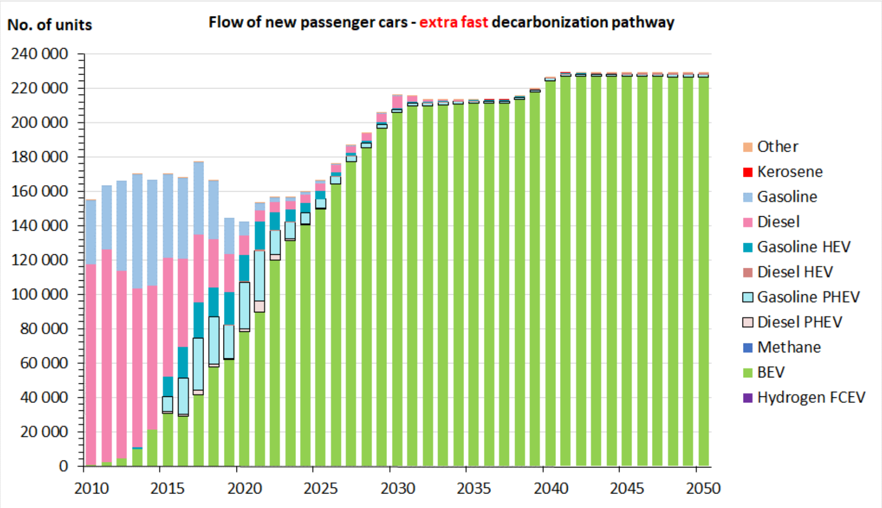

Figure E.6: Annual flows of new passenger cars registered 2010–2050, according to ***extra fast*** *decarbonization pathway.*

While Figs. E.2 through E.6 depict the *flows* of new passenger cars under the various scenarios, Figs. E.7 and E.8 show the *stocks* of cars resulting from two rather different decarbonization pathways.

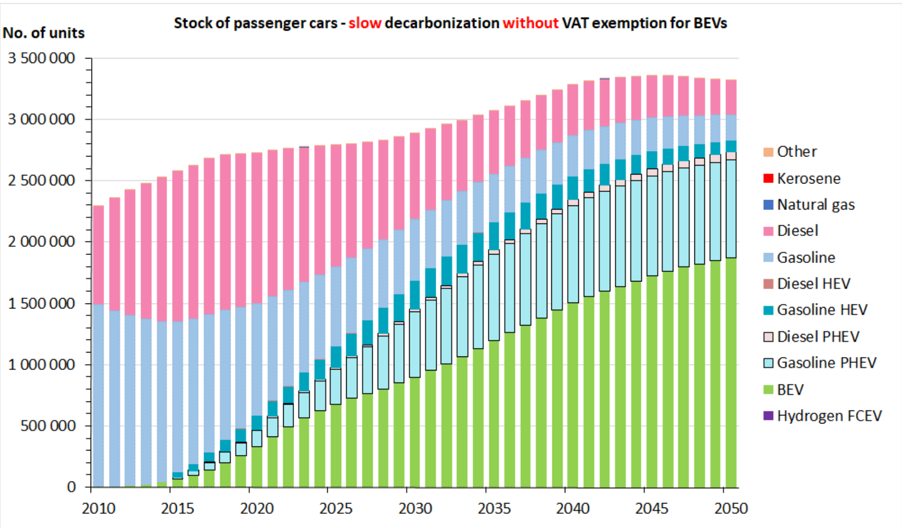

Figure E.7: Stocks of passenger cars 2010–2050, by energy technology, according to ***slow*** *decarbonization pathway* ***without*** *VAT exemption for BEVs.*

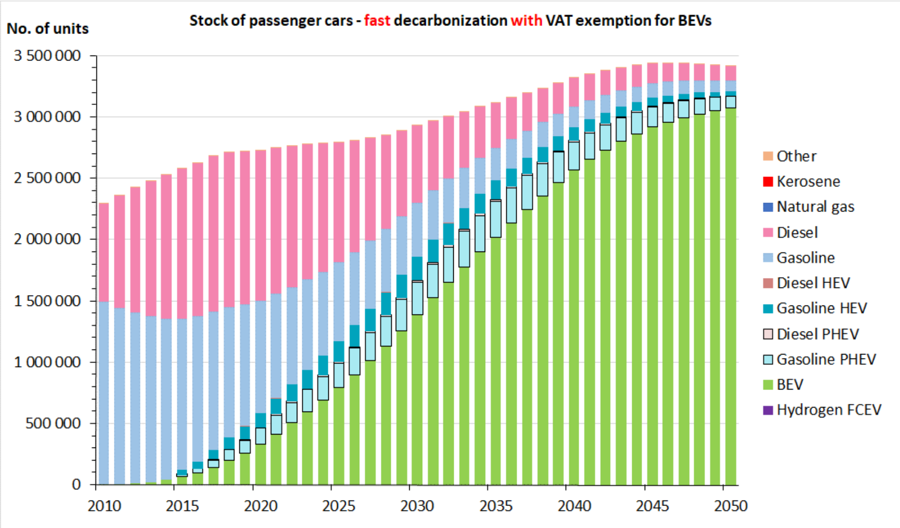

Figure E.8: Stocks of passenger cars 2010–2050, by energy technology, according to ***fast*** *decarbonization pathway* ***with*** *VAT exemption for BEVs.*

The resulting energy consumption by passenger cars according to the five pathways examined is shown in Fig. E.9. As internal combustions engines (ICE) are replaced by the more efficient electric motors, large energy savings will be reaped. In the long run, the aggregate energy consumption of automobiles may be reduced by as much as 70 percent from the 2018 level.

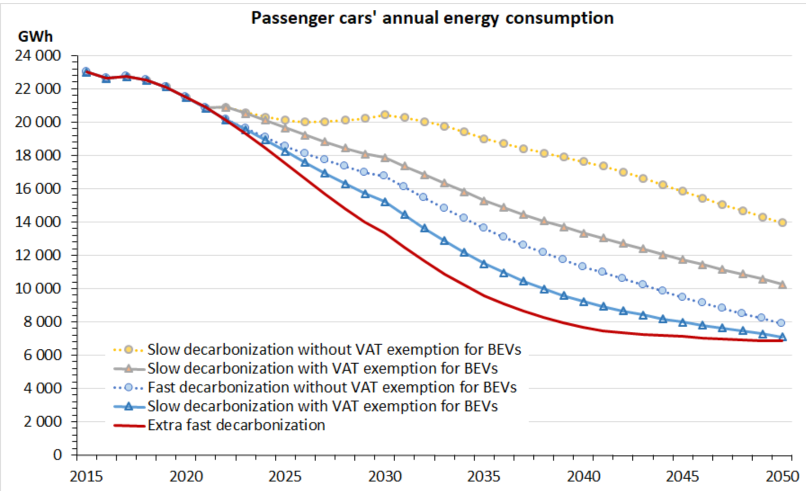

Figure E.9: Aggregate energy consumption by passenger cars in Norway 2015–2050, under five different decarbonization pathways.

The CO_2 emissions from passenger cars are shown in Fig. E.10. In the fast decarbonization scenario with VAT exemption for BEVs, emissions are down by 48 percent between 2018 and 2030, and by 93 percent at the 2050 horizon, before taking account of increased biofuel use.

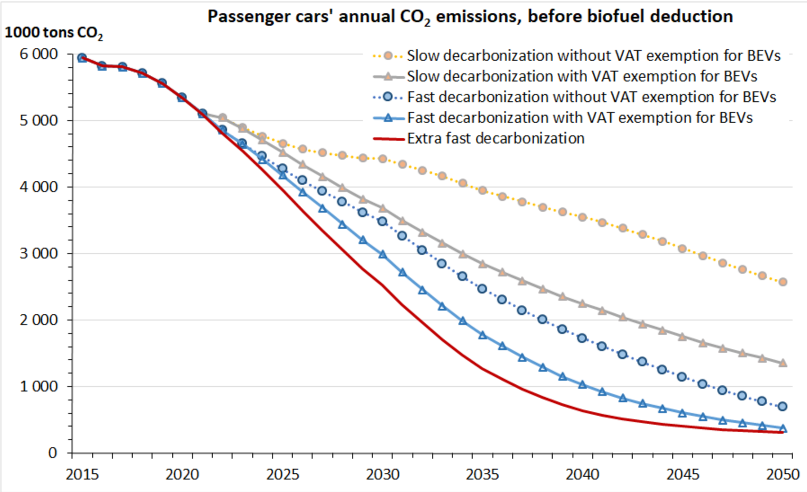

Figure E.10: Aggregate CO_2 emissions from passenger cars in Norway 2015–2050, before deduction for biofuel, under five different decarbonization pathways.

Light Commercial Vehicles

The assumed development of LCV powertrain market shares under the various scenarios is shown in Figs. E.11 and E.12. Note that for light and heavy-duty commercial vehicles, we do not distinguish between "fast" and "extra fast" decarbonization pathways. Nor do we develop different pathways with and without VAT exemption, since this exemption has virtually no importance for commercial vehicles.

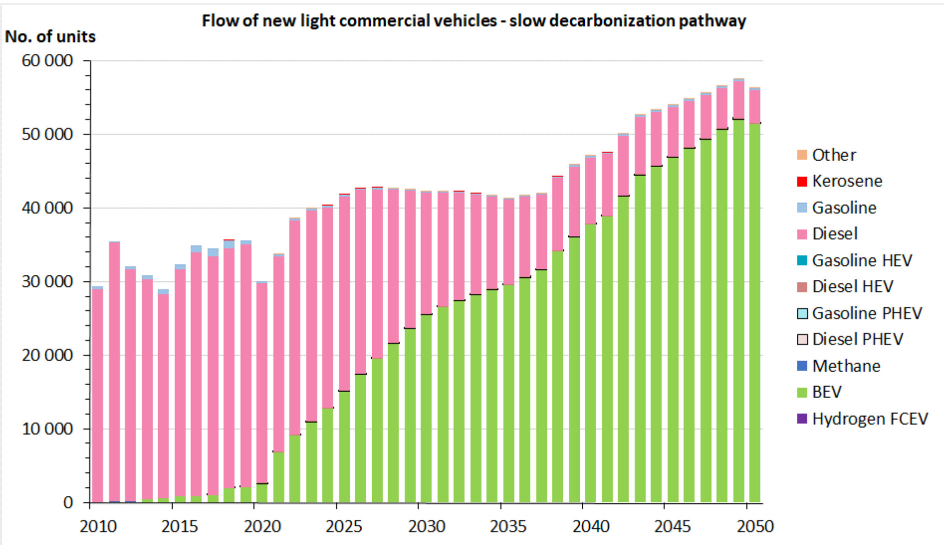

Figure E.11: Annual flows of new light commercial vehicles registered 2010–2050, according to **slow** *decarbonization pathway.*

Under the slow decarbonization scenario, the BEV market share grows steadily, but at a moderate pace, reaching 36 percent in 2025 and 60 percent in 2030 (Fig. E.11).

This results in a 12 percent share of the stock in 2025, and 27 percent in 2030 (Fig. E.13).

A somewhat brisker pace is foreseen in the fast decarbonization scenario (Fig. E.12). A 43 percent market share in 2025 and a 74 percent share in 2030 result in BEV stock penetration rates of 13 and 32 percent, respectively, in 2025 and 2030 (Fig. E.14).

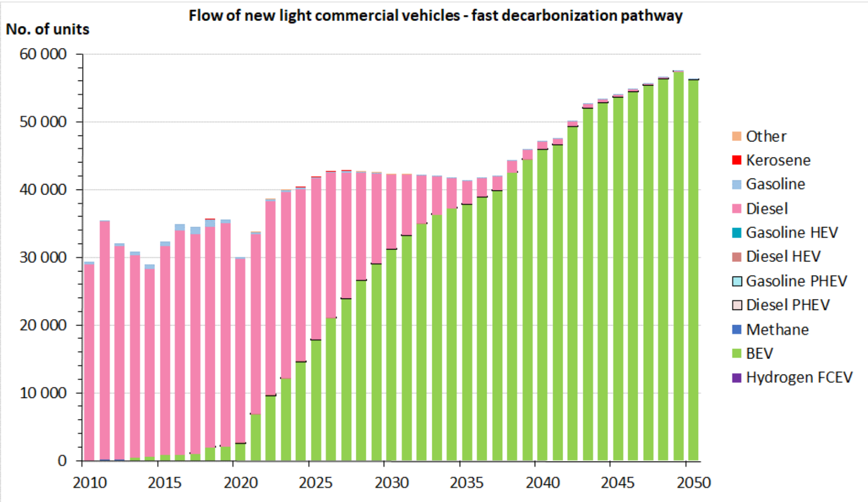

Figure E.12: Annual flows of new light commercial vehicles registered 2010–2050, according to ***(extra) fast*** *decarbonization pathway.*

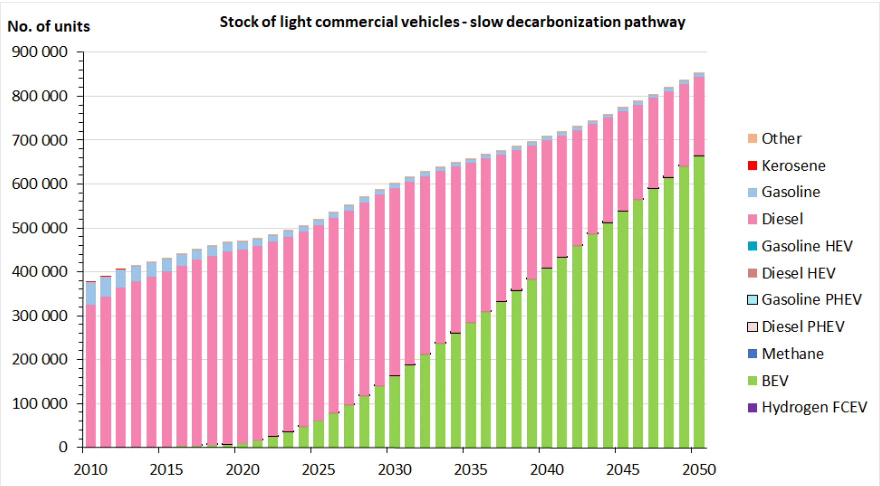

Figure E.13: Stocks of light commercial vehicles 2010–2050, by energy technology, according to ***slow*** *decarbonization pathway.*

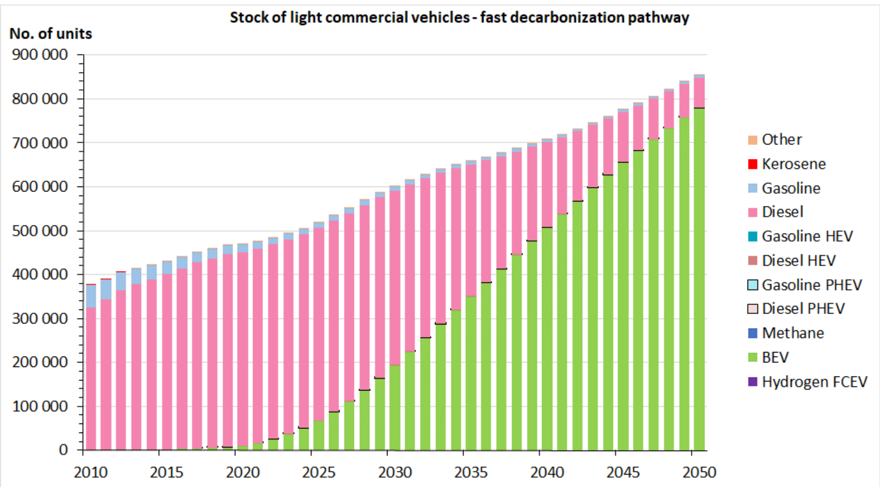

Figure E.14: Stocks of light commercial vehicles 2010–2050, by energy technology, according to ***(extra) fast*** *decarbonization pathway.*

Heavy-Duty Freight Vehicles

The postulated inflow of new heavy-duty freight vehicles, i.e. trucks and tractor units, under the slow decarbonization scenario is shown in Fig. E.15. Diesel ICE vehicles are assumed to dominate the new vehicle market well into the 2040s. Battery electric vehicles obtain a market share of 12 percent in 2030. An even smaller share – 2.5 percent in 2030 – is captured by vehicles powered by methane, be it in the form of CNG, CBG, LNG or LBG.

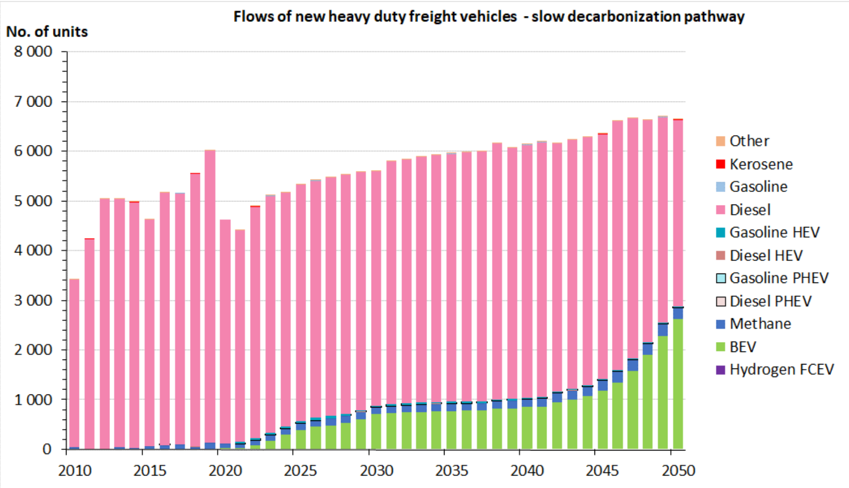

Figure E.15: Annual flows of new heavy-duty freight vehicles registered 2010–2050, according to ***slow*** *decarbonization pathway.*

In the fast decarbonization scenario, however, the market shares of methane, battery electric and fuel cell electric powertrains reach 17, 27 and 6 percent, respectively, in 2030 (Fig. E.16). By 2040, these zero emission technologies are assumed to constitute 89 percent of all new heavy-duty freight vehicle registrations.

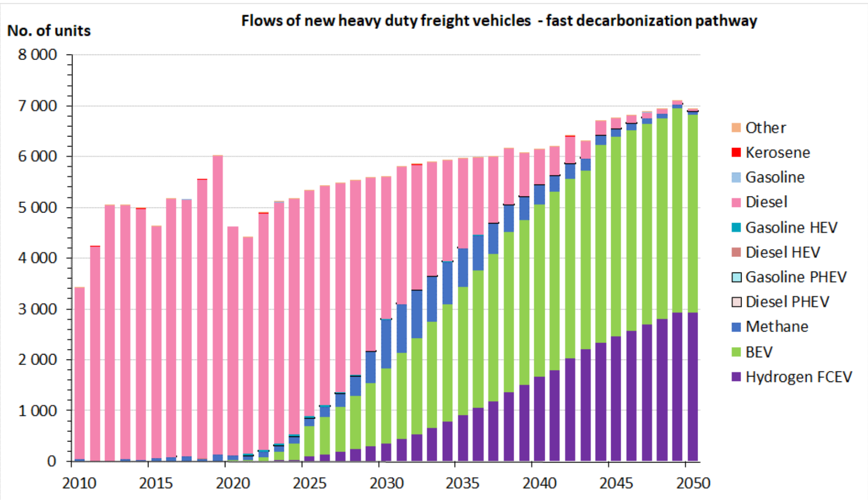

Figure E.16: Annual flows of new heavy-duty freight vehicles registered 2010–2050, according to ***(extra) fast*** *decarbonization pathway.*

But the stock of vehicles changes more slowly (Figs. E.17 and E.18). Even in the fast decarbonization scenario, zero emission vehicles constitute no more than 15 percent of the heavy-duty freight vehicle fleet in 2030, and 54 percent in 2040.

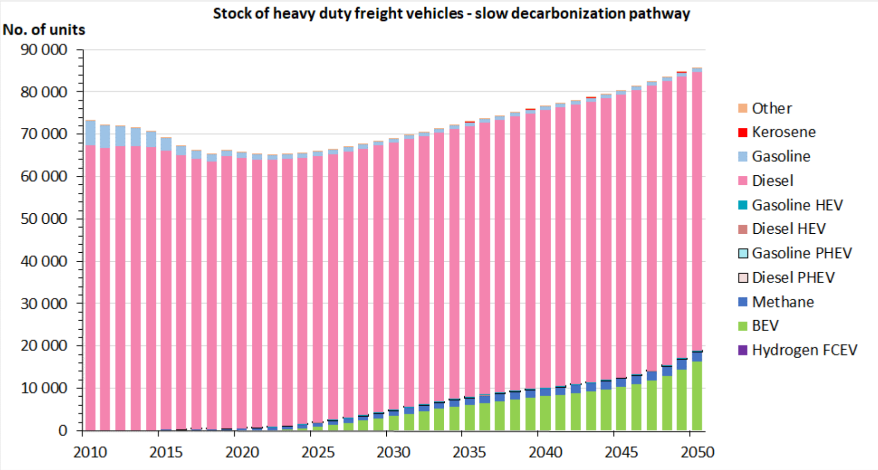

Figure E.17: Stocks of heavy-duty freight vehicles 2010–2050, by energy technology, according to **slow** *decarbonization pathway.*

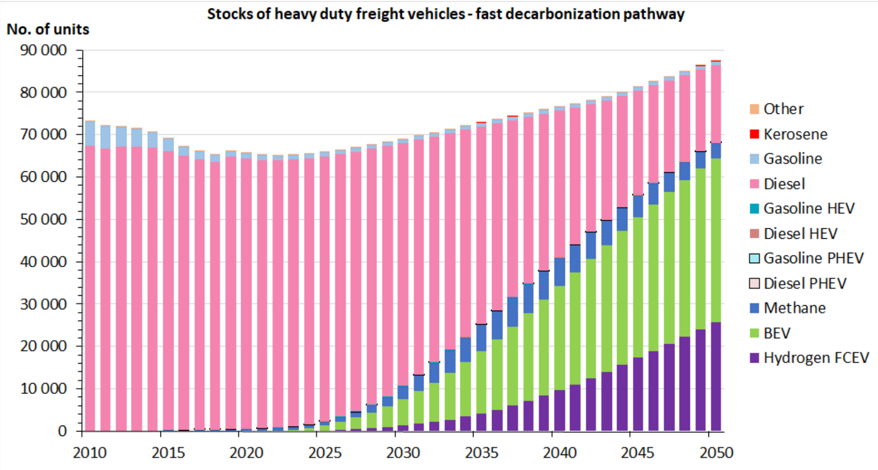

Figure E.18: Stocks of heavy-duty freight vehicles 2010–2050, by energy technology, according to **(extra) fast** *decarbonization pathway.*

Buses and Coaches

Buses and coaches represent a small share of the vehicle stock, less than 0.5 percent, and around 5 percent of the CO_2 emissions. An even smaller share of the emissions is due to campervans and motorhomes. We therefore treat these vehicle categories more summarily than the rest. For buses and coaches, a general pathway common to all scenarios has been developed, resulting in a fleet development as shown in Fig. E.19. Methane and battery electric powertrains are assumed to gradually obtain larger market shares, much in line with observed recent trends.

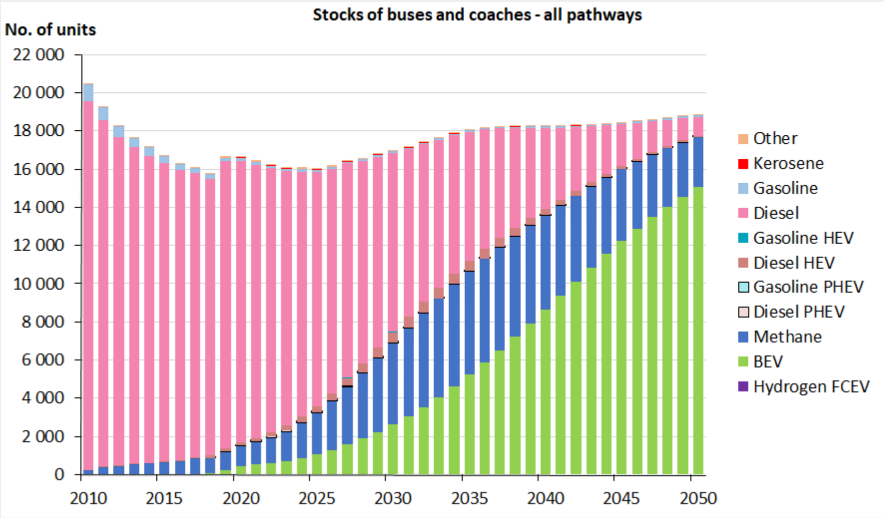

*Figure E.19: Stocks of buses and coaches 2010–2050, by energy technology, according to **all** pathways.*

Cross-Cutting Energy Perspective

In Fig. E.9, we showed how the five different scenarios developed would affect the energy consumption of passenger cars. In Fig. E.20, we provide a more comprehensive picture, encompassing all types of vehicle (except motorcycles, ambulances, snowmobiles and other off-road vehicles, ignored by our stock-flow projection model).

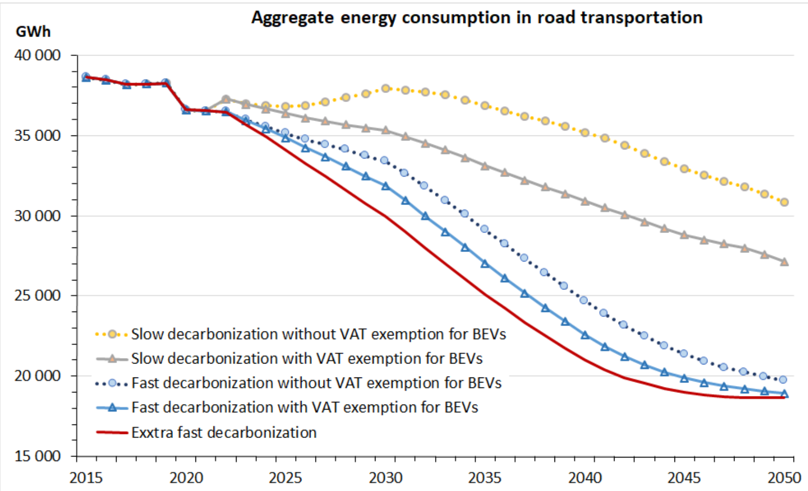

Figure E.20: Aggregate energy consumption in road transportation in Norway 2015–2050, under five different decarbonization pathways.

All scenarios lead to considerable energy savings in the long run, in spite of the projected traffic growth. But in the slow decarbonization pathway without VAT exemption, significant energy savings will probably not occur until the 2040s. The fast and extra fast decarbonization pathways, in contrast, are consistent with a 13 to 22 percent energy conservation by 2030, compared to 2019, and a full 48 to 51 percent reduction at the 2050 horizon.

In Figs. E.21 and E.22 we show, in somewhat greater detail, how the road energy demand will shift from diesel and gasoline to other – presumably more sustainable – energy carriers. There are, however, considerable differences between our most pessimistic, slow decarbonization pathway and the more optimistic, fast innovation scenarios.

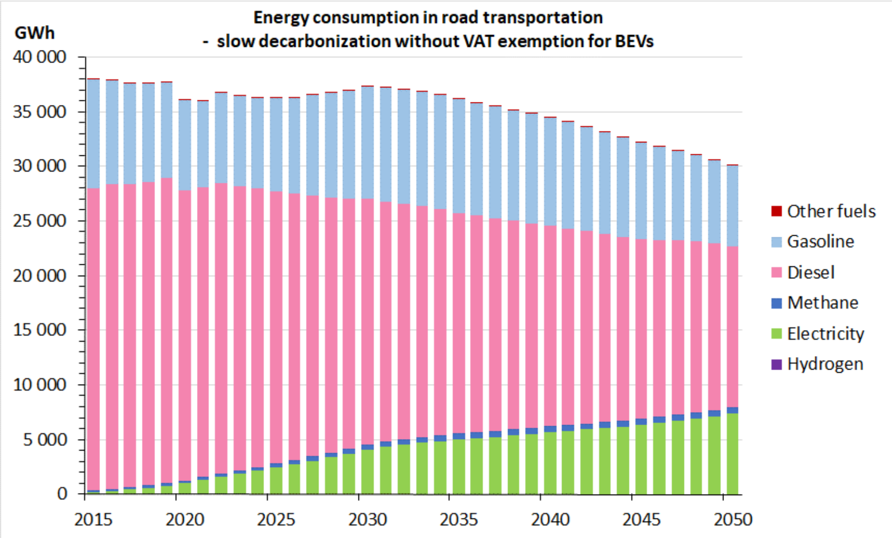

Figure E.21: Energy consumption in road transportation in Norway 2015–2050, by energy carrier, under the slow decarbonization scenario without VAT exemption for BEVs.

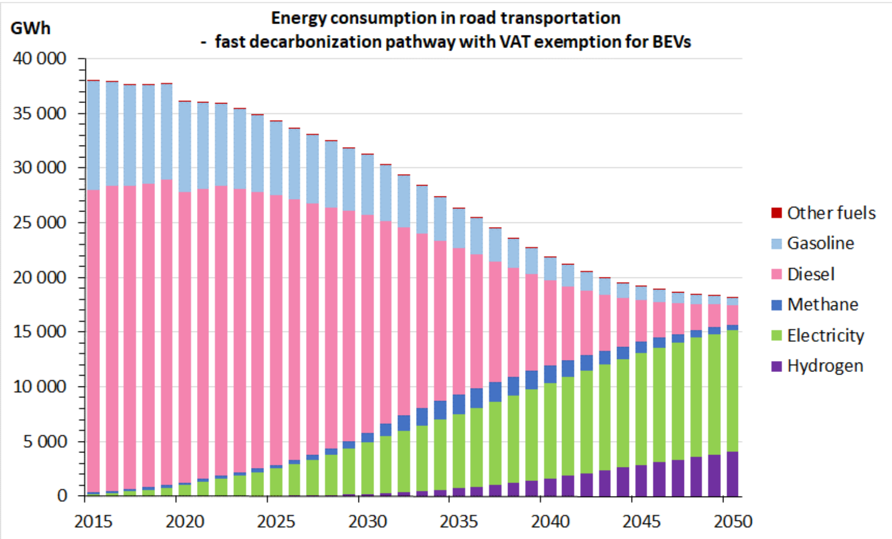

Figure E.22: Energy consumption in road transportation in Norway 2015–2050, by energy carrier, under the fast decarbonization scenario with VAT exemption for BEVs.

Climate Footprint

Aggregate carbon dioxide emissions from Norwegian road transportation are summed up in Fig. E.23. Under the fast decarbonization scenario, emissions are projected to come down by 30 percent between 2019 and 2030, assuming that the biofuel share will remain the same throughout the period. The extra fast decarbonization pathway provides a somewhat larger cut, viz. 35 percent, while the "business-as-usual" scenario promises no more than an 18 percent cut.

In Figs. E.24 and E.25, emissions are broken down by vehicle category. In the most pessimistic scenario, emissions from heavy-duty freight vehicles actually increase. But the fast decarbonization scenario with VAT exemption delivers cuts within every vehicle class.

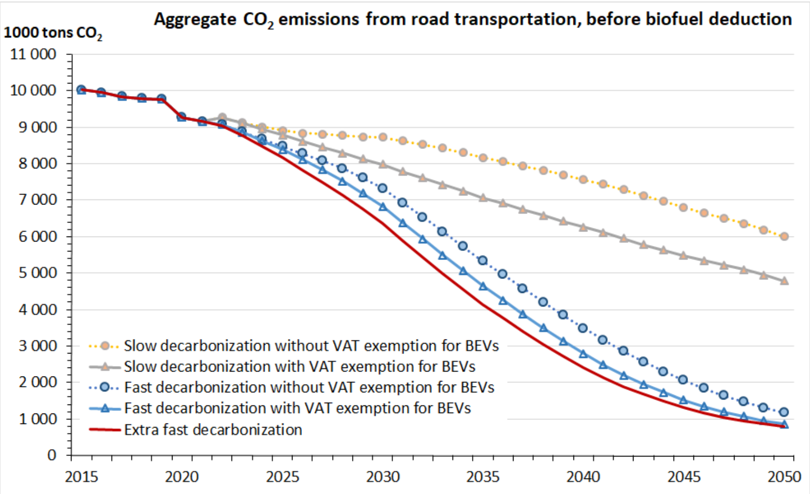

Figure E.23: Aggregate CO_2 emissions from road transportation in Norway 2015–2050, under five different decarbonization pathways.

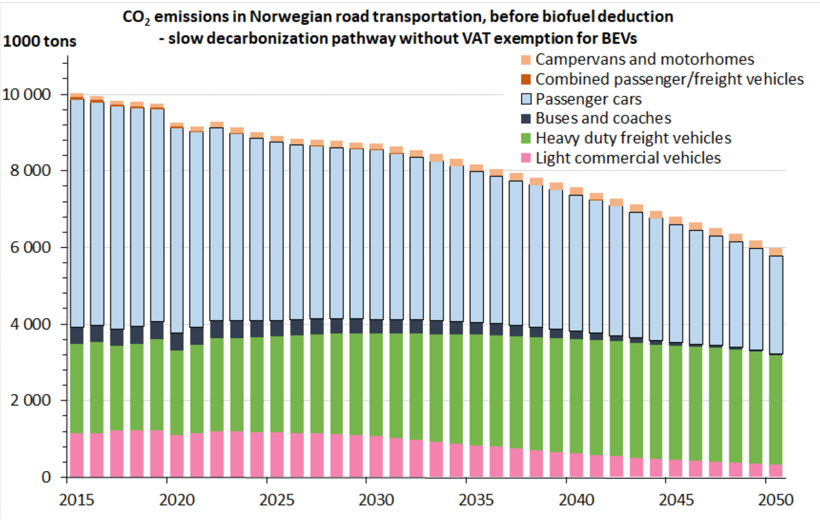

Figure E.24: Aggregate CO_2 emissions from road transportation in Norway 2015–2050, by vehicle category, under the slow decarbonization scenario without VAT exemption for BEVs.

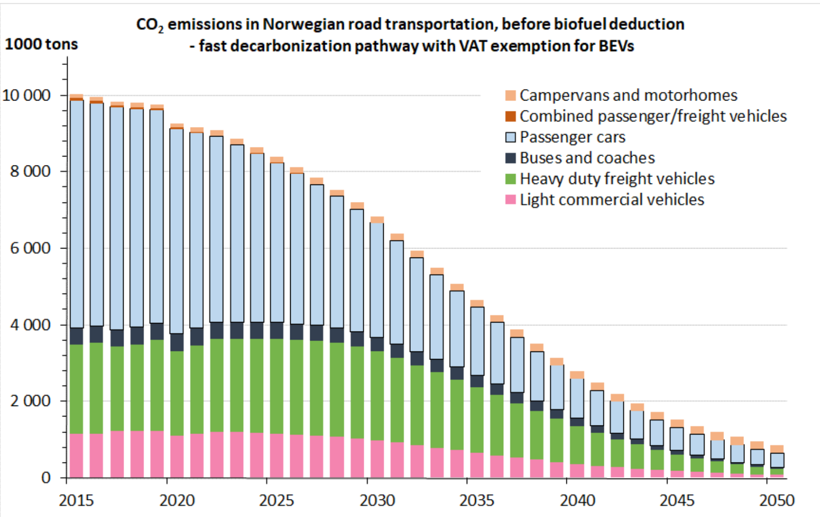

Figure E.25: Aggregate CO_2 emissions from road transportation in Norway 2015–2050, by vehicle category, under the fast decarbonization scenario with VAT exemption for BEVs.

Caveats and Qualifications

The scenarios developed by our stock-flow vehicle fleet projection model should not be interpreted as unconditional predictions or forecasts. Input parameters have been fixed through a process of informed judgment or conjecture. These assessments are subject to uncertainty. In an attempt to span the space of potential future outcomes, a set of widely differing pathways have been calculated.

For passenger cars, the flows of new acquisitions up until 2030 have been projected by means of a discrete choice econometric model estimated on a comprehensive disaggregate data set covering almost all new automobile transactions between 2003 and 2019 in Norway. But as in any model, there are numerous sources of error present, the size and direction of which are hard to tell.

For light and heavy duty commercial vehicles, as well as for passenger cars in the extra fast decarbonization scenario, new vehicle acquisitions have been fixed exogenously, based on trend extrapolation and/or an interpretation of the political, economic and technological outlook.

Synthesis and Policy Conclusions

The vehicle fleet is an inert matter. It changes slowly. It may take 8–25 years, in some cases even longer, before energy technological innovations affecting the flow of new vehicles have penetrated similarly into the stock. This energy transition time lag would tend to increase with the speed of innovation and with the target level of penetration, but decrease with the velocity of vehicle turnover.

Business-as-usual, understood as a continuation of present-day fiscal and regulatory incentives, is unlikely to produce the cuts in greenhouse gas (GHG) emissions from road transportation that are foreseen in the Norwegian government's planning documents. Increased use of (presumably climate neutral) biofuel may, however, in principle close the gap between the projected GHG emissions from road vehicles and the 50 to 55 percent cut suggested through Norway's Intended Nationally Determined Contributions under the Paris agreement.

A particular challenge is represented by the apparently inevitable revocation of the zero VAT rating for battery electric vehicles. This incentive, which would otherwise be at odds with European state aid regulations, has been approved by the EFTA Surveillance Authority until the end of 2022. Our discrete choice model of automobile purchase predicts that a reintroduction of value added tax on battery electric vehicles would reduce their sales by 30–40 percent at the 2030 horizon.

As battery electric cars replace the much less efficient internal combustion engine vehicles, aggregate energy consumption in road transportation is bound to decrease. In our fast decarbonization scenario with VAT exemption for BEVs, road energy consumption is down by 47 per cent between 2019 and 2050, despite an overall 34 percent traffic growth.

Decarbonization will be slower in the heavy-duty freight vehicle segment than for passenger cars. The future competitiveness of biogas, battery electric, fuel cell electric or other zero emission powertrains, as compared to traditional diesel engine technology, will determine the climate footprint of road transportation in the next few decades.