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FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI

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Decarbonization of transport

A position paper prepared by FME MOZEES and FME CenSES

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About CenSES and MoZEES

The objective of the national centres for Environment-friendly Energy Research (FME) is to establish time-limited research centres, which conduct concentrated, focused and long-term research of high international calibre in order to solve specific challenges in the field.

FME CenSES will develop fact-based knowledge for strategic decisions, relevant for both government and industry. The focus is knowledge for a national energy policy, for national and international climate policy and for strategies of innovation and commercialization.

FME MoZEES (Mobility Zero Emission Energy Systems) unites battery and hydrogen technology perspectives with the actual needs of the transport sector. The centre will aid user partners in the design of safe, reliable, and cost competitive zero-emission transport solutions for the future, focusing on new battery and hydrogen materials, components, and technologies for sea, road and rail applications.

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1. Introduction

This paper aims to provide an understanding of how electrification and hydrogen can play a role in decarbonizing the Norwegian transport sector.

In 2015, the government made a commitment to link Norwegian climate policy to that of the European Union (EU). An important instrument in EU's climate policy is the Emissions Trading Systems (EU ETS), which also covers greenhouse gas (GHG) emissions in Norway, and where the ambition is a 43% reduction for Europe as a whole by 2030 (compared to 2005). Electrically powered means of transport take their energy from power plants covered by the ETS and are hence included in the trading system. For emission sources outside the EU ETS, like fossil-fuelled means of transport, the national targets will be decided by negotiation, based on the respective countries' resources and capabilities. For Norway the expectation is that the target will be 40% reduction compared to 2005 levels. The National Transport plan towards 2029 outlines a climate strategy in the transport sector, with emissions reduced by 50% before 2030 (relative to today - amounting to 8.5 million tons CO_2 equivalents). For the transport sector, that implies reductions of 50% or more.

This report takes as a starting point that to meet Norway´s obligations, as described above, the transport sector will need a transition. Greenhouse gas emissions from transport can be cut in five different ways:

1. Reduced economic activity (GDP) and standard of living, resulting in reduced transport demand
2. Reduced mobility of people and goods at all income levels
3. Transfer of travel and freight to less carbon intensive modes
4. Improved energy efficiency of vehicles, vessels and craft
5. Transition to less carbon intensive energy carriers

We discuss these, and summarize the current knowledge regarding:

- What is the current state of policy and the observed effects on emissions?
- What are the barriers for further change?
- What is the potential for further electrification using batteries and hydrogen?
- Is a target of 50% reductions feasible within 2030, and what implications does it have for technology choice and welfare?

This paper builds on research carried out by MoZEES and CenSES research partners and summarize current knowledge on the role of electrification in the decarbonization of the transport sector in Norway. A major contribution from this work is that it builds on and integrates insight from several disciplines—science and technology studies, economics, engineering, energy systems and markets, industrial ecology, and political science. Methods employed in the various studies are literature reviews, interviews, focus group interviews, economic analysis, various statistical analysis, energy system models and scenario development.

2. Current policy and its effects

2.1 Greenhouse gas emissions from Norwegian transport

According to official statistics, the aggregate greenhouse gas (GHG) emissions from *mobile sources* in Norway amounted to 16.474 million tons of CO_2 equivalents ($mtCO_2e$) in 2016 (Fig. 2.1).

Not all of this is due to *transport*. Agricultural, construction and household machinery accounted for 2.082 $mtCO_2e$, and the fisheries for another 1.092 $mtCO_2e$. Transport as such was accountable for 13.300 $mtCO_2e$, of which 9.927 $mtCO_2e$ in the road sector, 1.991 $mtCO_2e$ at sea, and 1.305 $mtCO_2e$ in aviation[1]. Some 25 per cent of the 53.332 $mtCO_2e$ emitted on Norwegian territory in 2016 was due to transport.

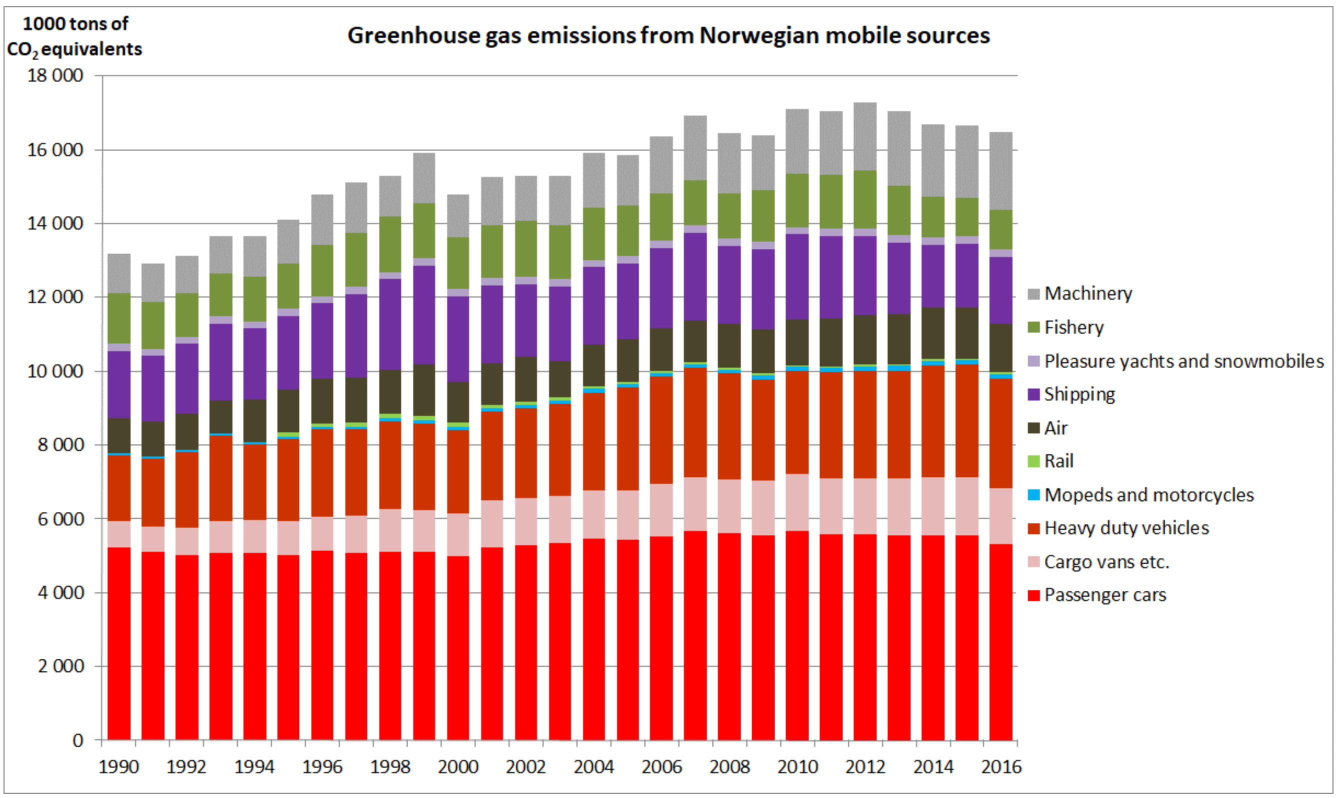

Fig. 2.1. Greenhouse gas emissions from Norwegian mobile sources 1990-2015. Source: Statistics Norway (Statistikkbanken).

In 2016, emissions from transport were 22.6 per cent higher than in 1990 and 1.5 per cent higher than in 2005.

However, the volume of transport has increased far more than the GHG emissions. Domestic motorized travel demand has increased from 54 billion person kilometres to more than 80, i.e. by 50 per cent (Fig. 2.2). In 2016, the car mode had become even more dominant, with its 80 per cent of all person kilometres, than it was in 1990.

[1] Counting Kyoto protocol gases only. The emission of particulate matter and water vapor at high altitudes probably adds another 25 to 75 per cent to the climate impact of aviation (Aamaas et al. 2013).

The demand for freight has increased even more, by 129 per cent between 1990 and 2015 (Fig. 2.3). Even here, the road mode has the largest market share, as measured in ton kilometres, with 48 per cent in 2015. The sea mode is, however, not much smaller, with its 46 per cent.

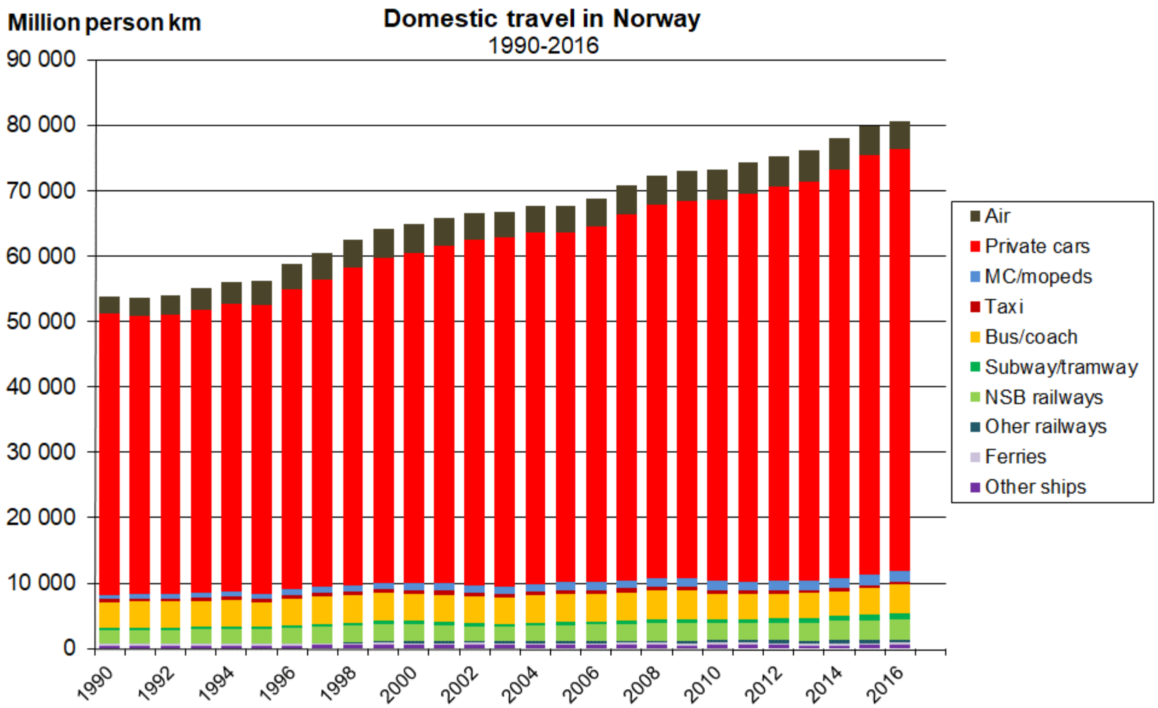

Fig. 2.2. Domestic volumes of motorized travel 1990-2016, by mode. Source: Farstad (2018).

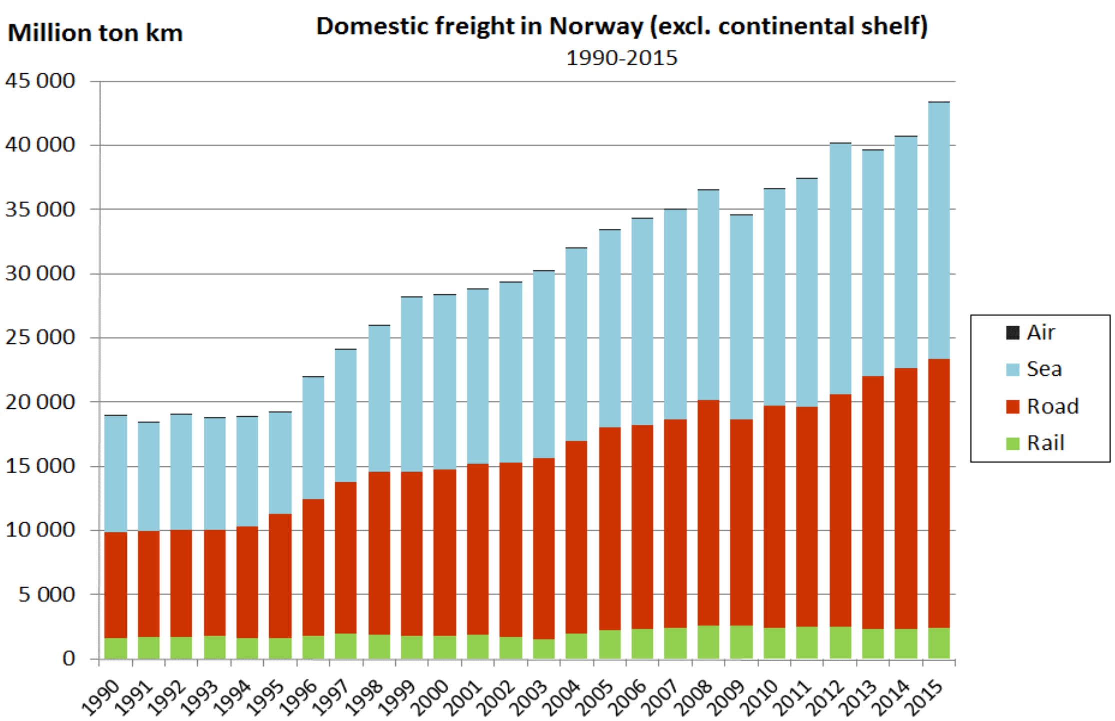

Fig. 2.3. Domestic freight volumes 1990-2015, by mode. Source: Farstad (2016).

2.2 Abatement strategies for transport

According to Banister (2008), there are in essence four ways to combat greenhouse gas (GHG) emissions in transport:

1. Reduced freight and travel demand, i.e. fewer trips and shipments
2. Distance reduction through land-use policy measures, i.e. shorter itineraries
3. Modal shift: from road and air to sea and rail
4. Increased efficiency through technological innovation.

A similar, well-known typology is the so-called *avoid-shift-improve* triplet. One can either (i) reduce the total amount of transport (*avoid*), (ii) shift travel and freight to more efficient and/or less carbon-intensive modes (*shift*), or (iii) replace the energy technology of vehicles, vessels and aircraft by more efficient and/or less carbon-intensive alternatives (*improve*). One notes that option (i) encompasses Banister's options 1 and 2, while (ii) and (iii) correspond to his options 3 and 4.

To fix ideas, consider the mathematical identity shown in Fig. 2.4. The total amount of emissions from travel or freight may be decomposed into five mutually exclusive and exhaustive factors. By operating on any one of these factors, one may, in principle, affect the total amount of emissions proportionately.

$$emissions = GDP \cdot \frac{ton\,/\,person\ miles}{GDP} \cdot \frac{vehicle\ miles}{ton\,/\,person\ miles} \cdot \frac{energy\ consumption}{vehicle\ miles} \cdot \frac{emissions}{energy\ consumption}$$

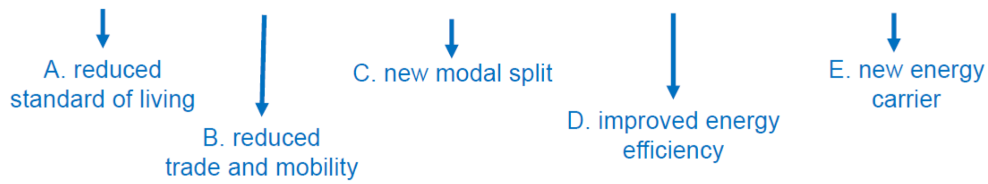

Figure 2.4. A multiplicative decomposition of emissions from transport. Source: Fridstrøm & Alfsen (2014).

The economic and political costs of GHG mitigation are likely to diminish as we move from left to right in the multiplicative decomposition. To reduce emissions (A) by deliberately reducing economic growth and the standard of living or (B) by limiting trade and mobility seems like an almost infeasible strategy in a democratic society. In the EU (2011b) white paper 'Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system', this is explicitly recognized when (in para. 18) it is stated quite bluntly that 'curbing mobility is not an option'.

If transport demand is to be reduced, the most realistic strategy may seem to be enhanced urban planning and densification, which could allow for generally shorter commutes and more competitive mass transit, bicycling and walking (Banister's option 2). However, this strategy would yield results only in the very long term, as it takes time to reshape a city and its land use.

In the short and medium term, ride sharing, car sharing etc. may seem to carry more promise. Modern information technology may reduce the barriers against these collective arrangements. Even so, it seems unlikely that these schemes could reduce the volume of traffic by more than a few per cent.

The *shift* strategy (C) is not very promising. Although modal shift – from road to sea and rail – has been part of the official policy for decades, at the EU level as well as in individual states, little has happened in terms of travel and freight market shares. According to Eurostat, road transport's share of freight ton kilometres in EU28 has hardly changed between 2001 and 2014, being stable between 74 and 77 per cent. As for the travel market, a comprehensive modelling study for Norway (Fridstrøm & Alfsen 2014) examined a large number of radical policy options, including 50 per cent higher fuel prices, 50 per cent higher toll rates, drastically improved mass transit, 50 per cent reduced transit fares, and/or 25 per cent higher airfares. According to the study, even if all of these measures were implemented together, they would not reduce GHG emissions from short and long distance domestic travel by more than 16 and 5 per cent, respectively.

Apparently, the competition between modes is not strong enough for politically feasible policy measures to bring about massive changes in the choices made by travellers and shippers, a result corroborated by Brand et al. (2013) in the travel demand case and by Marskar et al. (2015) in the freight demand case.

This leaves us with the *improve* strategy, in other words *energy technology transition*, as the most promising path forward. When demand cannot be capped or shifted away from the road mode, the road vehicles themselves, or possibly their fuel, need to be transformed (strategies D and E in Fig. 2.4). Enhanced capacity utilization could also help.

The extent to which existing vehicles, vessels and aircraft can be retrofitted with more energy efficient technology is limited. A certain potential exists for substituting compressed natural gas (CNG) for other, more carbon intensive fossil fuel combustion in existing ships. In some cases, it may even be possible to replace one or more combustion engines by battery or fuel cell electric motors. In the road and air sectors, however, energy transition can only take place through vehicle and aircraft fleet renewal. If one can make sure that the next generations of cars and trucks are consistently eco-friendlier than the previous ones, the vehicle fleet will be steadily improving in terms of its environmental footprint.

Driven by the need to comply with the emission targets set by the European Commission for 2021, manufacturers have endeavoured to bring down the CO_2 emission rate of new automobiles, as measured by the New European Driving Cycle (NEDC). As averaged over all new passenger cars brought to the EU market, the NEDC rate of emissions should not exceed 95 gCO_2/km in 2021.

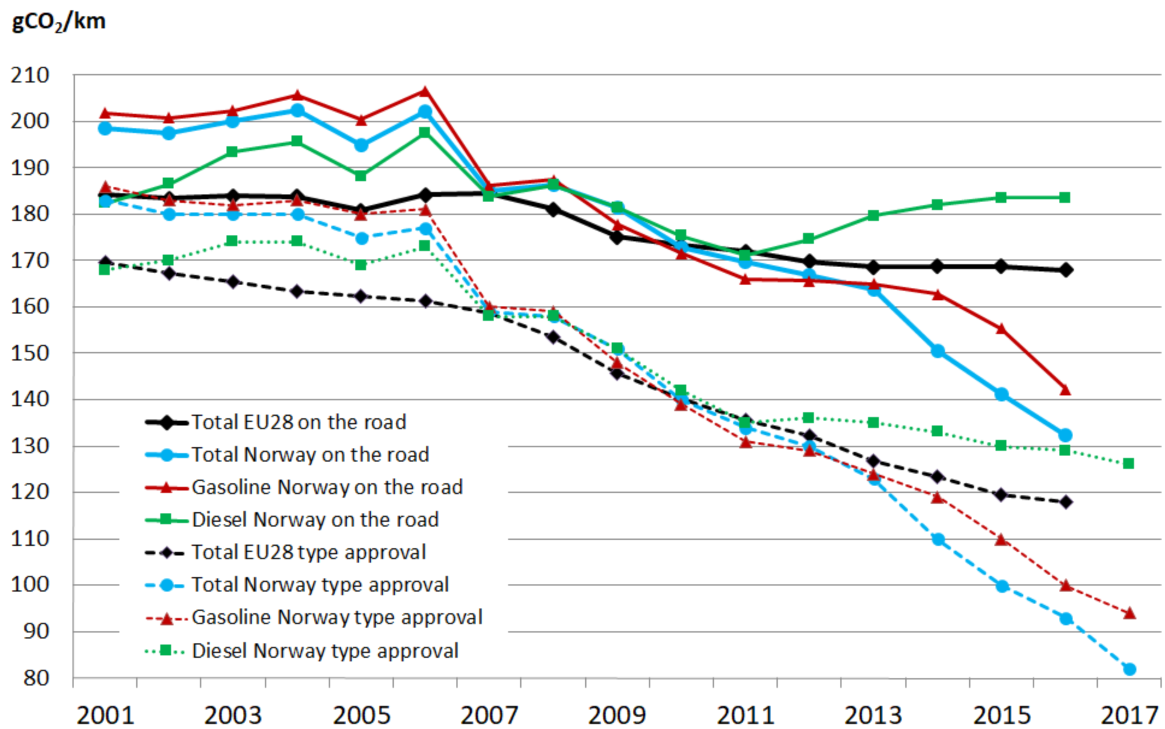

Fig. 2.5. Annual average type approval (NEDC) and estimated on-the-road rates of CO_2 emission from new passenger cars registered in EU28 and in Norway 2001-2017. Sources: Updated from Fridstrøm & Østli (2017) and www.ofvas.no.

Between 2001 and 2016 this rate, as evaluated for EU28, has come down by 30.5 per cent, from 170 to 118 gCO_2/km. A large part of this decline is, however, due to enhanced performance at the laboratory test rather than to improved real world, on-the-road fuel mileage. According to Tietge et al. (2017), the discrepancy between on-the-road and type approval emission rates has grown from an estimated 9 per cent in 2001 to a full 42 per cent for the 2016 cohort of passenger car models. Considering the growing divergence, the 2001-2016 decline in CO_2 emission rates among new cars in EU28 reduces to less than 9 per cent – from 184 to 168 gCO_2/km (Fig. 2.5).

In Norway, type approval and real-world emissions rates have decreased much faster than in the EU. This is due primarily to the rapid market uptake of battery electric vehicles (BEVs), and secondarily to the growing market share of plug-in hybrid electric vehicles (PHEVs), grouped in Fig. 2.3 together with the conventional gasoline and diesel vehicles, respectively. Thanks to these two circumstances, the type approval and real-world emission rates of new Norwegian registered automobiles have come down by 49 and 33 per cent, respectively, between 2001 and 2016. As of 2017, the type approval rate is down by a full 55 per cent, to 82 gCO_2/km.

Apparently, the potential for improving the energy efficiency of the internal combustion engine (ICE) is limited. This suggests that there are only two possible pathways to carbon neutral road transport: (a) widespread substitution of biofuel for fossil fuel in ICEs, or (b) all-out vehicle fleet electrification.

Although certain biofuels (such as corn ethanol) appear no more climate friendly than their fossil counterparts, chances are that option (a) may contribute to a non-negligible decrease in GHG emissions, most notably in the short and medium term. In fact, the bulk of the road transportation emissions reduction from 2015 to 2016 visible in Fig. 2.1 is due to increased biofuel use.

However, the challenges are numerous. Unless the biofuel is based on plants with a relatively short rotation cycle, its GHG abatement effect will be too slow in view of the urgent need to bring emissions down. Secondly, the indirect land use change (ILUC) impacts of biofuel production may be difficult to predict and control. Last, but not least, the amount of photosynthesis occurring on the planet is simply not sufficient to satisfy more than a relatively modest part of worldwide transport energy needs.

Option (b), on the other hand, carries considerable promise. Many analysts foresee that the total costs of ownership (TCO) of BEVs will drop below those of ICE cars some time before 2025, even without government incentives. As for heavy-duty freight, Moultak et al. (2017) identify three possible zero emission technologies based on electric motors: (i) battery electric vehicles (BEVs), (ii) hydrogen fuel cell electric vehicles (FCEVs), and (iii) catenary (trolley wire) or other along-the-road electric charging. All of these options imply replacement of the rolling stock. They are, however, quite different in terms of their infrastructure requirements and potential geographic scope.

The BEV option has the great advantage of offering a three- to fourfold energy efficiency improvement compared to the ICE. Thus, the long-term operating costs of BEVs are likely to be considerably lower than for gasoline or diesel driven cars – depending, though, on the relative prices of energy carriers. Their main drawback is the weight of the battery – about 75 times higher per unit of energy than a can of diesel.

For short-sea shipping and ferrying, this drawback is of lesser importance. Non-negligible emission cuts could be achieved by electrifying all or most of Norway's 120 ferry crossings. In heavy trucks, however, battery packs are liable to cut too much into the payload. Hence, in this case hydrogen fuel cell technology is considered by many to be a more promising zero emission technology (Rosenberg et al. 2010, Moliner et al. 2016, Maniatopoulos et al. 2015). Nevertheless, the energy efficiency improvement of an FCEV replacing a diesel powertrain is quite limited, and much smaller than in the case of BEVs. Thus, the cost hurdle against zero emission technology in heavy trucks is considerably higher than for passenger cars.

The catenary option amounts to electrifying not only the vehicles, but also the road. The right-most lane of the highway would typically be equipped with overhead electric wires or, possibly, with cables for inductive charging embedded in the road surface. The cost of such infrastructure would most probably mean that only the busiest arteries could be equipped with it. On other parts of the network, vehicles would have to rely on batteries, fuel cells or ICEs.

2.3 Current policies in Norway

The Norwegian government has committed itself to climate policy goals in line with the Paris agreement and with the European Commission's targets for sectors outside the EU Emissions Trading System (ETS). The overall GHG emissions target for 2030 is a 40 per cent reduction from the 1990 level. In the non-ETS sector, which includes transport, the preliminary target at the EU level has been set at 30 per cent reduction by 2030 compared to 2005. It is expected that Norway will face a 40 per cent reduction requirement. At the 2050 horizon, the overall national target is a nearly carbon neutral society (CNS), quantified as an 80-95 per cent GHG emissions reduction (Meld. St. 41 2016-2017).

In this context, emission reductions in transport appear crucial. In its climate strategy, the government has put forward rather ambitious targets for the market uptake of zero and low emission vehicles in 2025 and 2030:

- By 2025, *all new passenger cars* and *all new urban buses* acquired are to be zero emission vehicles (ZEVs), i.e. BEVs or fuel cell electric vehicles (FCEVs).
- By 2030, the same should apply to *all new light commercial vehicles (*LCVs, or 'cargo vans'), to *three quarters of all new interurban buses and coaches*, and to *half of all new heavy duty freight vehicles* (HDVs, i. e. trucks and semitrailer tractors).

In the market for private cars, strong incentives have already been implemented. The probably most important one is the differentiated, one-off *vehicle purchase tax*, payable upon first registration of any passenger car or cargo van equipped with an ICE. As of 2016, the purchase tax was a sum of four independent components, Based on calculations of *curb weight*, *ICE power*, and *type approval* CO_2 and NO_X emission rates, respectively (Fig. 2.6). The CO_2 component was introduced in 2007 and the NOx component in 2012. As of 2017, the engine power component has been abolished (Fig. 2.7).

Compared to other examples internationally, the Norwegian CO_2 differentiated vehicle purchase tax is special. While a textbook recommendation for CO_2 abatement is to tax fuels only, the Norwegian vehicle tax is well designed to influence vehicle choice: it is technology neutral (with the exception of the special treatment of ZEVs and PHEVs, see below), it provides continuous rather than stepwise incentives, and it is high; much higher than any measure of the social costs of carbon (Yan and Eskeland, 2018, Eskeland, 2012). As such, the Norwegian policies offer an example internationally to test the potential for carbon-leaner vehicles.

Particularly strong incentives apply to zero emission vehicles (ZEVs), be they battery or fuel cell electric. ZEVs are *exempt of vehicle purchase tax, and have reduced or no road tolls* and *public parking charges*. They benefit from strongly *reduced ferry fares, lower annual circulation tax* and *lower income tax on company cars*. Moreover, they are generally allowed to *travel in the bus lane* and may be *recharged for free* in many public parking lots. Last, but not least, while ICE and hybrid cars are subject to a standard 25 per cent value added tax (VAT) on the price exclusive of purchase tax, *ZEVs, their batteries and their leasing contracts are exempt of VAT*.

The incentives work (Figenbaum & Kolbenstvedt 2015, 2016; Figenbaum 2017; Ryghaug and Skjølsvold 2019; Yan and Eskeland 2018; Fridstrøm and Østli 2017, 2018). Thanks to a 29 per cent BEV market share and a 19 per cent PHEV share[2], the mean type approval rate of CO_2 emissions from new passenger cars registered in Norway during January-March 2018 was 72 gCO_2/km, equivalent to a fuel economy of 75 miles per gallon (mpg) for a gasoline driven car. When BEVs are excluded, the mean rate comes out at 101 gCO_2/km. In March 2018, the mean type approval rate of CO_2 emissions from new cars reached its all-time low of 63 gCO_2/km (blue curve in Fig. 2.10).

[2] Source: www.ofvas.no.

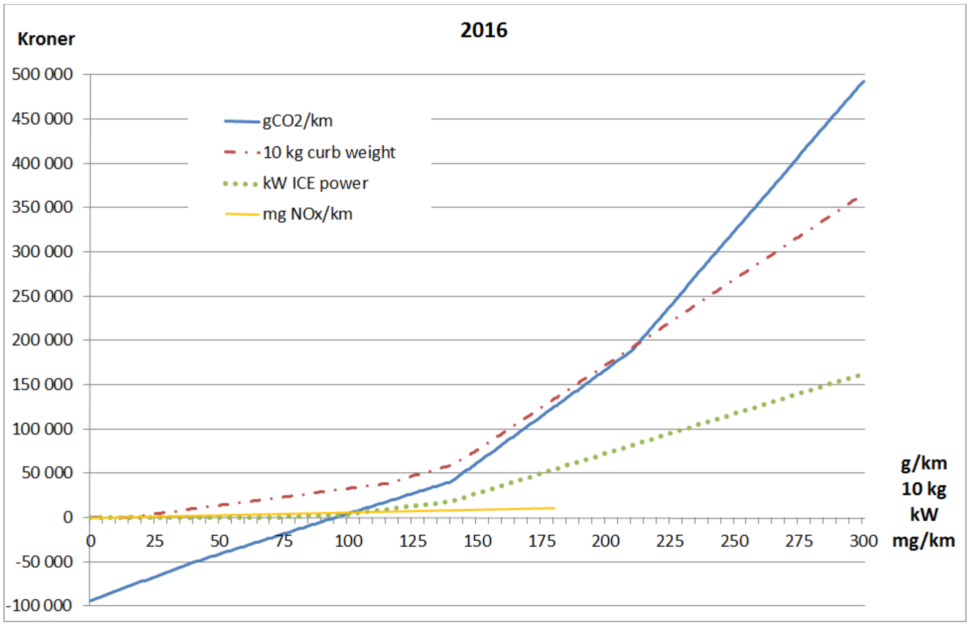

Fig. 2.6. Norwegian vehicle purchase tax 2016, as a function of curb weight, combustion engine power, and type approval CO_2 and NOx emission rates. Source: Fridstrøm (2017b).

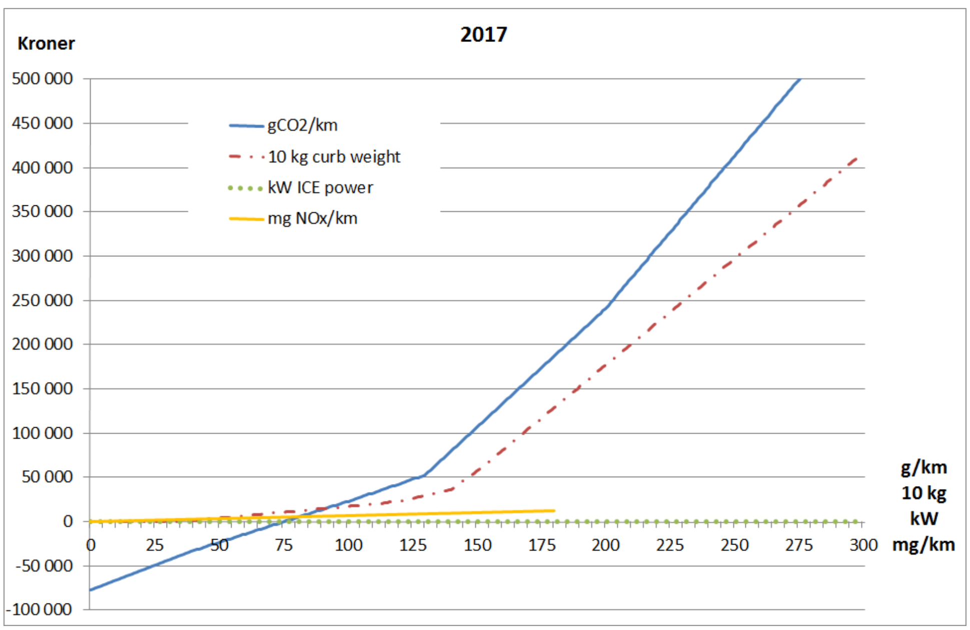

Fig. 2.7. Norwegian vehicle purchase tax 2017, as a function of curb weight and type approval CO_2 and NOx emission rates. Source: Fridstrøm (2017d).

2.4 The climate impact of vehicle and fuel taxation

A considerable scientific literature exists on the respective merits of vehicle and fuel taxation[3]. Although no general consensus exists, economists would traditionally argue that a pigovian fuel tax, or a carbon cap-and-trade system encompassing road transport, would constitute a near-optimal way of internalizing the costs of tailpipe emissions generated by fossil fuel combustion.[4] Since households generate no external costs simply by owning a vehicle, only when they use it, most economists would argue that taxing the vehicle as such would be misguided.

On the other hand, it may be argued that next to residential choice, the acquisition of a car represents the most basic and long-term decision bearing on travel behaviour that is made by the typical private household. Choice of vehicle model affects society's GHG emissions for the coming 15-20 years, regardless of whether the vehicle remains at the hands of its first owner, or is traded second hand. In this perspective, it makes as much sense to tax the car at its first registration as when it is driven.

In addition, some studies have emphasized the apparently greater GHG abatement potential of fiscal incentives directed towards vehicle purchase and ownership. The large, upfront expenditure involved in buying a (more expensive) car is more likely to affect consumer behaviour than the relatively marginal extra cost caused, in some near or distant future, by a fuel tax.

2.4.1 The value added tax and the differentiated vehicle purchase taxes

For ICE vehicles, the Norwegian VAT and purchase tax taken together typically add 50 to 150 per cent on top of the pre-tax value – or even higher for the largest and least energy efficient vehicle models (Fridstrøm & Østli 2017). Thanks to the tax exemptions, battery electric vehicles (BEVs) come out with a mean retail price in Norway that is on a par with small and medium sized gasoline or diesel cars.

For plug-in hybrid electric vehicles (PHEVs), certain special rules apply. To leave the standardized weight of the battery pack out of the tax calculation, the taxable curb weight of PHEVs is reduced by 23 per cent. Since the CO_2 component is generally negative for cars emitting less than 70 gCO_2/km (as of 2018, down from 95 gCO_2/km in 2016), lightweight PHEVs may come out with zero of near-zero purchase tax. However, the purchase tax cannot become negative, as in the French feebate system (D'Haultfoeuille et al. 2013).

For LCVs (cargo vans), the same kind of incentives apply, however with less force, since in this case the purchase tax rates are typically 20-25 per cent of the rates applicable to passenger cars. In 2017, 2.5 per cent of all new and second-hand imported cargo vans registered in Norway were BEVs[2].

In addition, the VAT exemption does not carry much weight in the case of LCVs, since most of these are bought by VAT registered companies. Hence, whatever input VAT is levied on the vehicle will be written off against the output VAT payable by the company.

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[3] See, e.g., references in Fridstrøm and Østli (2017).

[4] A fuel tax would not, however, correctly internalize all other marginal external costs, such as road wear, congestion, noise, accidents, or particulate matter released from tarmac or brake pads (Thune-Larsen et al. 2016). For these externalities, electronic road pricing would be more appropriate (Fridstrøm 2017f).

For passenger cars, in contrast, a special tax rule prevents companies from writing off the input VAT, except in those cases where the commercial use or trading of the vehicle constitutes the core business activity of the company. This applies to car dealers, to car rental and leasing companies, as well as to taxi companies, commercial limousine services, etc. However, for passenger cars used in an ordinary company's daily operations, or placed at the disposal of employees, no input VAT is deductible under Norwegian law.

The exemptions from VAT, reduced road toll, as well as reduced income tax and annual circulation tax for BEVs have been notified to the EFTA Surveillance Authority, which, in its decisions of April 21, 2015 and of November 8, 2017, approved these fiscal incentives. Without such approval, the incentives would fall into the category of illegal state aid under the rules of the single European market. The BEVs' exemption from purchase tax is, however, not subject to notification, since this rule was implemented already in 1990, before the conclusion of the European Economic Area (EEA) agreement, which incorporates Norway into the single market.

A fairly general consensus exists between the political parties to continue and reinforce the incentives for zero and low emission vehicles, at least until 2021, to drastically reduce the CO_2 emissions from new vehicles at the 2025 and 2030 horizons. However, the EFTA approval of the VAT exemptions on BEVs and on their batteries and leasing contracts expire on December 31, 2020. The continued use of these fiscal instruments, beyond 2020, will be contingent upon renewed EFTA approval.

The impacts of changing the vehicle purchase tax components for passenger cars were calculated by means of the discrete choice model developed by Østli et al. (2017). If, in 2014, all purchase tax components had been uniformly 10 per cent higher, the average type approval CO_2 emission rate of new cars would have been an estimated 2.41 gCO_2/km lower, corresponding to an elasticity –0.21. The elasticity of the CO_2 emission rate with respect to each of the CO_2, weight and engine power components, respectively, came out as –0.10, –0.10, and –0.01 (Fig. 2.8)[5]. Thus, the weight and CO_2 components are just about equally effective CO_2 abatement instruments, while the engine power component has a lesser impact.

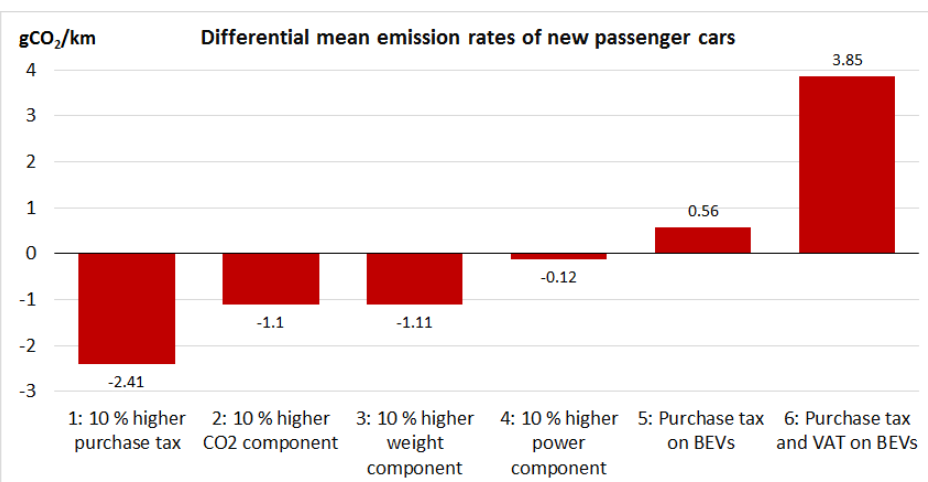


Fig. 2.8. Absolute changes in mean type approval CO_2 tailpipe emission rates of new passenger cars, compared to 113 gCO_2/km reference case, under six fiscal policy scenarios calculated for 2014. Source: Østli et al. (2017).

[5] The initial level was 113 gCO_2/km, so a –1.1 gCO_2/km change corresponds to –1 per cent.

A revocation of the VAT and purchase tax exemptions for BEVs was found, in the same study, to be consistent with a 3.85 gCO_2/km (or 3.4 per cent) increase in the average type approval emission rate of new passenger cars. Note, however, that this result hinges critically on the assumed alternative tax regime, in this case that BEVs be subject to the same purchase tax rules as PHEVs. Incidentally, this is precisely what the Government proposed in its fiscal budget for 2018 (Prop. 1 LS 2017-2018). This proposal was not approved by the Parliament.

Østli et al. (2017) also carried out a counterfactual back-casting exercise, in which they simulated the demand for passenger cars during 2007-2014 under alternative tax regimes (Fig. 2.9). They found that without the CO_2 component and the VAT and purchase tax exemptions for BEVs, the average type approval emission rates of new cars in 2014 would have been 23 gCO_2/km (or 20 per cent) higher.

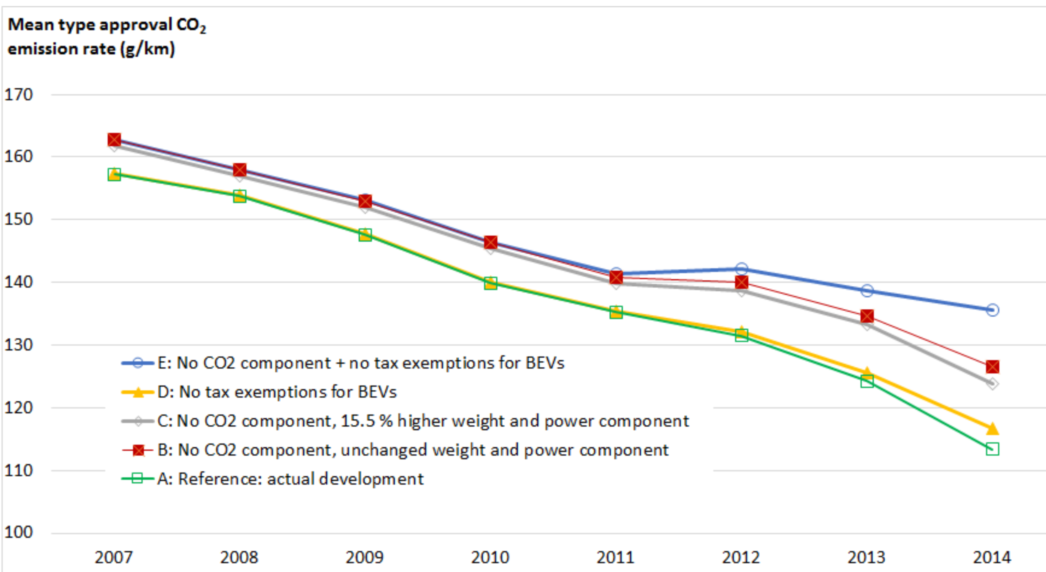


Fig. 2.9 Counterfactual back casting simulating the non-introduction of CO_2-graduated purchase tax and/or tax exemptions for battery electric cars 2007-2014. Source: Østli et al. (2017).

Yan & Eskeland (2018) conclude with some additional observations. First, they notice that the Norwegian CO_2 differentiated vehicle purchase tax is well designed from the perspective of influencing future emissions via the vehicle choice decision: it is continuous rather than stepwise, and it is almost technology neutral. In observing that the vehicle owner/driver has no direct interest in CO_2 other than through associated qualities (acceleration, space, luxury), they note that this instrument cost-effectively stimulates a combination of innovation, efforts and sacrifices at the hands of vehicle manufacturers and buyers. The study finds an elasticity of emitted CO_2 grams with respect to the car's price (when raised by the CO_2 fee) of minus one half, so if the CO_2 differentiated tax raises the average car's price by 20 percent, then average emissions per vehicle kilometre decline by ten percent. The way the tax makes people choose leaner vehicles is found to be about half the reductions from choosing vehicles in leaner segments (say: from large to mid-size cars) and half from choosing leaner models within a segment.

In summary, the Norwegian vehicle purchase tax and the tax exemptions for ZEVs have had a decisive impact on the prospective climate footprint of private cars. In September 2017, the mean type approval rate of CO_2

emissions from new cars reached an all-time low of 71 gCO_2/km (blue curve in Fig. 2.10). When BEVs are excluded (red curve), the mean rate comes out at 100 gCO_2/km. The upward spikes in the red curve typically reflect the rush to buy certain high emission car models in December, before next year's stiffened purchase tax makes these cars even more expensive – another testimony that vehicle customers behave much like economic men, responsive to financial incentives.

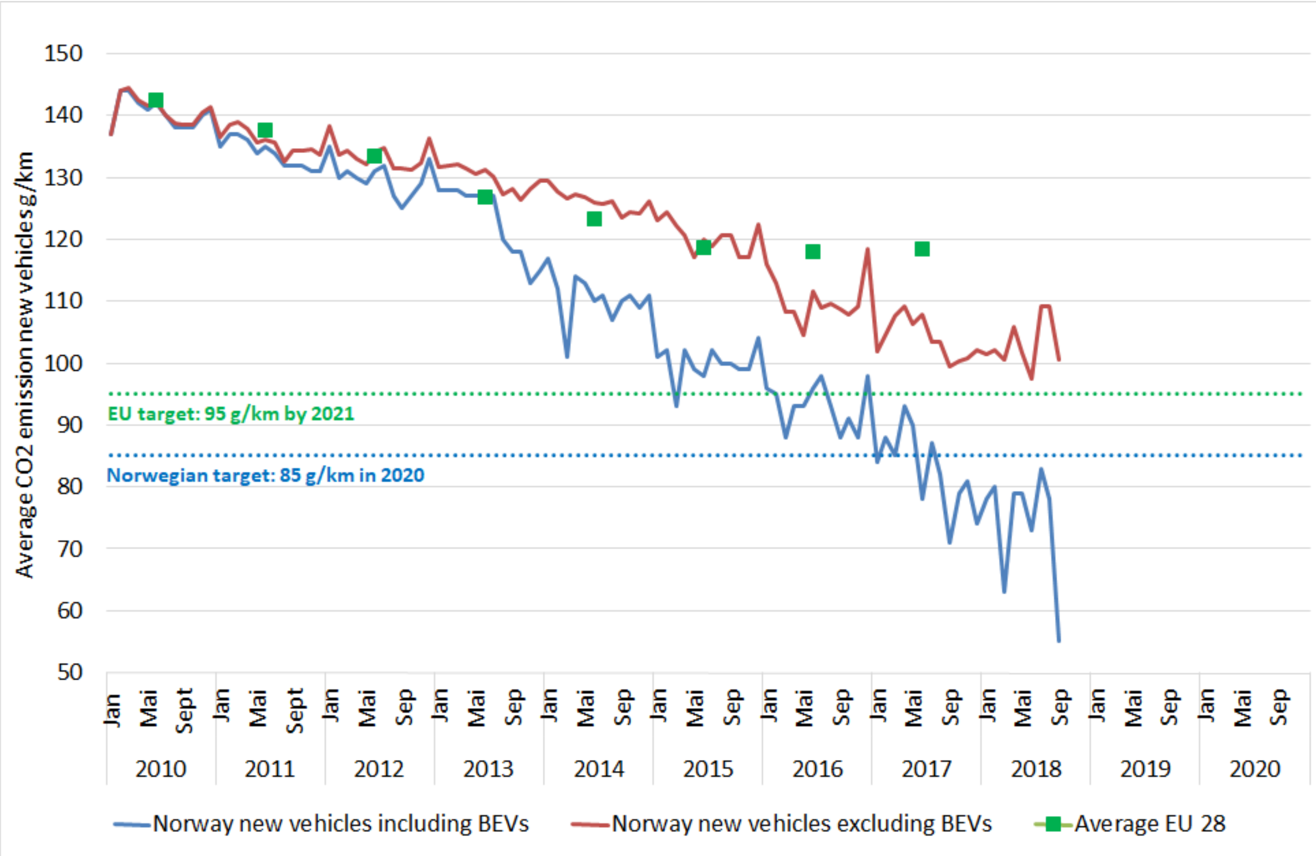


Fig. 2.10. Monthly average type approval emission rates (gCO_2/km) of new passenger cars registered in Norway 2010-2018, with EU28 annual averages. Sources: Updated by from Figenbaum (2017) and www.ofvas.no.

2.4.2 The fuel tax

In addition to the tax exemptions applying to the vehicles, the fuel taxes (NOK 6.33 per litre gasoline and NOK 5.08 per litre diesel as of 2018) also represent an inherent incentive for CO_2 leaner cars and ZEVs. Since these vehicles do not depend on liquid fuel, they get by without paying the 'road use' component (NOK 5.17 and NOK 3.75) included in the fuel tax, despite the fact that the externalities due to road wear, noise, accidents and congestion are not very different between ZEVs and ICE cars. The fuel tax also serves to make lean, low emission ICE and hybrid vehicles more attractive to the consumer.

The price elasticity of demand for fuel is a key parameter in determining the climate impact of changes in the fuel tax. International meta-analyses (Brons et al. 2006, Labandeira et al. 2016) suggest elasticities in the area around –0.35 for gasoline and –0.20 for diesel.

However, the fuel price elasticity depends crucially on the geographic and economic context. Its numerical value will be higher in urban areas with quantitative potential in high quality mass transit supply and/or many opportunities for bicycling or walking than in remote rural districts with few alternatives to the private car. As argued by Fridstrøm (2017b), fuel demand must be expected to be less elastic in sparsely populated Norway than in practically any other EU or EFTA country.

Similarly, there are obvious reasons to expect higher fuel demand responsiveness to prices (greater absolute value of the price elasticity) in the long run, with greater freedoms, than in the short run. The greater long run demand elasticity can reflect not only car choice (more fuel efficient cars under higher gasoline prices, when car replacement decision arrives; Eskeland and Feyzioglu 1996), but also locational choices, habit formation, supply responses in bus service, etc. Eskeland and Yan (2018) found leaner car choice in Norway to be about as sensitive to fuel prices as to the CO_2 differentiated tax, when calibrated to cost the buyer the same amount.

Steinsland et al. (2016) study the impact of NOK 0.20 increase in the per kilometre fuel cost of car driving. They find that in the so-called intercity region around Oslo (i.e., the triangle formed by the cities of Skien, Lillehammer and Halden, with surroundings); short-haul car travel demand would decrease by an amount corresponding to a fuel price elasticity of –0.22. For long-haul domestic car trips, they find an elasticity of –0.11.

Studying short-haul trips in and around Bergen, the country's second largest metropolitan area, Madslien & Kwong (2015) find an elasticity of –0.17. There is reason to believe that in other parts of Norway, with less developed mass transit supply, fuel demand is less elastic than in the two most important metropolitan areas.

In addition to the direct travel demand effects, fuel prices influence GHG emissions through the vehicle purchase choices made by households and companies. Higher fuel prices make people choose leaner cars. Fridstrøm & Østli (2018) calculated the elasticity of the average type approval CO_2 emission rate of new passenger cars with respect to the fuel price at –0.21 as of 2016.

This elasticity has a long-term interpretation. The full effect will materialize only when the entire fleet has been replaced. Since the life expectancy of Norwegian passenger cars is around 17 years (Fridstrøm et al. 2016), the effect is only –0.01 in the course of the first year. In the long term, however, the indirect car fleet effect seems to be just about as important as the direct travel demand effect. Yan and Eskeland's estimate of an elasticity of the average CO_2 intensity in new car sales with respect to new car prices (when these change due to the CO_2 tax rate) of minus one half is in the ballpark of estimates for price elasticities for polluting goods, though in the high end, the high responsiveness perhaps reflecting a time of technological change in which similar services increasingly can be offered with less or even zero CO_2 emissions per vehicle kilometre.

Commercial freight vehicles also use diesel fuels. Here, estimates of the price elasticity of demand are hard to come by. However, Hansen et al. (2017) carry out a model simulation resulting in CO_2 abatement effects compatible with an overall fuel freight demand elasticity of –0.11, calculated as the weighted average of –0.09 for domestic consignments and –0.23 for border-crossing ones. For freight vehicles, too, the potential in our time of technological change is important, and should not be ignored in the design of policy instruments in particular directed towards technology development and early adaptation.

2.4.3 Rebound effects through changes in car ownership

The above impact estimates ignore rebound effects due to changes in aggregate car ownership. Such effects are potentially important. D'Haultfoeuille et al. (2013) find, e.g., that the French fee bate (bonus-malus) system for automobiles is counterproductive in terms of CO_2 abatement, because the bonus has made car ownership affordable to a larger number of families. In Norway, the tax exemptions for ZEVs have enlarged the assortment of relatively inexpensive cars with low operating costs. It is conceivable that this might lead to increased household car ownership and use. To answer this question, an econometric model of aggregate automobile demand is needed.

Importantly, however, there is no doubt that Norway and Norwegian cities have certain additional policy instruments to manage demand both for freight and mobility, in total as well as in modal split. Illustrations are public transport policies, bicycle paths as well as fuel taxes and Norway's pioneering toll rings, where the latter can be embryonic versions of more advanced forms of road charging, accounting for local as well as temporal and global objectives.

2.5 Global versus local effect of Norwegian emission reductions in transport

A central question when establishing policy to reduce emissions in a single sector in a single country is whether the local emission reductions will have effects globally or if carbon leakage will occur. Treaty approaches from the Climate Convention (1992) onwards have chosen a territorial approach to emissions accountability, but as long as cooperation is incomplete or weak, checking emission consequences outside natural borders has become important (Ellingsen et al., 2014, Yihui and Chan, 2005).

When considering emissions from producing the energy used in operations in the transport sector (fuels, or electricity), the effects of the EU ETS must be considered. If one does not take into account the cap-and-trade system, and instead calculate emission effects from electrification based on the average (or marginal) carbon intensity of the European power sector, one would strongly underestimate the actual effects of switching to electricity in European transport. For electricity in Europe, emissions from power generation is capped by the EU ETS. Increased demand for electricity in Norway due to electrification of transport will therefore not increase emissions elsewhere in Europe, since the number of available allowances in the ETS sectors is fixed (Eskeland, 2012). This is one of the main properties that makes emission reductions in the transport through electrification attractive. Local emission reductions in Norway when switching from fossil fuels to electricity reduce emissions in the Norwegian non-ETS sectors; there is no increase in transport emissions in other countries and no increase in emissions within the EU ETS. From an energy perspective, the local effects in terms of emission reductions equal the global effects.

When including effects originating from vehicle manufacturing, the picture is more nuanced. The production intensity for a mid-sized BEV is around 6.0–7.4 ton CO_2-eq/ton of car, while for ICE vehicles it is around 4.2–5.5 ton CO_2-eq/ton of car (Ellingsen et al., 2018). The difference in emission intensity is particularly due to the Li-ion battery.

The high GHG emissions from production of the Li-ion battery stem mainly from the battery cells (Kim et al., 2016; Ellingsen et al. 2014). While the cell materials contribute to a relatively small share of these cell-related GHG emissions (, the energy demand in cell manufacture is a significant contributor (45-60% of total battery production GHG emissions). The reason for this is that currently, the energy demands in the cell manufacturing processes are high and met with carbon intensive energy sources.

Production location affects the GHG emissions of cell manufacture as it has bearings on both the energy demand and energy sources. In terms of energy demand, the production location is important because the climate affects the air humidity levels and this, in turn, affects the energy demand in dry room operations. Dry room operation has been identified as a particularly energy demanding processes in cell manufacture (Ellingsen et al., 2014; Yuan et al., 2017). Currently, lithium-ion cells are primarily produced in South Korea, China, and Japan. Regions of these three countries are affected by the East Asian Monsoon, which is characterized by a warm, rainy monsoon season lasting from early May to September (Yihui and Chan, 2005). Thus, the humid monsoon summer is likely to affect the energy use in dry room operation (Ellingsen, 2017). In terms of energy sources, South Korea, China, and Japan are all countries that rely on a large share of fossil sources for to generate heat and electricity. Consequently, moving cell manufacture to areas with lower humidity and cleaner energy sources will be beneficial for reducing the GHG emissions of battery production. The use of renewable energy sources in cell manufacture can reduce the GHG emissions of battery production by around 50% (Ellingsen et al., 2014). Dynamics of regime shifts and sustainability transitions

A whole series of different factors are often seen as barriers to the use of sustainable technologies in transport: technological factors, government policies and regulatory framework, cultural and psychological factors, demand factors, production factors, infrastructure and maintenance, undesirable societal and environmental effects of new technologies. According to Hoogma et al. (2002: 17), these barriers altogether constitute "a structure of interrelated factors that feedback upon one another and jointly give rise to inertia in, and specific factors of, technological change." In order for large-scale electrification of the transport sector to happen, Hoogma et al. (2002) have pointed out some general features that may be seen as key aspects of technological regime shifts (Kemp, 1994). These are, to put it shortly: (1) To have enough time (2) To have deep interrelations between technological progress and the social and managerial environment in which they are put to use, including new user-supplier relationships. (3) Availability of complementary technologies (4) perceptions and expectations of the new technology Structural regime shift is a co-evolutionary process that entails a number of structural changes at different levels that happens simultaneously. Change processes often meet resistance from vested interests and give rise to public debates as to the efficacy and desirability of the technology. In the next section, we will highlight some of the factors that have contributed to the electrification of the transport sector in Norway, with a special focus on user experiences, perceptions and the expectations of BEV technology.

3. Publics and users

3.1 Creating transitions to electric road transport in Norway

The politics of technology involve translations between various interrelated settings ranging from the context of design to the context of use. People, institutions, and firms must be aligned, moulded, and disciplined to create (and accept) technological development (Sovacool 2014). Governance in relation to technological development is a many faceted process, in which many different actors and circumstances plays a role (Ryghaug and Skjølsvold 2019). A relevant CenSES study in this respect looked at the way different forms and modes of governance influences mobility practices in Norway, with a special focus on BEVs (Ryghaug and Toftaker 2016). This study focused on the role of user imaginaries in relation to electric vehicles and analyses the role these imaginaries play in the ongoing transition towards electrification of the transport sector.

The study found that the incentives implemented to achieve an accelerated use of EVs in Norway, formed specific user imaginaries that played a role in shaping the governance. Norwegian stakeholders have largely recognized that the responsibility for a rapid transition towards a sustainable transport sector lies beyond individual behavioural choices. Whereas early users were somewhat individualized and given agency on the grounds of being environmentally engaged, economically resourceful and with a particular interest in technology, future users were generalized as aggregates that were not particularly preoccupied with pro-environmental behaviour or a particular technology. Overall, current and future users were described as primarily concerned with technological qualities and motivated by the economic advantages of owning and using EVs. Users were therefore seen as needing to be equipped with economic and political predictability in order for the deployment of electric cars to continue, and in order to create a self-propelled market for EVs. Thus, the furthering of electric transport was described as best achieved using economic incentives or removing technical barriers such as low battery capacity and insufficient charging infrastructure. This strategy may be recognized in the actual electrification policies, such as the “incentives package” to which many of the stakeholders had contributed. Further, the stakeholders in unison claimed that a premature ending of current incentives would be detrimental, as it would be likely to slow down or even stop the deployment of electric cars in Norway.

By working towards making the electric car equivalent to the ICE car in terms of range, comfort, size, and design, the experts chose mainstreaming as their preferred strategy. However, this way, one might overlook the transformative potentials of the practice of driving electric cars, as shown by Ryghaug and Toftaker (2014) in their chapter on user practices and preferences.

3.2 Public perceptions and experiences with transport electrification

The rapid expansion of electric cars in Norway to date has most likely been prompted by strong financial and regulatory incentives such as free access to toll roads, ferries, public parking and charging stations, in addition to reduced taxes and access to bus lanes. However, in order to be successful, alternative technologies like the electric vehicle need to generate sufficiently strong support beyond the institutional level, for instance by providing users with alternative values and expectations without challenging accepted standards of socio-technical behaviour (Hård and Jamison 1997; Ryghaug and Skjølsvold 2018). This means that we need to include users when researching processes of technological innovation, policy development, and policy implementation. In papers studying actual use of electric vehicles in Norway (Ryghaug and Toftaker 2014; Ingeborgrud 2014) found that electric cars are often seen as a better and more comfortable than the ICE car due to their small size, electric engine and fast acceleration – but also due to the good feeling of driving a less polluting car. Hence, driving electric vehicles is seen as advantageous beyond saving time and money. Further, driving range is seldom found to be a problem, as most daily trips are within the range capability of modern BEVs and most users have adopted their usage accordingly (often, the household also have a conventional car at their disposal). Electric car drivers also found charging at home to be easier than using gasoline stations.

Overall, these studies pointed to some interesting findings regarding the possibilities of reframing vehicles, a task that historically has been difficult to achieve (Hård and Jamison 1997; Hård and Knie 2000). For many years, electric vehicles have been referenced as inferior, as the next solution, or as an incomplete innovation because of weaknesses regarding size and driving range compared to conventional cars. Ryghaug and Toftaker (2014) on the other hand show that electric vehicles have other qualities that have not been previously considered essential, such as comfort. The study also highlights that electric cars might have some transformative properties in that they reintroduce novelty to its users and re-sensitizes them to mobility issues. To some extent, electric vehicles contribute to users rethinking, being more aware and changing own mobility patterns (i.e. substituting driving for flying) while also raising awareness of their electricity consumption (Ryghaug and Toftaker 2014, Throndsen et al., 2017; Ryghaug, Skjølsvold and Heidenreich 2018). Studies also show that the electric car ownership seem to trigger an interest in producing renewable energy, e.g., installing solar Photovoltaics (PV) and energy transition dialogues more in general (Throndsen et al. 2017; Ingeborgrud and Ryghaug 2017).

3.3 The effect of stable framework conditions on behaviour

Previous studies have shown the importance of consistent governance, demonstrations of political will and problem-solving actions for the creation of pro-environmental behaviour among the public. Thus, clear, visible and forceful conditions are in themselves important for the adoption of electric cars and the electrification of the road transport. The importance of stable framework conditions for the development and implementation of new technologies are, of course, not only important to end users and customers, but also to industry. This has been proved repeatedly regarding new renewable energy technologies such as offshore wind (Steen and Hansen 2011).

A number of studies have demonstrated that the Norwegian "incentives package" comprising both economic and other incentives has been important for the adoption process in Norway. An understated point is the way the incentives *themselves* produce a type of "certification" of the technology as a good environmental choice (Ingeborgrud 2014). In other words, when people see that exactly this technology is supported by a long list of political incentives, this also contributes to their understanding of the technology as environmentally sound and as a future oriented choice, and something that reduces the risks involved for those who are interested in taking environmentally sound choices (Ingeborgrud 2014). In the end, this also means that if you start taking away incentives or reducing them drastically, this could potentially destabilize the public perceptions of the electric vehicle as an environmentally sound technology, at least to some degree. Overall, this underlines the point that the symbolic effect of consistent and encompassing electric vehicle incentives is important and goes beyond the economic and practical benefits that they foster.

4. The impact on the distribution and transmission grids

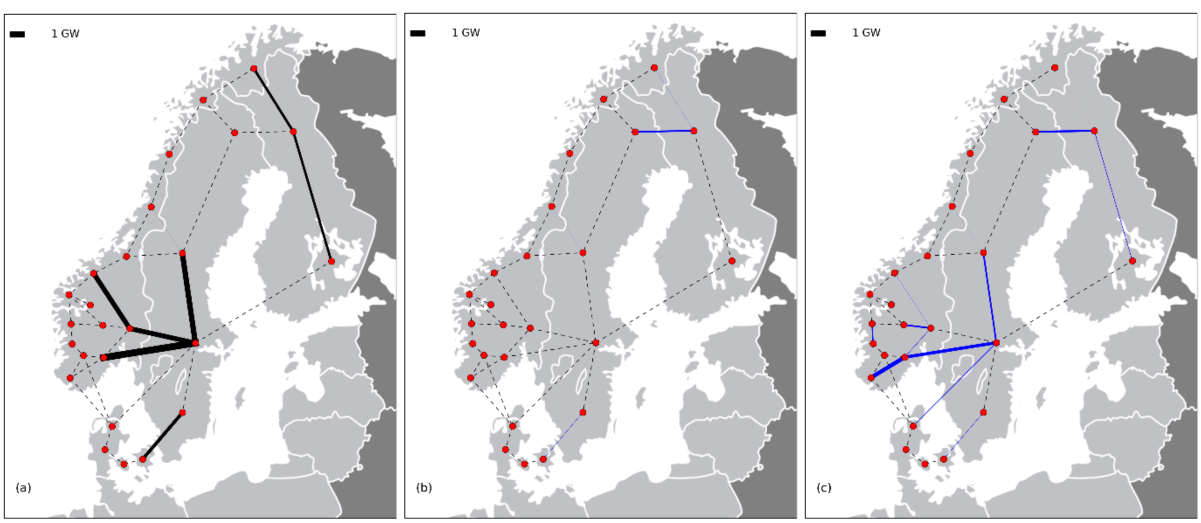
4.1 The transmission grid is strong enough for electric vehicles

The transmission grid is often called the backbone of the electricity system. Compared to the cost of electricity distribution and generation, electricity transmission represents only a fraction of the final cost of electricity. Yet given its importance, the long lifetime of the transmission infrastructure, the visual impact and often low social acceptance for building new transmission lines, the process of transmission capacity planning is an arduous one. A 100% electrification of the passenger vehicle fleet would add about 6 TWh to the total yearly electricity consumption in Norway, compared to 130 TWh today and projected 144 TWh in 2050. At Nordic level, a total electrification of the passenger vehicle fleet would add about 30 TWh per annual. This additional consumption will raise the need for new transmission capacity. A study, Graabak et.al, 2016 assessed just how much additional transmission capacity will be needed if all passenger cars were to be electric by 2050, in line with Norway's target of completely decarbonizing domestic travel by that year. This study estimated transmission capacity needs for 2050 based on the Nordic projected electricity consumption and a simplified grid representation. To evaluate the impact of BEVs, it compared a reference case with no BEVs and two cases with a 100% share of BEVs in the Nordic passenger car fleet.

- **Reference case**; based on the projected electricity consumption for 2050 that foresees a complete carbon neutrality but excludes BEVs.
- **Unresponsive charging**; includes the extra consumption of the BEVs. It is assumed that vehicles start charging upon arrival until they are fully charged.
- **Responsive vehicle charging**; Vehicles try to minimize the electricity cost by adjusting the start and end of charging according to the movement of spot market prices.

Figure 4.1 shows the necessary additional Nordic transmission capacity. Case (a) depicts with black full lines the extra capacity with respect to existing and already planned capacity. The difference in the additional capacity between the cases of unresponsive and responsive charging is shown in case (c). It is significant, but what is more important is that if vehicles were to respond to market prices, the additional capacity with respect to the reference case would be minor – case (b).

Figure 4.1. Transmission capacity additions in 2050.



(a) Reference case (b) Responsive – Reference (c) Unresponsive - Responsive

In fact, as Table 1 shows, with responsive charging the transmission capacity needed would amount to 410 MW or 4% over the reference case on the connection between Norway and Finland. The transmission capacity between Norway and Sweden would need an extra 9 MW or 0, 5% over the reference case's 1807 MW, whereas no additional capacity would be needed between Norway and Denmark or in Norway internally.

Table 1 Transmission capacity requirements in MW.

	Norway internal	Connection Norway Finland	Connection Norway-Sweden	Connection Norway Denmark
Existing and planned capacity	29825	50	4000	1700
Additional capacity excluding electric vehicles (reference case)	747	394	1807	0
Additional capacity with unresponsive charging	1885	408	2305	0
Additional capacity with responsive charging	747	410	1816	0

In sum, the Nordic transmission system seems to be quite strong. It will require some interventions to be able to accommodate the future load growth. Graabak et al. 2016 indicates that a 100% electrification of the passenger vehicle fleet could entail investments into additional transmission capacity in the order of a few percent of the existing capacity. The actual amount of required investments can be drastically reduced by employing smart or coordinated charging technology.

4.2 The major challenge is the distribution grid

A study conducted by Seljeseth et al. (2013) measured the effects of slow and fast charging of electric vehicles on the distribution networks for six operators. The objective was to identify large voltage deviations, flicker and increased harmonics due to EV charging. Measurements were carried out for five different vehicles and a pool of 15 vehicles charging simultaneously. Both slow and fast charging did not seem to cause significant issues with flicker or harmonics, other than flicker appearing as a disturbance in the garage where a vehicle was being charged. Around 70% of the Low Voltage (LV) distribution system in Norway is type 230 V IT, unlike the more common 400 V elsewhere. This results in higher currents and voltage drops when adding BEVs to the network. The study showed in fact that voltage drops caused by the charging could already represent an issue in a network approaching its limits.

Distribution grids are able to host a certain number of electric vehicles without difficulties. As the share of electric vehicles grows, the bottlenecks start to appear at an accelerating pace. According to the Norwegian Water Resources and Energy Directorate (NVE), one battery electric vehicle for every two households would add an average of 1 kW to the household peak load causing close to 4% of distribution transformers to be overloaded, or an almost tripling compared to the current situation. One-battery electric vehicles per household would increase the average peak load of the households by 5 kW and result in more than 31% of distribution transformers being overloaded.

NVE estimates that 33 billion NOK will be invested in the high voltage distribution and 15 billion NOK in the low voltage distribution grid in the period 2016-2025. An additional 10 billion NOK will be needed in providing every consumer with a smart meter by 2019. Herein lies the solution.

As has been demonstrated in other countries, coordinated charging can significantly increase the hosting capacity of distribution networks. In fact, coordinated or smart charging should be implemented, as its benefits are considerable at both the distribution and transmission level. Smart meters are enablers of flexible charging. Combined with a network tariff based on the peak load of the consumer, the distribution overloading will be alleviated.

5. Potential and barriers for hydrogen in future transport

The 2016 white paper on energy policy (Meld. St. 41 (2016-2017), pp. 226-227) states that hydrogen can become important as an emission free energy carrier in Norway, both in transport and in stationary energy supply. The white paper emphasized that hydrogen is a technology where major advances may come within a short time frame. National Norwegian GHG emissions targets are stated in the Climate Agreement (St. Meld. 34 (2006 -2007); Innst. S. nr. 145 (2007–2008)). Reduced emissions in the transport sector will be important to reach these targets. Hydrogen is an emission free energy carrier, when produced by electrolysis using renewable electricity, and near emission free using natural gas with carbon capture and storage (CCS). Hydrogen can as such play an important role in the "green shift" as a key part of Norwegian climate policy.

5.1 The demand and potential role of hydrogen in different transport segments

Several studies address the potential for hydrogen in the Norwegian transport sector. The NorWays study (Stiller et al., 2010) illustrates the effect of different parameters on the profitability of hydrogen in competition with other energy carriers for car use. A study conducted by SINTEF and NTNU in 2016 (Tomasgard et al., 2016) estimates the potential for future hydrogen demand based on three scenarios with varying assumptions about market shares of hydrogen vehicles in different transport segments. Funded by major Norwegian cities, the study submits input to a national hydrogen strategy, in terms of national policy instruments, the need for infrastructure, and the potential for hydrogen. Ulleberg et al. (2015) carried out a Norwegian feasibility study to take a closer look at the opportunities for the use of hydrogen fuel cells ships. The work presents a case study on how hydrogen can be cost-effective compared to liquefied natural gas (LNG). The market for hydrogen in the maritime sector can contribute to build infrastructure in harbours and terminals, and thus have a positive impact on the implementation of hydrogen as an energy carrier in road transport. The use of hydrogen in the maritime sector in Norway can contribute to increased demand for hydrogen, and thereby help lower the costs.

5.2 The role of infrastructure – hydrogen fuelling stations

In Tomasgard et al. (2016), total demand for hydrogen within different transport vehicle segments (freight, passenger cars, taxis, buses and boat/maritime) towards 2030 is calculated for three different scenarios. The scenarios differ with respect to the assumed growth rates of hydrogen vehicle stocks in the various segments (low, medium and high adoption of hydrogen vehicles). Consequences in terms of the volumes of hydrogen used for each segment and the need for filling stations are then calculated.

The low scenario assumed that there is little or no regulation of investments in hydrogen in fleet vehicles such as taxis and buses, while the supply of FCEVs remains low, and trucks, either with fuel cells for direct propulsion or with range extender, account for the largest consumption of hydrogen fuel. Both the *medium and high scenario* assume a targeted focus on fleet vehicles in the period up to 2020, where the taxi fleet will contribute to over half of total consumption until 2020, and along with buses account for more than 80% of total consumption in the next five years. In these scenarios, other transport segments will take over as the largest consumers of hydrogen after 2020, and in 2030, the passenger car market will account for approximately 30-40% of total consumption of hydrogen fuel.

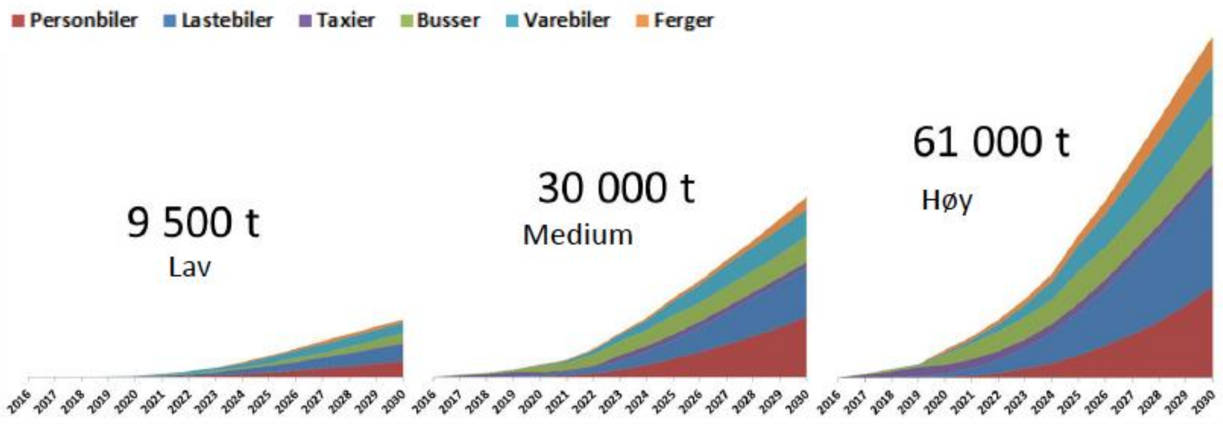


Figure 5.1. Total hydrogen demand (in kg H2/year) for the three scenarios in Tomasgard et al. (2016)

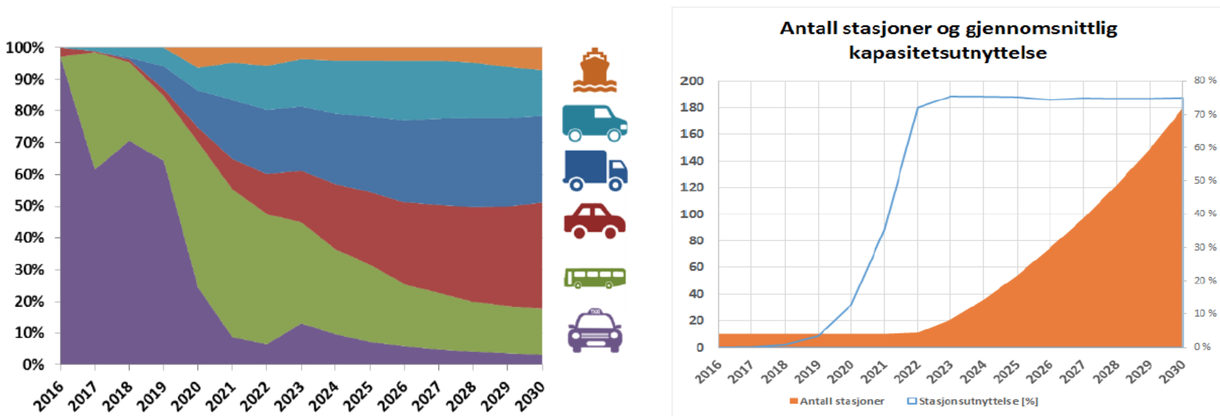


Figure 5.2. *Left:* Relative consumption of hydrogen in different segments in the medium scenario. *Right:* Number of filling stations needed and their utilization ratio. Source: Tomasgard et al. (2016).

It is assumed that hydrogen is produced by local electrolysis. Figure 5.2 presents an estimate of the need for stations and their utilization.

5.3 Policy measures supporting early introduction of hydrogen

Establishing infrastructure for hydrogen fuelling (stations) will be particularly important in the early stages of the introduction phase. Calculation of costs and profitability of these in Tomasgard et al. (2016) indicates that the investment and operation of hydrogen stations will be financially demanding for several years. The main reason is limited sales of hydrogen per station in an introductory and development phase and therefore modest sales revenue that would not recover cost if hydrogen is priced competitively. A successful introduction of hydrogen fuel in the transport sector in the next years therefore requires measures that stimulate both the supply side, through the establishment of hydrogen fuelling stations, and the demand side, to ease introduction of FCEVs in the market.

Such measures should only be implemented to support immature technologies under the belief that the long-term benefits in terms of reduced emissions will outweigh the costs of the short-term support. In the case of hydrogen, implementation today would require both investment support and operational support.

Investment support: The investment support should be organized as a tender or reverse auction. Investment support can be provided through national schemes, but also through local support in the form of, for example, cheap or adapted areas for stations.

Operational support: Since the volumes are expected to be small in the early years, the operators of hydrogen stations also need operational support. The first stage of operational support should cover the disadvantage of having to recover fixed costs at a time when volumes and revenues are modest. The next stage of operational support should cover the fixed operating costs. These are relevant in a period after the volumes have increased to the extent that the utilization of each hydrogen station is at a sufficient level, but operating costs are still too high to defend profitability.

If the objective is to achieve early introduction, we recommend that national authorities in an initial phase be responsible for investment and operational support for filling stations. This should be followed up at a national level in terms of policies that stimulate demand. Local means such as zero-emission zones in the city centres and zero-emission requirements in public procurement policy will effectively stimulate demand, but in many cases favour more mature technologies than hydrogen. Targeted use of instruments for establishing hydrogen-fuelling stations will be susceptible to stimulate rapidly increasing stocks of FCEVs. It would be natural that demand for hydrogen fuel in an initial phase is stimulated in the same way as we have seen for the introduction of BEVs. Tax exemptions and other privileges have proven to work very effectively. We recommend retaining the tax exemption and current privileges for hydrogen cars, until a number of at least 50 000 such cars are operating on Norwegian roads. As a demand stimulus, Norway's major cities and regional authorities can play a key role in its regulation and its procurement policy.

A significant barrier to the introduction of hydrogen is uncertainty regarding the number of FCEVs that will be available on the market at the 2020 and 2025 horizons. It is likely that a combination of instruments on both the supply and demand side will be sufficient to make Norway an interesting market for FCEV manufacturers. Norway has long lacked a national hydrogen strategy, and politically endorsed plans and ambitions for the introduction of hydrogen as an alternative zero-emission fuel. This has most likely reduced the potential for Norway becoming an interesting market for FCEV manufacturers. If the purpose is to reduce this uncertainty, it is crucial to establish a national hydrogen strategy, with quantified targets for the introduction of hydrogen as a fuel. A well-developed hydrogen infrastructure in the major cities can turn Norway in to an interesting market for international suppliers of fuel cell electric vehicles.

6. Transition strategies

As one important pillar of exploration, the CenSES and MoZEES Centres for Environmentally Friendly Energy (FME) develop and apply quantitative models of the energy, vehicle and transport markets and their interaction. In this chapter, we use three of these models – BIG, REMES and TIMES – to outline some quantitative analyses of the transition strategies that can bring us towards 50% emission reductions in the transport sector compared to 1990 levels. Some fundamental questions to be addressed are (i) how fast the GHG emissions from road transport can be expected to come down, (ii) whether and how the energy system will be able to support such a transition, and (iii) what will be the effects for society in terms of production and welfare.

We further discuss some of the main hurdles, where further policy needs to be developed, and finally discuss briefly some of the trends that may change the picture. The main objective of the scenario development activity is to provide research-driven knowledge and analyses of how a low GHG emission scenario could be achieved for domestic transport in Norway within 2030.

6.1 REMES and TIMES scenarios for 50% emission reductions

NTNU and IFE have linked the regional economic model REMES with the energy system models TIMES. This provided an opportunity to study what types of technology scenarios that would be compatible with a 50% reduction in greenhouse gas emissions in the transport sector before 2030, and what kind of welfare and distribution effects such a technology switch would have (Helgesen et al., 2017). Figure 6.1 shows four different technology mixes denoted *exog*, *bau*, *co2* and *co2k* that result from varying underlying assumptions. Here the most interesting one is *co2k*, where the 50% emission constraint is enforced, and the households' capital is adjusted to reflect the increased investments as compared to business-as-usual (*bau*) without CO_2 restrictions. The *co2k* scenario reduces GHG emissions by 50% from the Norwegian transport sector as compared to 1990. The target is reached by making technology investments in FCEVs as well as in BEVs. In the (co2) scenario, the analysis naively assumes that investments in emission reductions in the energy system model do not affect capital growth REMES. In (exog) energy service demand is given exogenously to TIMES from a national projection, and this is included for reference.

The considerable technology investments needed to achieve a 50% reduction in GHG emissions consume capital and limit the capital stock growth, decreasing the value of total production in 2030 by 2.8 per cent. The decrease in household welfare corresponds to a 6.5 per cent salary reduction. We see that all transport segments experience substantial reductions in this scenario but should particularly note the dramatic effects for road transport, where emissions are reduced to approximately 1.5 million tons (coming mainly from long distance trucks).

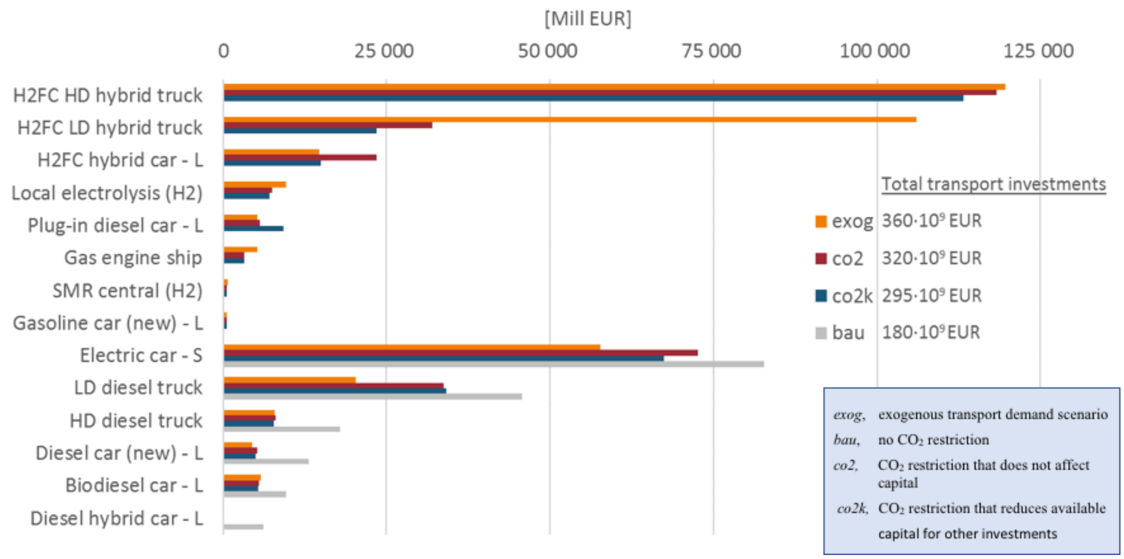


Figure 6.1. Total transport investments comparing the CO_2 constrained scenarios with the bau scenario (H2FC = hydrogen fuel cell, HD = heavy duty, LD = light duty, L = long distance and S = short distance). Source: Helgesen et al. (2017). *Some of the effects on different segments are shown in Fig. 6.2.*

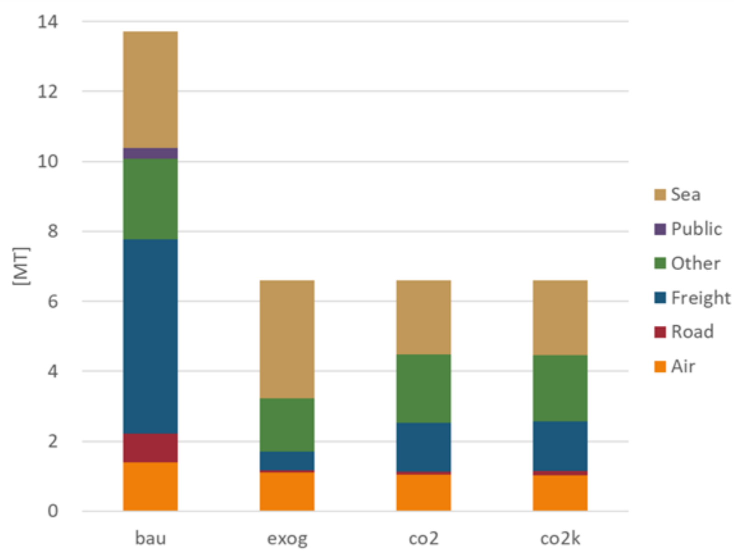


Figure 6.2. CO_2 emissions from transport in 2030, comparing the CO_2-constrained scenarios with the bau scenario. Based on Helgesen et al. (2017).

6.2 Vehicle fleet projections

The BIG stock-flow model of the Norwegian motor vehicle fleet gives another perspective. Developed by TØI, the model constitutes a uniquely detailed accounting framework forecasting the fleet onto the 2050 horizon and beyond. Projecting year-by-year changes in the fleet of vehicles in each of seven categories, each crossclassified by age, energy technology and weight, the model produces output in the form of segmented vehicle stocks, vehicle kilometres travelled, ton kilometres transported, energy consumed (by energy carrier), and CO_2 emissions. The main input consists in segmented flows of new vehicles registered in each calendar year. For the flow of new passenger cars, a generic discrete choice model has been estimated (Østli et al. 2017), linking the car customers' choice of vehicle model to (changes in) fuel and vehicle taxation.

Relying on this accounting framework, Fridstrøm & Østli (2016) developed several scenario projections onto the 2050 horizon. Their 'ultra-low emissions' (ULE) scenario is roughly consistent with the government's target for the market uptake of zero emission vehicles by 2025 and 2030 (Fig. 6.3).

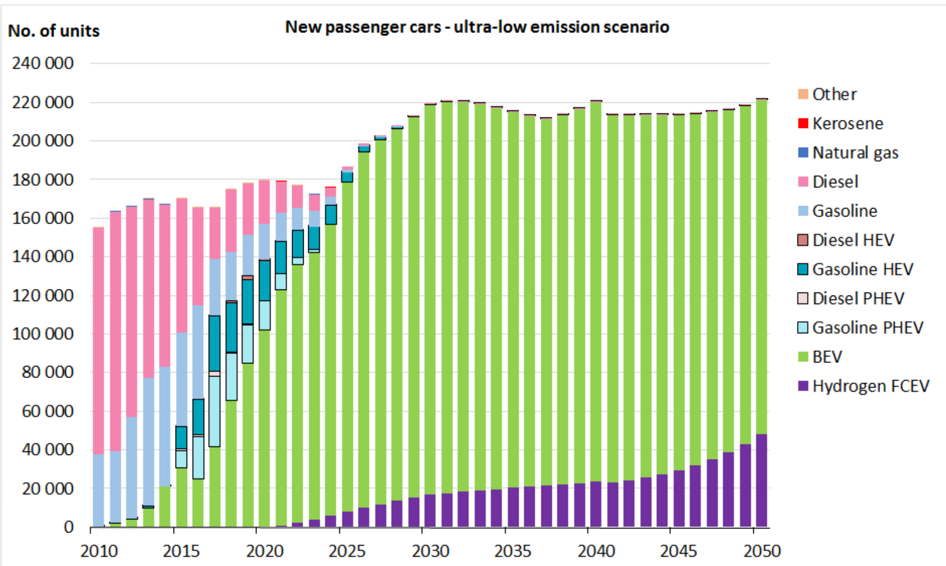


Fig. 6.3. Annual flow of new passenger cars, by energy technology, under ultra-low emission scenario. Source: Fridstrøm & Østli (2016).

Fig. 6.4. Their less demanding 'trend' scenario, on the other hand, is essentially an extrapolation of the market developments observed during 2010-2016.

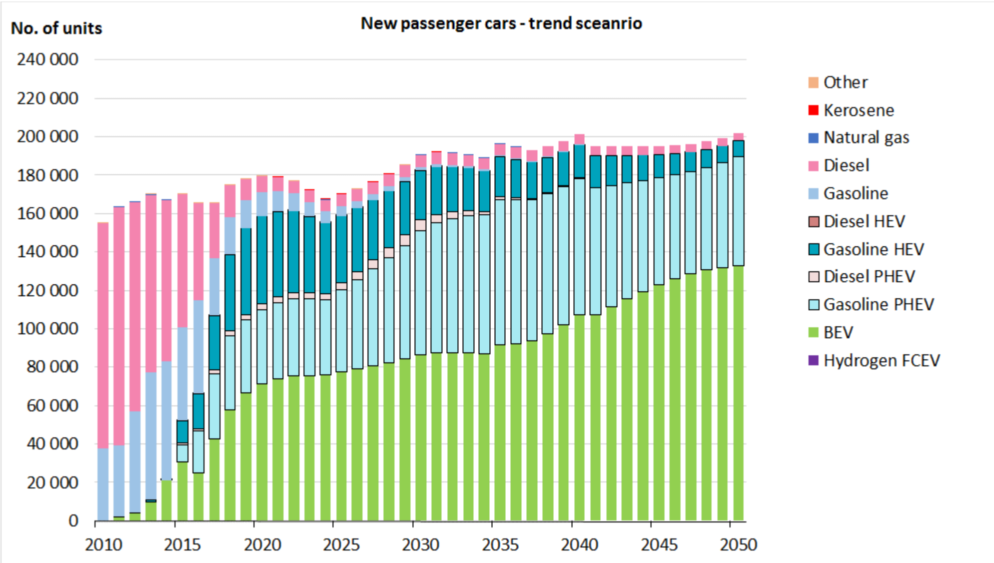


Fig. 6.4 Observed and projected flow of new passenger cars, by energy technology. Trend path extrapolated from 2010-2015. Source: Fridstrøm & Østli (2016).

Under the highly optimistic assumptions implicit in the ULE scenario, CO_2 emissions from the Norwegian motor vehicle fleet could drop by 45 per cent between 2015 and 2030, before taking account of a possibly increased biofuel share (Fig. 6.5).

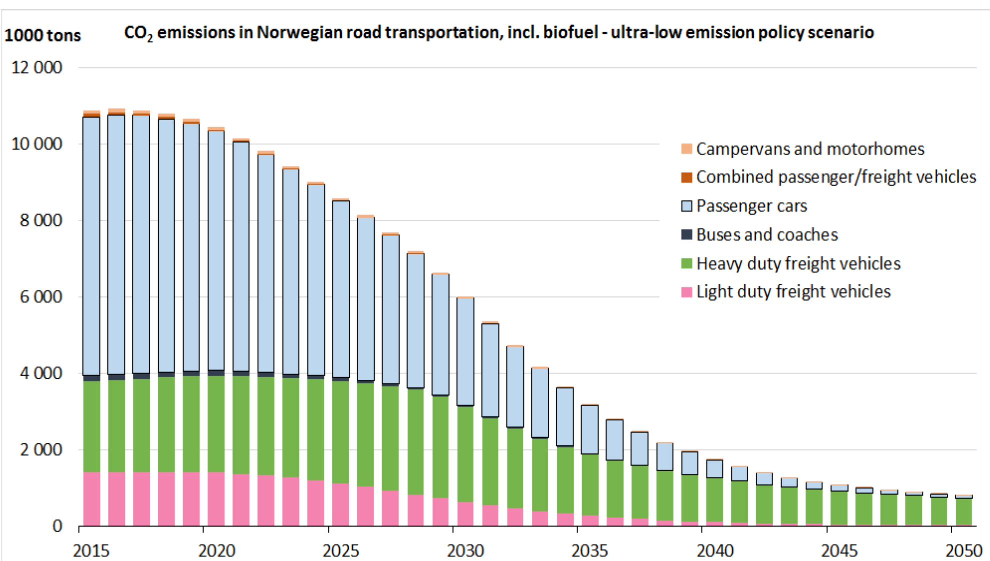


Fig. 6.5. Projected metric tons of annual CO_2 emissions from Norwegian road transport under ultra-low emission scenario, by vehicle category. Emissions from biofuel combustion are included. Source: Fridstrøm & Østli (2016).

This is not to say that large cuts in emissions will come easy. There is a risk that such downward-bending emission curves be misinterpreted as prophecies, in which case they might give rise to complacency rather than to effective policy intervention. It remains an open question if there are policy instruments strong enough to induce vehicle customers to behave as presumed in the ULE policy scenario.

Under the less radical assumption that the market trends of the near past continue, the BIG model projections suggest a 21 per cent reduction in GHG emissions from Norwegian road transport between 2015 and 2030, before biofuel effects (Fig. 6.6).

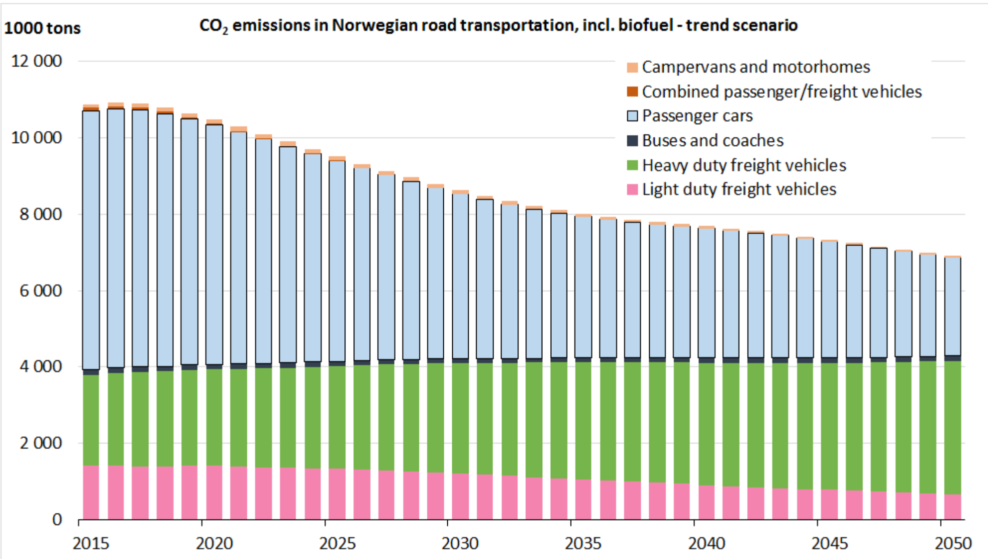


Fig. 6.6. Projected metric tons of annual CO_2 emissions from Norwegian road transport under trend scenario, by vehicle category. Emissions from biofuel combustion are included. Source: Fridstrøm & Østli (2016).

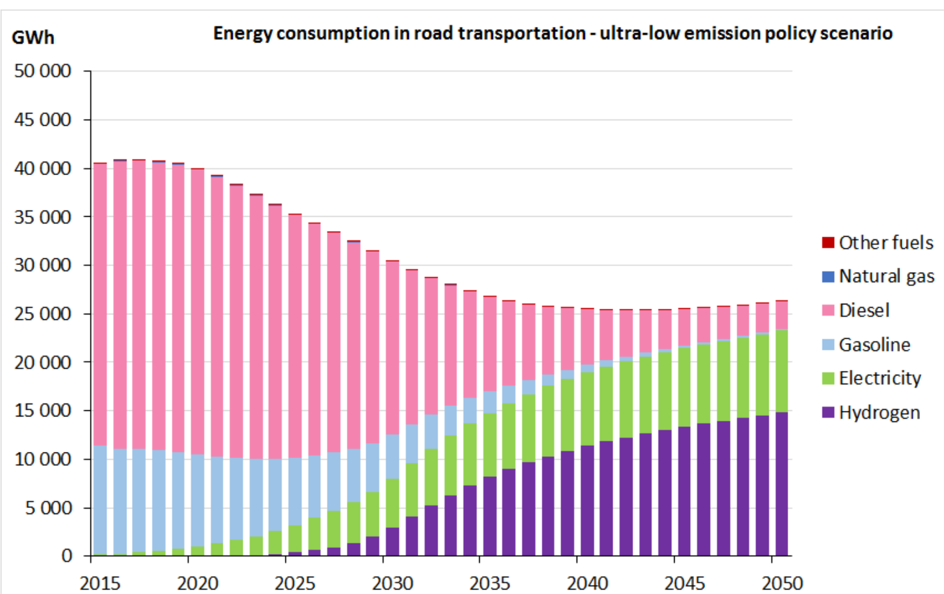


Fig. 6.7. Projected energy consumption in road transport under ultra-low emission policy path, by energy carrier. Biofuel combustion is included. Campervans, motorhomes and combined passenger/freight vehicles are left out. Source: Fridstrøm & Østli (2016).

As evidenced by the BIG stock-flow model, there is considerable inertia in vehicle fleet developments. It may take 5 to 15 years before innovations affecting the flow of new vehicles have penetrated similarly into the stock (Fridstrøm 2017a). This time lag would depend on the velocity of vehicle fleet turnover, on the target level of penetration, and on the speed and steadiness of the technological diffusion process.

In Fig. 6.7. we show the development of the energy mix in road transport in the ULE scenario. The share of zero emission technologies – hydrogen and electricity – is projected to grow from 0.35 per cent in 2015 to 26 per cent in 2030 and 89 per cent in 2050. The electricity consumption of light duty BEVs comes out at 8.4 TWh in 2050, while hydrogen driven HDVs require an estimated 14.9 TWh of electricity, if hydrogen is to be produced through water electrolysis. Taken together, these consumption figures correspond to around 17 per cent of present-day annual hydropower output in Norway. At the same time, road users will save around 4 billion litres of liquid fuel annually, with an energy content of around 37 TWh.

6.3 Main challenges

Based on the studies above we have identified some main challenges in decarbonizing strategies for the transport sector.

Road transport towards zero emission

Road transport will play a major role in decarbonization towards 2030. If the transport sector as a whole were to reduce emissions by 50%, road transport would most likely have to take a higher share than the other segments. While the REMES/TIMES analysis show that this would be possible from a technology and energy perspective, it would presuppose a dramatic transformation of the vehicle fleet. While today’s support schemes seem to be efficient as a market stimulus, they would not be sufficient to achieve such a dramatic change alone. Enhanced use of fiscal and regulatory measures as well as support for biofuels, hydrogen technologies and infrastructure would be needed in addition.

A special focus would be needed for long-haul freight. Looking at the statistics and literature from the period 1993-2013 we can conclude that systematic policies aimed at achieving reductions in energy use or GHG emissions from road freight transport have only to a very limited degree been implemented in Norway, with the exception of biofuel regulations and increased railway investment. Apparently, the market potential for transferring freight from road to rail is very limited indeed (Marskar et al. 2015).

Nor have we been able to detect any important autonomous technological changes that might substantially contribute in the same direction—although average load factors have improved slightly (Walnum et al. 2015), and road freight vehicles are becoming steadily larger and hence more energy efficient as reckoned per ton kilometre (Fridstrøm 2017b). The volume of freight transport and the accompanying energy use and GHG emissions have increased (confer Figs. 2.1 and 2.3, Walnum and Aall 2016, Walnum et al. 2015).

International air travel by Norwegians

International air travel by Norwegian residents is not included in official GHG emissions, which is based on a geographical approach to responsibility for emissions, in which all emissions generated by economic activities within a country’s territory are included in the total emissions for that country. Hille (2015) estimated that plane travel abroad by Norwegian residents corresponded to 24 billion passenger-kilometres (pkm) in 2006 and grew by 37% to 32.96 billion pkm by 2013. A recent study found that when all transport activities by Norwegians, both domestic and abroad, were estimated for their absolute global change potential per unit of emission in a 50-year time period (AGTP 50), Norwegians' air travel abroad represented 51%, compared to 39% for the car mode (Aamaas and Peters, 2017). This reflects the fact that air travel abroad is the fastest growing transport segment for Norwegians, and even in the short term has the highest share of GHG emissions.

Production and welfare effects

The TIMES/REMES studies show that the energy transition in the transport sector will have a negative effect both on the national output and on aggregate welfare. The fulfilment of Norway's climate policy obligations comes at a cost. To the extent that GHG mitigation is considered a political imperative, the relevant policy question is not whether the energy transition represents a first-best economic improvement, but whether there are other second-best policy options available that will achieve the mitigation goals at a lower social cost.

6.4 The impacts of new trends in mobility

Various chapters in this report highlight the complexity of interrelationships between GHG emissions, energy use, car ownership and transport behaviour. Given these interrelationships, it has been argued that the most important principle to reduce transport demand is 'non-ownership of cars' (Gilbert and Perl 2008). Where people do not have access to a private car, transport volumes will decline. This is because much transport behaviour is "script-based" and impulsive (Gärling and Axhausen 2003), with strong evidence that transport choices can be influenced in favour of bicycle and public transport, particularly in city contexts (Buehler et al. 2017; Pucher and Buehler 2012). Such interventions are supported by various trends. Some of these are briefly discussed below; it deserves to be noted, however, that these have relevance mostly concerning urban passenger transport, and they do not themselves constitute evidence of changes in overall transport demand.

Changes in driver's license penetration

The trend of declining driver's license penetration among younger people was first discovered in Sweden and Norway in the late 1990s, where Berg (2001) found a decline in license holding among young adults by over 10% between the mid-1980s and the late 1990s. Sivak and Shoettle (2012) later on found, for the period 1991-2009, that license holding among 18-34-year olds in Norway had declined from 58-89% to 40-76%, depending on age bracket (18, 19, 20-24 or 25-34). Similar trends have been noted even in France, Germany, and Australia (Delbosc and Currie 2013; Kuhnimhof et al. 2013).

Note, however, that aggregate license holding across all age groups in Norway keeps mounting (Fridstrøm 2018), and that license holding among Norwegian 18-year-olds has increased every year since 2007 (Nordbakke et al. 2016), thus reversing the trend towards lower license penetration among the young.

An important question is whether future automated cars will make it unnecessary to have a driver's license. If yes, car use will become available to new groups of travellers, possibly contributing further to the growth in car use demand.

City cycling

In many areas, cycling is experiencing rapid growth, most notably in European cities, but even in various developing countries (Pucher et al. 2010). Statistically, the city of Groningen in the Netherlands appears to be leading this development, with cycling representing more than 60% of all trips (The Guardian 2016). In Copenhagen, bicycling represents around 50% (Gössling 2013). In Norwegian cities, cycling shares hover between 4 and 9 % (Hjorthol et al. 2014, Lunke et al. 2017). With various measures in place to increase cycling shares in Norwegian cities, there is a likelihood of cycling becoming more widespread. Cycling levels are largely dependent on bicycle infrastructure and perceived safety, and often supported socio-culturally by changes in perceptions of the desirability of working out for better health. Many cities pro-actively support cycling to ease density problems. Overall, for reasons rooted in climate and topography, city cycling may have more limited importance in Norway than elsewhere, although electric bikes have the potential to overcome the topography barrier.

Information and communication technology (ICT)

Applications have made public transport far more navigable. In particular smartphone applications help to access travel information (departure times, cost), intermodal connection (tram, train, subway, bus, rental bikes, car sharing), and payment. Advanced apps already include delay control and crowding indicators. Public transport is also increasingly well-adjusted to passenger expectations, with many buses or trains now offering wireless Internet access, usually free of charge (Gössling 2017a). ICT is also behind novel approaches to bicycle sharing, such as the 'ofo' bikes (www.ofo.com), representing commercial approaches to bicycle sharing, based on very low fees and free floating, as these bikes can be left anywhere after the rental period. Even car sharing is important in terms of the contribution it makes to non-car ownership principles. In 2010, car-sharing systems were already available in 1100 cities in 26 countries (Shaheen and Cohen, 2013), and most large cities in Europe now have several competing car-sharing operators. Apps facilitate reservations, billing, and electronic keys. Where cities systematically reallocate parking spaces to car-sharing programs, on a citywide basis, this can push rental systems (Gössling 2017b).

While car-sharing schemes are susceptible to reduce car use within families that would otherwise possess their own private car, they also serve to make cars available to a larger number of families, and at a lower fixed cost. It is therefore an open question whether aggregate automobile use will increase or decrease with the expansion of car sharing schemes.

Automation

Automated vehicles are largely understood as mobility game changers. They can transform automotive systems in two general directions, depending on whether vehicles continue to be privately owned or if these operate out of pools, i.e. as offers of mobility as a service. In the former scenario, individuals continue to own vehicles that can now drive and navigate by themselves. This is a scenario favoured by the car industry, which is also suggesting that cars will be able to more efficiently use road space (safety distances) and become accident avoidant. However, in this scenario, problems of resource use to build cars, energy consumption, space-requirements, and particulate matter pollution from brake pads, pavement and tires will continue to have relevance for the sustainability of transport systems. Notably, in this scenario, there would also be considerable rebound effects in terms of transport demand (Gössling 2017b). Unregulated private access to autonomous cars could increase the transport volumes as measured in vehicle kilometres, if not in person kilometres. If the car can bring its owner to the job and then return on its own, the parking barrier against commuting by car has been overcome, resulting in drastically reduced occupancy rates and increased traffic flows and congestion, especially during rush hours. Moreover, in autonomous cars, drivers would be able to spend their time on something else than driving, thus neutralizing the most important competitive advantage presently held by public transport means.

The alternative scenario is one where cars are no longer privately owned, but ordered on demand, either as a robotized taxi, or as a pool version in which rides are shared between several passengers. In both cases, costs are likely to come down, primarily because the drivers' payroll could be reduced to almost zero. In principle, this could make some 70% of all cars redundant. In cities, larger shares of transport needs are covered by bicycles, while public transport opportunities have been developed and become more attractive. Longer distances are also covered by public transport or rented cars.

Whether such a scenario transforming mobility into a service is desirable for larger parts of the population, and will be politically supported, is currently unclear. Developments somewhere between the two most extreme scenarios may seem like the most likely outcome.

The underlying logic of exploration is rather clear, however: vehicle services *as such* may be provided at a lower cost (construction, energy, parking) as ICT and automation facilitate that vehicles are used more intensively (more than an hour per day, more than 1.2 passenger kilometres per vehicle kilometre). Thus, vehicles that are less idle can be built better. As an illustration, assume that an electric car costs NOK 50 thousand more to build. Used an hour per day, it can be unaffordable even though it costs less to use. But it can be eminently affordable if it serves more households and is used more hours.

7. Discussion and policy implications

7.1 Five general strategies

Greenhouse gas emissions from transport can be cut in five different ways:

6. Reduced economic activity (GDP) and standard of living, resulting in reduced transport demand
7. Reduced mobility of people and goods at all income levels
8. Transfer of travel and freight to less carbon intensive modes
9. Improved energy efficiency of vehicles, vessels and craft
10. Transition to less carbon intensive energy carriers

Option 1 is unattractive to the extent of being politically infeasible in democratic societies. To obtain a one per cent cut in Norwegian GHG emissions through a proportional (i.e., one per cent) cut in GDP, the cost in terms of foregone value added would amount to around NOK 62 000 per ton of CO_2 equivalents (tCO_2e). A middle-of-the-road estimate of the marginal global damage cost of GHG emissions is, by comparison, in the order of NOK 450 per tCO_2e (NOU 2015:15), and the current (April 13, 2018) price of emission allowances in EU ETS is approximately NOK 130 per tCO_2e.

Option 2 runs counter to the very ideas of trade, integration, freedom of movement and division of labour – the generally acknowledged, fundamental recipes for economic growth and wellbeing. Hence, the European Commission categorically rejects this avenue as a workable possibility.

Some versions of option 2, however, do not necessarily detract from economic efficiency or welfare. Smart urban planning and regulation may reduce the distances between key points of attraction and pave the ground for competitive public transport, bicycling and walking. The long-term difference in energy use and GHG emissions between a dense city and an urban sprawl is vast. In the short and medium term, however, the GHG abatement potential of this strategy is limited, as it takes time to reshape a city and its land use.

In essence, this leaves us with *decarbonization* as the sine qua non of GHG abatement policies in the transport sector. The question is how such transition can be brought about. This is the topic of the present position paper.

Option 3, understood as a transfer from gasoline and diesel driven vehicles to electrically powered rail transport, to bicycling and walking, or to buses and coaches powered by biogas, hydrogen, batteries or trolley lines, will indeed amount to a de facto decarbonization of transport and hence contribute to a reduction in GHG emissions. It probably also implies energy conservation, since electric motors are much more energy efficient than internal combustion engines (ICEs). Even diesel driven buses and coaches may represent an improvement compared to the private car, since – depending on occupancy rates – they tend to consume less energy per passenger kilometre.

However, the GHG abatement potential of this strategy is constrained by the low degree of intermodal competition, which is more limited than commonly assumed – in the freight as well as in the travel market. Very powerful incentives are needed in order to change the modal split in a way that really makes a difference. This is true in sparsely populated Norway more than almost anywhere else. No EU or EFTA country exhibits a lower share of public transport and a higher share of private car use than Norway. Bicycling is also relatively infrequent – deterred by weather and topography.

Options 4 and 5, on the other hand, offer many opportunities that are only beginning to be exploited. Both options imply *technological transition* in one form or another. To achieve Norway's GHG mitigation goals, it is essential that policy makers put their main emphasis on strategies to support technological innovation. Only a massive substitution of zero and low emission vehicles and vessels for conventional ICE technology could bring about emissions cuts of the order needed to meet the national mitigation goals.

The main challenge for policy makers is to identify and implement the most effective policy instruments and strategies. Technological advances are not sufficient in themselves. Equally important are their successful introduction into the market. Transport operators, shippers, clients, public agencies, households and individuals must see it in their interest to opt for climate friendly modes of operation. The adoption of new, low or zero emission technologies must become profitable – if necessary by means of government incentives and regulation.

In searching for effective GHG abatement measures, policy makers should be aware of the need to avoid unfavourable *technological lock-in* effects. Strategies that seem expedient in the short or medium term may turn out to hamper or delay a more fundamental transition needed for long-term carbon neutrality, since assets such as vehicles, vessels and infrastructure may have a service life stretching across several decades.

To minimize the risk of lock-in effects and other developments adverse to the attainment of carbon neutrality, it is generally thought that incentives and regulations ought to be technology neutral. Manufacturers exposed to the test of the market are better prepared for the necessary risk assessment than any government agency.

If possible, fiscal and regulatory instruments should be directed towards the very aim of the policy itself rather than towards some intermediary or subsequent circumstance. If, e.g., the goal is to minimize CO_2 emissions, one should tax the emissions themselves rather than a particular kind of technology, which may or may not become carbon neutral in the near or more distant future.

In some – not so rare – cases, however, the positive network externalities of a new technology are large enough to warrant government intervention to ease market introduction. Zero emission vehicle technology is a case in point. Battery and fuel cell electric vehicles will continue to be considerably more expensive than conventional ICE vehicles until their manufacturing has reached comparable economies of scope and scale. In addition, the network infrastructure needed to serve these vehicles is bound to be commercially unprofitable in the start-up phase, which is why government subsidies and regulations to stimulate its rollout are economically well founded.

To minimize the risk run by early movers in the technology transition, and hence encourage their initiatives, predictability is key. Policy makers should be consistent in their signals to market, announcing changes in the policy framework with a maximum possible lead. This is not to say that, when new information emerges, policies cannot be changed – they should.

The instruments available to public policy makers are quite diverse. One could distinguish between (i) fiscal instruments, (ii) regulatory measures, (iii) public investment and procurement, (iv) organizational and institutional measures and (v) communication and control.

7.2 Fiscal instruments

Among the fiscal measures available, the CO_2-graduated one-off vehicle purchase tax for passenger cars, with its exemption for zero emission vehicles, stands out as remarkably effective. Another forceful measure is the ZEVs' exemption from value added tax (VAT). For freight vehicles up to 7.5 tons, however, the tax rate is too low to provide a forceful incentive, and the VAT exemption is without importance, since most buyers are VAT registered companies. The heavy-duty freight vehicles are not subject to purchase tax at all.

The fuel tax consists of a CO_2 component and a road use component. The CO_2 component has been set in accordance with international estimates of the global damage cost. The road use component, on the other hand, is quite inadequate, in that it does not at all reflect how the marginal external costs of road use vary widely in space and time, as well as with vehicle characteristics. Of course, the behavioural response of consumers depends on the sum of the two fuel tax components, without regard to how each of the two is labelled. Even so, the price elasticity of demand for fuel is too low for the fuel tax to provide a forceful instrument for GHG abatement.

Liquid biofuel sales in excess of the mandatory minimum share (10 per cent in 2018) are exempt of fuel tax. Biofuel incentives make sense in the short and medium term, since it will take time before vehicle fleets and energy infrastructure have been renewed. Increased use of biofuel, in contrast, has an immediate effect on the GHG emission accounts. This goes to illustrate the merit of technology neutral policies: When powered by biofuel, ICE vehicles are not as harmful to the climate as when they run on fossil fuel. A policy that rules out the use of that particular technology – ICE – may not be the fastest or most efficient pathway to the low carbon society. The term 'fossil cars' is meaningless, since modern cars run as well on renewable fuel as on its fossil counterpart.

Road pricing and tolling constitute a third category of fiscal instruments. As traditionally practiced in Norway, tolling is very different from the optimal form of marginal cost road pricing favoured by economists. While the latter corrects the behaviour of road users in the direction of maximum welfare, the former, as applied to uncongested highways, tunnels and bridges, gives rise to a deadweight loss that reduces the benefit of the investment. In recent years, several cordon toll rings have introduced differentiated rates – a small step in the direction of marginal cost pricing. Zero emission vehicles are generally exempt of toll – a powerful incentive towards vehicle electrification in certain communities.

A possible *future* system – for instance satellite based – for general road pricing, can incorporate the multiple purposes for *present* tolls, fuel taxes and annual circulation taxes:

(i) A vastly more correct internalization of the road users' external costs (road wear, congestion, air pollution, noise, accidents);

(ii) Elimination of the deadweight loss following from of fixed-point tolling on uncongested roads,

(iii) Government revenue

(iv) An opportunity to create sufficient incentives to make light and heavy-duty freight vehicle owners invest in zero or low emission technology, and to make these incentives sensitive to local conditions.

Finally, a very important system of economic incentives bearing indirectly upon the road transport sector is the European Union's Emissions Trading System (EU ETS). All electrically driven means of transport are, in a sense, covered by the ETS, since all power plants above 20 MW effect are. Trivially, this means that the GHG emission from an extra train or metro departure is zero. More interestingly, it also applies to battery electric cars. If the entire vehicle fleet has been electrified, a most important national source of emission has been moved *into the cap-and-trade system*. Hence, the climate relevant emission from the operation of an electric vehicle is zero.

7.3 Regulatory measures

The biofuel regulation requires fuel providers to sell a minimum of 10 per cent biofuel during 2018, of which at least 4 per cent is to be suited for gasoline engines and a minimum of 3.5 per cent is to be so called 'advanced' biofuel fulfilling certain criteria of sustainability. By gradually raising the mandatory biofuel share, the government will be able to ensure a certain decrease in accountable GHG emissions from transport.

A certain percentage of first-generation biofuel, such as the well-known fatty acid methyl ester (FAME) often produced from rapeseed, can be blended into fossil diesel without impairing or harming the operation of the engine. Second generation biofuels, such as hydrogenated vegetable oil (HVO), are usually pure enough to be used in diesel engines without any blending with fossil fuel.

While the use of biofuels in ICE vehicles has an immediate effect on the GHG emission accounts in the Norwegian transport sector and may even be needed to reach a target of 50% emission reductions, the global emission reduction effects depend heavily on how and where the biofuels are produced. Hence, a focus on the sustainability and actual global GHG emissions of the biofuels used in the coming years is critical if the expected climate effects are to be achieved. This can be managed mainly by regulatory measures.

Low emissions zones are becoming common in many European cities. Although their purpose is to combat local air pollution rather than to reduce GHG emissions, the latter may follow as a collateral effect, when residents convert to public transport, bicycling or battery electric vehicles. Strict parking regulations may have similar effects.

7.4 Public investment and procurement

Through its role in public procurement and infrastructure provision, the government has a powerful set of instruments at its hands. In Norway, more often than not, public transport companies run their business under a tendered contract with the local, regional or national government. The same applies to the air routes operated as part of a carrier's 'public service obligation' (PSO).

The government can exploit its monopsony position to lay down mandatory environmental standards of operation. Bus operators may be required to provide a certain share of emission free vehicles or to satisfy certain maximum levels of aggregate exhaust emissions. Ferry operators may be encouraged to use low or zero emission vessels. In the not so distant future, air carriers may be asked to use low emission craft or fuel.

These regulatory measures may give rise to non-negligible GHG emission cuts. There is, however, a pitfall. If the duration of the contract is much shorter than the service life of the assets acquired by the operator, the next round of tendering, involving sharpened environmental requirements, may result in a lot of stranded assets –

buses and ferries than can no longer be used or sold. In a global life cycle assessment (LCA) perspective, this is hardly a desirable outcome.

Another potential improvement with a bearing on modal split and GHG emissions is the conversion from gross-cost to net-cost contracts. As of today, most public transport tenders in Norway are for gross-cost contracts, in which the operator accepts to service the route for a given amount of money, covering the operator's gross cost. The ticket revenue collected belongs to the public authority. In this case, the operator has no incentive to increase ridership. In a net-cost contract, however, the operator keeps the revenue and has every incentive to satisfy his customers and attract additional ones. The operator will therefore strive to enhance the quality of his supply, improving his competitive position versus the private car.

Even more important than public procurement is public investment. The government funds and decides the provisions of road, rail, coastal and aviation infrastructure. By allowing climate and environmental concerns to bear on the decisions made, the government can make a big difference towards the long-term goal of carbon neutrality. Climate assessment studies should identify and estimate the GHG abatement consequences of the respective investment options on the table.

As cities, municipalities, counties and other public bodies are considering priorities for local and global environmental goals in their procurement and concessions, improvements along several lines will become more pressing. One such is the trade-off between professionalization, standardization and stability on the one hand, and local conditions on the other. As an example, counties ambitious in CO_2-lean concessions (ferries, buses), see these as hard to justify, in part because CO_2 is not taxed in marine diesel, in part because positive spill overs offered by technological advances and demonstrations will not necessarily pay off to the region.

The three government agencies covering road, rail and coastal shipping all have climate and environmental goals written into their programs. Considering the fact that more than half the climate footprint stemming from Norwegian citizens' travel behaviour is due to aviation, domestic and international, it seems paradoxical that Avinor, as the only government transportation agency, is pursuing a growth target that takes precedence over the GHG mitigation objective. This growth target translates into an investment proposal for a third runway at Oslo airport Gardermoen.

For transportation, a most important investment area in the decades ahead will be the power grid. Massive electrification of the vehicle fleet will lead to increased demand for electric power as measured in TWh per annum. Previous studies have concluded that this aggregate increase in demand is entirely manageable for the Norwegian energy supply system. More critically, the simultaneous recharging of millions of vehicles may strain the distribution grid beyond its present capacity. To successfully realize the energy transition foreseen in transportation, substantial investment will be required in the power sector. Local grids will have to be strengthened, and smarter systems of demand management will have to be implemented to shave off the peaks in electricity demand and possibly even exploit the energy storage capacity of vehicles through vehicle-to-grid (V2G) systems of power exchange.

7.5 Organizational and institutional measures

Transport and communication are network industries. Interestingly, the various sectors of transport and communication in Norway are all regulated and organized in different ways. Suffice it to mention the rail sector and the mobile telephone sector. In the latter case, the dominant company, Telenor, owns and operates its own network, however on the explicit condition that competitors be allowed to sell services in Telenor's network, having bought access to it at wholesale prices regulated by the Norwegian Communications Authority (Nkom). Behind this regulation is the recognition that, for a network company to have sufficient incentives for investment and innovation, they must be able to reap at least part of its benefit by selling services delivered by the network. In the rail sector, in contrast, vertical separation is the rule, severing the economic link between the network and the services produced, and ridding the infrastructure company of all financial incentives to provide high quality services. This probably helps explain how the vast investments to construct double track railway lines in the outer parts of the so-called Intercity Triangle around Oslo can continue, without regard to the fact that no more trains can operate on these tracks until the bottleneck formed by the railway tunnel through Oslo has been removed.

The present tendering of contracts within rail service production seems to rely on the misconception that rail transport be a separate, relevant market, within which one must ensure competition, while in reality, for most origin-destination pairs, the market consists of rail, road, sea and/or air transport competing with each other. For the rail sector to become a more powerful instrument in climate and environmental policies, the present degree of fragmentation and separation would have to be replaced by a strong, competitive and fully integrated national rail company, regulated and privatized in ways similar to Telenor.

7.6 Communication and control

Government leadership and advocacy may help raise awareness and provide understanding for the need for effective climate policy action. Information campaigns directed towards the public are another well-known instrument of publicity and public outreach. The behavioural effects of such campaigns are, however, according to multiple research studies, quite limited. In general, one cannot achieve the GHG mitigation goals by appealing to the conscience and good will of the individual citizen. Only measures taken at the collective, political level, inducing large numbers of individuals and businesses to move in the same, climate friendly direction, have the potential to make a significant difference. However, certain measures of communication and control could make a non-negligible contribution. Suffice it to mention climate legislation and carbon budgeting and monitoring.

7.7 First-best vs. second-best policies

The public debate on climate and environmental policies is obfuscated by the fact that different actors have different interests, perspectives and agendas. A more fruitful and scientifically founded discourse could be accomplished if the actors would agree on the objectives to be pursued, or at least agree to keep the arguments about political goals separate from those pertaining to the choice of instruments. Given the objective, the most effective choice of policy means would, at least in principle, be an empirically researchable question. However, when ends and means are continually meddled together, opinions can hardly be subjected to the test of contradiction in such a way as to sort out the most tenable and relevant arguments and arrive, in the end, at a consensus about policymaking.

Economists instinctively consider policymaking in light of their theory of first-best welfare maximization. According to this tenet, an external cost should ideally be internalized by a tax corresponding exactly to the marginal damage caused by the single decision maker. A higher or lower tax than this leads to a welfare loss, i. e. to a deviation from the most efficient (first-best) resource allocation. Economists sometimes argue about climate policy options in general and transport policy in particular as if it is derived from a goal of maximizing welfare.

However, when the Parliament has decided on policy objectives in line with the Paris accord and the climate agreement between Norway and the European Union, this means that the first-best economic solution has already been discarded. Democracy has opted for a constraint on welfare maximisation. For Norwegian transport policy, the political imperative will be to reduce emissions by at least 50% in 2030. The policy challenge is no longer to find a path towards first-best economic resource allocation, but rather to identify the second-best combination of policy measures which obeys the constraint, achieving the mitigation goals at minimum economic cost.

We believe that the climate policy discourse would benefit from all participants' distinguishing clearly and explicitly between ends and means, i. e. between goal setting and the choice of policy instruments.

8. Recommendations

The CenSES and MoZEES centres of excellence on environment-friendly energy take the position that the goals of the climate and environmental policy should be determined by our system of representative democracy rather than by special groups of interest or by advocates of particular scientific approaches. Despite their distinctive insights, engineers, economists, physicists or climatologists, to name a few, are in no position to prevail upon the democratic process of goal setting.

One of the most important decisions by the government is to link Norwegian climate policy to EU climate policy. This means that the Norwegian sectors outside the EU ETS most likely need to reduce emissions by 40% before 2030. In practice, as also reflected in the NTP (2017), this means that the transport sector emissions need to be reduced by at least 50% before 2030 relative to today (8.5 million tons CO_2 equivalents). Norway is committed to this goal, while also ensuring quality of life, maintaining welfare and economic growth. This report has discussed these challenges based on research.

Transfer of travel and freight to less carbon intensive modes will not be sufficient to achieve the ambitious target of 50% emission reduction in the Norwegian transport sector by 2030. Hence, it is important to continue and strengthen current policies towards:

- Improved energy efficiency of vehicles, vessels and craft
- Transition to less carbon intensive energy carriers

Actions that would support such strategy:

1) The CO_2-graduated one-off vehicle purchase tax for passenger cars, with its exemption for zero emission vehicles, stands out as remarkably effective. Another important measure is the corresponding exemption from value added tax (VAT). **We recommend** to further support transition to BEVs and FCEVs by favouring them using fiscal tools, adjusting rates as necessary.
2) **We recommend** regulation to ensure that necessary biofuels are produced sustainably.
3) **We recommend** local government to play a major role in the transition, enhanced by national policies, taking account of the interaction with their local environmental priorities (low emissions zones, ambitious policies for public procurement and public investment in the transport sector).
4) **We recommend** the government to formulate strong GHG mitigation objectives for Avinor, in line with those set for other government transportation agencies.
5) In sea freight, **we recommend** a strategy distinguishing coastal from deep sea shipping, where the former allows more radical approaches (like zero-emission ferries), and the latter must focus on the demands of a globally competitive market for transport services. In both, global influence is a guiding motivation.
6) **We recommend** efforts towards a system for satellite based general road pricing (from the *present* tolls, fuel taxes and annual circulation taxes).

Finally, to minimize the risk run by early movers in the technology transition, and hence encourage their initiatives, predictability is key. **We recommend** policy makers to be consistent in their signals to the market, announcing changes in the policy framework with a maximum possible lead.

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