CenSES
Centre for Sustainable Energy Studies

MoZEES
Mobility Zero Emission Energy Systems

FME
FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

Decarbonization of transport

Short version of a position paper prepared by FME MoZEES and FME CenSES

This report is based on a position paper prepared by MoZEES and CenSES. For author list, full scientific elaboration and references, we refer to the original paper.

The position paper builds on research carried out by MoZEES and CenSES research partners and summarizes current knowledge on the role of electrification in the decarbonization of the transport sector in Norway. It integrates insight from several disciplines—science and technology studies, economics, engineering, energy systems and markets, industrial ecology and political science. The multidisciplinary approach provides a broad picture of the issue.

About CenSES and MoZEES

The objective of the national centres for Environment-friendly Energy Research (FME[1]) 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 develops 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.

[1] FME: Forskningssenter for miljøvennlig energi

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1. Introduction

In 2015, the government made a commitment to link Norwegian climate policy to that of the European Union (EU). An important instrument in the EU's climate policy is the Emissions Trading System (EU ETS), which also covers greenhouse gas (GHG) emissions in Norway. Its ambition is a 43% reduction for Europe 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 expected target is a 40% reduction compared to 2005. 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.

Our research is based on the assumption that the Norwegian transport sector will need to undergo a transition to meet the obligations.

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 almost 16.5 million tons of CO_2 equivalents ($mtCO_2e$) in 2016.

Not all of this is due to transport. Agricultural, construction and household machinery accounted for more than 2 $mtCO_2e$, and the fisheries for more than 1 $mtCO_2e$. Transport as such was accountable for 13.3 $mtCO_2e$, of which almost 10 $mtCO_2e$ in the road sector, almost 2 $mtCO_2e$ at sea, and 1.3 $mtCO_2e$ in aviation. A quarter of the CO_2 emitted on Norwegian territory in 2016 was from transport.

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

The volume of transport has increased far more than the GHG emissions. Domestic motorized travel demand has increased by 50% between 1990 and 2016, the car mode increasing its dominance to 80% of all person kilometres.

The demand for freight has increased even more; by 129% between 1990 and 2015. Also here, the road mode has the largest market share with 48% ton kilometres in 2015, closely followed by the sea mode with 46%.

2.2 Abatement strategies for transport

According to the *avoid-shift-improve* concept, there are three ways to combat GHG emissions in transport:

(i) reduce the total amount of transport (*avoid*),
(ii) move travel and freight to more efficient and/or less carbon-intensive modes (*shift*)
(iii) replace the energy technology of vehicles, vessels and aircraft by more efficient and/or less carbon-intensive alternatives (*improve*).

The total amount of emissions from travel or freight may be decomposed into five factors. Operating on any one of these may 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 2.1. A multiplicative decomposition of emissions from transport[2]

The economic and political costs of GHG mitigation are likely to diminish as we move from left to right in the multiplicative decomposition (figure 2.1.). 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.

The most realistic strategy to reduce transport demand seems to be enhanced urban planning and densification, which could allow for shorter commutes and more competitive mass transit, bicycling and walking. 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 and the likes 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. A comprehensive modelling study of the Norwegian travel market[3] examined many radical policy options. According to the study, even if all these measures were implemented together, they would not reduce GHG emissions from short and long-distance domestic travel by more than 16% and 5% respectively. Apparently, the competition between modes is not strong enough for politically feasible policy measures to bring about massive changes.

This leaves us with the *improve* strategy, or *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. 2.1.). 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,

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[2] Fridstrøm, L., Alfsen K. H. (eds.) (2014). *Vegen mot klimavennlig transport.* [TØI Report 1321], Institute of Transport Economics, Oslo.

[3] Fridstrøm, L., Alfsen K. H. (eds.) (2014). *Vegen mot klimavennlig transport.* [TØI Report 1321], Institute of Transport Economics, Oslo.

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 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. Averaged over all new passenger cars brought to the EU market, the New European Driving Cycle (NEDC) rate of emissions should not exceed 95 gCO_2/km in 2021.

Between 2001 and 2016 this rate, as evaluated for EU-28[4], has decreased by 30.5%, 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. In reality, the 2001-2016 decline in CO_2 emission rates among new cars in EU-28 reduces to less than 9 per cent – from 184 to 168 gCO_2/km.

In Norway, type approval and real-world emission rates have decreased much faster than in the EU. Thanks to the rapid market uptake of battery electric vehicles (BEVs), and to the growing market share of plug-in hybrid electric vehicles (PHEVs), the type approval and real-world emission rates of new Norwegian registered automobiles have come down by 49% and 33% respectively between 2001 and 2016. As of 2017, the type approval rate is down by a full 55%t, 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 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[5]) 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 battery electric vehicles (BEVs) will drop below those of ICE cars sometime before 2025, even without government incentives. As for heavy-duty freight, Moultak et al.[6] 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.

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[4] EU-28: the European Union consisting of 28 countries.

[5] the unintended consequence of releasing more carbon emissions due to land-use-changes around the world induced by the expansion of croplands for ethanol or biodiesel production in response to the increased global demand for biofuels (Wikipedia)

[6] Moultak, M., Lutsey N., Hall D. (2017). *Transitioning to Zero-Emission Heavy-Duty Freight Vehicles.* ICCT, Berlin.

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 petrol or diesel driven cars – depending 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. Considerable emission cuts could be achieved by electrifying Norway's 120 ferry crossings.

In heavy trucks, 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.[7]

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. Due to the cost of such infrastructure, most probably 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

At the 2050 horizon, the overall national target is a near carbon neutral society (CNS), quantified as an 80-95% GHG emission reduction[8]

In this context, emission reductions in transport are crucial. In its climate strategy, the government has put forward 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, like the CO_2-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*

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[7] Rosenberg, E., Fidje A., Espegren K. A., Stiller C., Svensson A. M., Møller-Holst S (2010). Market penetration analysis of hydrogen vehicles in Norwegian passenger transport towards 2050. *International Journal of Hydrogen Energy*, 35: 7267-7279.

[8] Meld. St. 41 (2016-2017). *Klimastrategi for 2030 - norsk omstilling i europeisk samarbeid*. Klima- og miljødepartementet, Oslo

weight, *ICE power*, and *type approval CO_2* and *NO_X*[9] emission rates. The engine power component was abolished in 2017.

Compared to international examples, 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 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 much higher than any measure of the social costs of carbon.[10] [11]As such, the Norwegian policies offer an example to test the potential for carbon-leaner vehicles.

Particularly strong incentives apply to zero emission vehicles (ZEVs), both battery and fuel cell electric. ZEVs are *exempt of vehicle purchase tax, 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, *ZEVs, their batteries and their leasing contracts are exempt of the standard 25% value added tax (VAT)*.

The incentives appear to work. Thanks to a 29% BEV market share and a 19% PHEV share[12], 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) or 32 km per litre (km/L) for a petrol 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.

2.4 The climate impact of vehicle and fuel taxation

Although no general consensus exists, economists traditionally argue that a Pigovian fuel tax[13], or a carbon cap-and-trade system encompassing road transport, constitutes a near-optimal way of internalizing the costs of tailpipe emissions generated by fossil fuel combustion.[14] 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 is misguided.

[9] **NO_x** is a generic term for the nitrogen oxides that are most relevant for air pollution, namely nitric oxide (NO) and nitrogen dioxide (NO_2). These gases contribute to the formation of smog and acid rain, as well as affecting tropospheric ozone.

[10] Yan, Shyiu and Eskeland, G. S. 2018. Greening the Vehicle Fleet: Norway's C02 Differentiated

[11] Eskeland, G.S. (2012) Electrification of transport: Which emissions are ours? Economist (*Sosialøkonomen*, Norwegian, Oktober).

[12] Source: www.ofvas.no.

[13] A **Pigovian tax** is a tax on any market activity that generates negative externalities (costs not included in the market price). The tax is intended to correct an undesirable or inefficient market outcome and does so by being set equal to the social cost of the negative externalities. (Wikipedia)

[14] A fuel tax would not, however, correctly internalise 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).

On the other hand, 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.

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% on top of the pre-tax value – or even higher for the largest and least energy efficient vehicle models. Thanks to the tax exemptions, battery electric vehicles (BEVs) come out with a mean retail price that is on a par with small and medium sized petrol or diesel cars.

There are special rules for PHEVs. To leave the standardized weight of the battery pack out of the tax calculation, the taxable curb weight of PHEVs is reduced by 23%. Since the CO_2 component is generally negative for cars emitting less than 70 gCO_2/km, lightweight PHEVs may come out with zero or near-zero purchase tax. However, the purchase tax cannot become negative.

For cargo vans (LCVs), the same kind of incentives apply, however with less force, since in this case the purchase tax rates are typically 20-25% of the rates applicable to passenger cars.

The VAT exemption does not carry much weight in the case of LCVs, since most of them 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.

For passenger cars, 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, car rental and leasing companies, taxi companies, commercial limousine services, etc. For passenger cars used in an ordinary company's daily operations or placed at the disposal of employees, no input VAT is deductible.

The exemptions from VAT, reduced road toll, as well as reduced income tax and annual circulation tax for BEVs have been approved by the EFTA Surveillance Authority. Without such approval, the incentives would fall into the category of illegal state aid under the rules of the single European market.

There is a general consensus between the political parties to continue and reinforce the incentives for zero and low emission vehicles, at least until 2021. The continued use of these fiscal instruments, beyond 2020, will be contingent upon renewed EFTA approval.

Analyses show that the weight and CO_2 components are equally effective CO_2 abatement instruments, while the engine power component has a lesser impact[15].

[15] Østli, V., Fridstrøm L., Johansen K. W., Tseng Y. (2017). A Generic Discrete Choice Model of Automobile Purchase. *European Transport Research Review*, 9: 16.

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%) increase in the average type approval emission rate of new passenger cars.

Yan & Eskeland[16] observe 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. 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.

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. When BEVs are excluded, the mean rate comes out at 100 gCO_2/km.

2.4.2 The fuel tax

Fuel taxes (NOK 6.33 per litre petrol 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 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. However, fuel price elasticity depends highly 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. Fuel demand will be less elastic in sparsely populated Norway than in practically any other EU or EFTA country.[17]

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 petrol prices, when car replacement decision arrives[18]), but also locational choices, habit formation, supply responses in bus service, etc. In Norway, leaner car choice is found to be about as sensitive to fuel prices as to the CO_2 differentiated tax[19].

There is reason to believe that in parts of Norway with less developed mass transit supply, fuel demand is less elastic than in the metropolitan areas.

Fuel prices also influence GHG emissions through the vehicle purchase choices made by households and companies. Higher fuel prices make people choose leaner cars.

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[16] Yan, Shyiu and Eskeland, G. S. 2018. Greening the Vehicle Fleet: Norway's C02 Differentiated

[17] Fridstrøm L. (2017b). Bilavgiftenes markedskorrigerende rolle. *Samfunnsøkonomen*, 131(2): 49-65.

[18] Eskeland, G.S. & Feyzioglu, T. (1997). Is Demand for Polluting Goods Manageable? An Econometric Study of Car Ownership and Use in Mexico. *Journal of Development Economics* 53(2):423–45.

[19] Yan, Shyiu and Eskeland, G. S. 2018. Greening the Vehicle Fleet: Norway's C02 Differentiated

This elasticity has a long-term interpretation. The full effect will materialize only when the entire fleet has been replaced. In the long term, the indirect car fleet effect seems to be as important as the direct travel demand effect.

For freight vehicles, which use diesel fuels, 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

Rebound effects due to changes in aggregate car ownership can be important. The French fee bate system, for example, is counterproductive in terms of CO_2 abatement, because the bonus has made car ownership affordable to a larger number of families.[20] In Norway, the tax exemptions for ZEVs have enlarged the assortment of relatively inexpensive cars with low operating costs. This might lead to increased household car ownership and use.

Norway and Norwegian cities have additional policy instruments to manage demand both for freight and mobility, like for example public transport policies, bicycle paths and fuel taxes. Norway's pioneering toll rings are 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 weak, checking emission consequences outside natural borders is important.

For electricity in Europe, emission from power generation is capped by the EU ETS. Increased demand for electricity in Norway due to electrification of transport will not increase emissions elsewhere in Europe, since the number of available allowances in the ETS sectors is fixed[21]. This makes emission reductions in 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. The difference in emission intensity is particularly due to the Li-ion battery because the energy demands in the cell manufacturing processes are high and met with carbon intensive energy sources.

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[20] D'Haultfoeuille, X., Givord P., Boutin X. (2013). The Environmental Effect of Green Taxation: The Case of the French Bonus/Malus. *The Economic Journal*, 124: F444-F480.

[21] Eskeland, G.S. (2012) Electrification of transport: Which emissions are ours? Economist (*Sosialøkonomen*, Norwegian, Oktober).

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. Currently, lithium-ion cells are primarily produced in South Korea, China, and Japan in regions characterized by long, warm, wet monsoon seasons. The humid monsoon summer is likely to affect the energy use in dry room operation. These countries all rely on a large share of fossil sources 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%.

2.6. Dynamics of regime shifts and sustainability transitions

Factors often considered barriers to the use of sustainable technologies in transport include technology, government policies and regulatory framework, cultural and psychological aspects, demand, production, infrastructure and maintenance, undesirable societal and environmental effects of new technologies. These barriers constitute "a structure of interrelated factors that feedback upon one another and jointly give rise to inertia in, and specific factors of, technological change."[22] In order for large-scale electrification of the transport sector to happen, key aspects of technological regime shifts have been identified[23]: : (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 simultaneously. Change processes often meet resistance from vested interests and give rise to public debate as to the efficacy and desirability of the technology.

3. Publics and users

3.1 Creating transitions to electric road transport in Norway

People, institutions and firms must be aligned, moulded and disciplined to create (and accept) technological development.[24] Governance in relation to technological development is a many-faceted process, in which many different actors and circumstances play a role.[25] A CenSES study looked at the way different forms of governance influence mobility practices in Norway, with a special focus on BEVs.[26] It analyses the role of user

[22] Hoogma R, Kemp R, Schot J & Truffer B (2002) Experimenting for sustainable transport: The approach of strategic niche management. London: Spon Press.
[23] Kemp, Rene (1994). Technology and the transition to environmental sustainability: The problem of technological regime shifts. Futures, Vol. 26 (10), pp. 1023-1046.
[24] Sovacool, B.K. & M.V. Ramana (2014). Back to the future: small modular reactors, nuclear fantasies, and symbolic convergence. *Science, Technology, and Human Values*, 40 (1): 96-125.

[25] Ryghaug, M., T. M. Skjølsvold and S. Heidenreich (2018). Creating energy citizenship through material participation. *Social Studies of Science* 48 (2), pp. 283 – 303.
[26] Ryghaug, M. & M. Toftaker (2016). Creating transitions to electric road transport in Norway: The role of user imaginaries. *Energy Research & Social Science*, 17: 119-126.

imaginaries in relation to electric vehicles and 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 need to be equipped with economic and political predictability 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 claimed that a premature ending of current incentives would be detrimental, as it would likely 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.

3.2 Public perceptions and experiences with transport electrification

The rapid expansion of electric cars in Norway 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. This means that we need to include users when researching processes of technological innovation, policy development and policy implementation. Electric cars are often seen as a better and more comfortable than ICE cars 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 adapted their usage accordingly. Many households also have a conventional car at their disposal. Electric car drivers also found charging at home to be easier than using petrol stations.

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. Yet electric vehicles have other qualities that have not been previously considered essential, such as comfort.[27] 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 their own mobility patterns (i.e. substituting driving for flying) while also raising awareness of their

[27] Ryghaug, M. & M. Toftaker (2014). A Transformative Practice? Meaning, Competence and Material Aspects of Driving Electric Cars in Norway. *Nature and Culture* 9, 146-163.

electricity consumption. Electric car ownership also seems to trigger an interest in producing renewable energy, e.g. installing solar Photovoltaics (PV) and general energy transition dialogues.

3.3 The effect of stable framework conditions on behaviour

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.[28] Thus, clear, visible and forceful conditions are important for the adoption of electric cars and the electrification of road transport. Stable framework conditions for the development and implementation of new technologies are not only important to end users and customers, but also to the industry.

Studies have demonstrated that the Norwegian "incentives package" 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. 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, something that reduces the risks involved for those who are interested in taking environmentally sound choices.[29] 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.

4. The impact on the distribution and transmission grids

4.1 The transmission grid is strong enough for electric vehicles

The Nordic transmission system is strong but will require some interventions to be able to accommodate the future load growth. 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[30]. 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

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 vehicle 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.

[28] Ryhaug – Næss _ ikke i referanselista
[29] Ingeborgrud L (2014) Ren elektrisk kjøreglede – Elbilen i komfortkulturen. Master's Thesis. Trondheim, Norway: Norwegian University of Science and Technology.
[30] Graabak, I., Wu, Q., Warland, L., Liu, Z. (2016). Optimal planning of the Nordic transmission system with 100% electric vehicle penetration of passenger cars by 2050. *Energy* 107: 648-660.

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 to provide every consumer with a smart meter by 2019. Herein lies the solution.

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

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

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.[31], 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 differing in 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.

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

[31] Tomasgard, A., Møller-Holst S., Thomassen M. S., Bull-Berg H., Damman S., Bjørkvoll, T.H. (2016). Nasjonale rammebetingelser og potensial for hydrogensatsingen i Norge. *SINTEF Rapport A27350*, Trondheim, Norway.

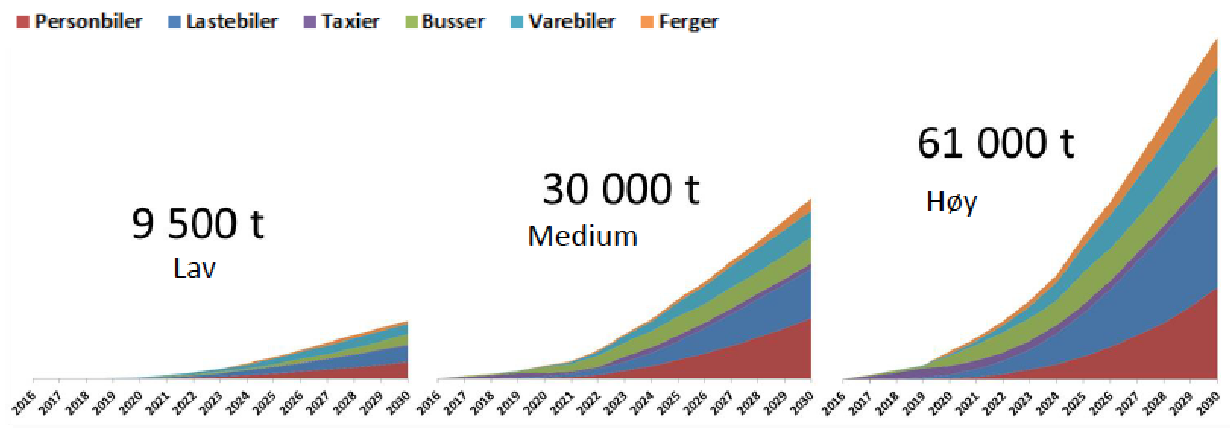

Figure 5.1. Total hydrogen demand (in kg H2/year) for the three scenarios in Tomasgard et al. (2016)

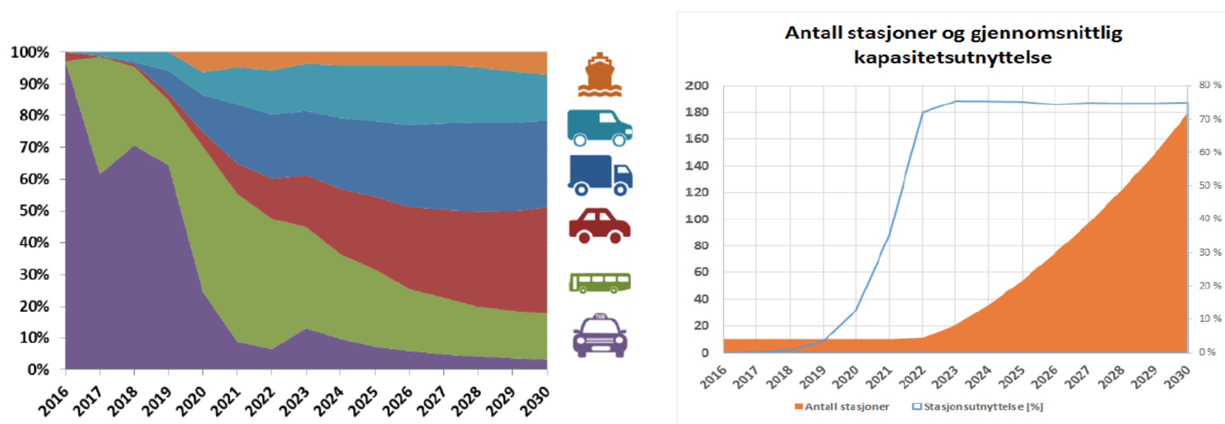

Figure 5.2. *Left:* Relative consumption of hydrogen in different segments in the medium scenario. *Right:* Number of filling stations needed and their utilization ratio. Source: Tomasgard et al. (2016).

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[32] 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. Therefore, successful introduction of hydrogen fuel in the transport sector in the next years 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.

[32] Tomasgard, A., Møller-Holst S., Thomassen M. S., Bull-Berg H., Damman S., Bjørkvoll, T.H. (2016). Nasjonale rammebetingelser og potensial for hydrogensatsingen i Norge. *SINTEF Rapport A27350*, Trondheim, Norway.

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.

<u>Investment support</u> 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.

<u>Operational support:</u> Since the volumes are expected to be small in the early years, the operators of hydrogen stations also need operational support. The first stage should cover the disadvantage of having to recover fixed costs at a time when volumes and revenues are modest. The next stage 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 national authorities in an initial phase to 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 for hydrogen fuel demand in an initial phase to be stimulated in the same way as 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 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 lacks 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 into an interesting market for international suppliers of fuel cell electric vehicles.

6. Transition strategies

How could a low GHG emission scenario be achieved for domestic transport in Norway within 2030?

Fundamental questions to be addressed:

(i) how fast the GHG emissions from road transport can be expected to come down,

(ii) (ii) whether and how the energy system will be able to support such a transition, and

(iii) (iii) what will be the effects for society in terms of production and welfare.

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 in order to study what types of technology scenarios 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.[33]

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%. The decrease in household welfare corresponds to a 6.5% 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).

6.2 Vehicle fleet projections

The BIG stock-flow model of the Norwegian motor vehicle fleet gives another perspective. The model constitutes an accounting framework forecasting the fleet onto the 2050 horizon and beyond.

Relying on this accounting framework, Fridstrøm & Østli[34] 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.

Under the highly optimistic assumptions implicit in the ULE scenario, CO_2 emissions from the Norwegian motor vehicle fleet could drop by 45% between 2015 and 2030, before taking account of a possibly increased biofuel share (Fig. 6.1).

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[33] Helgesen, P.I, Lind, A., Ivanova, O., & Tomasgard, A. (2017). Using a hybrid hard-linked model to analyze reduced climate gas emissions from transport. *CenSES working paper 3/2017.*

[34] Fridstrøm, L. & Østli V. (2016). Kjøretøyparkens utvikling og klimagassutslipp. Framskrivinger med modellen BIG. *TØI Report 1518*, Institute of Transport Economics, Oslo.

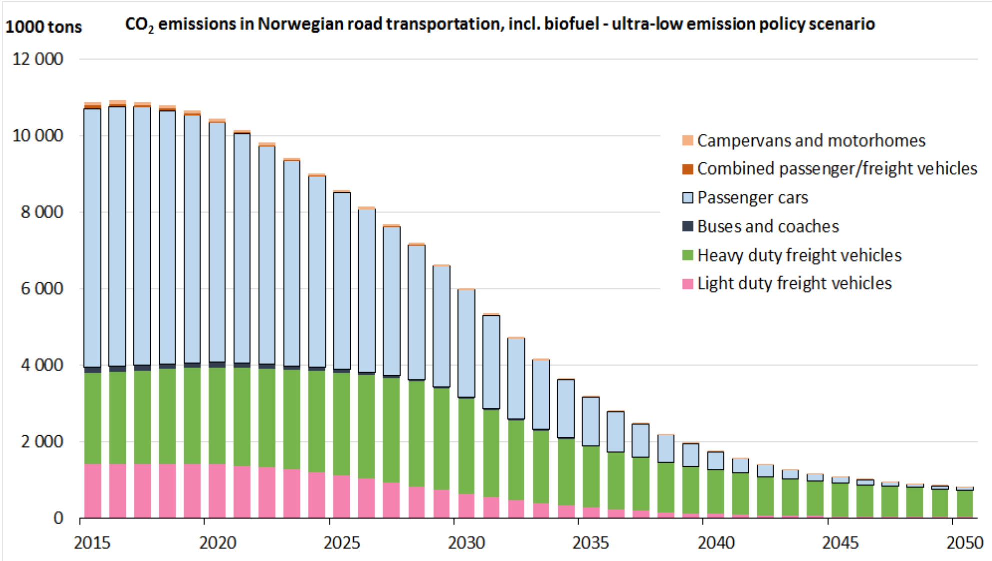

Fig. 6.1. Projected metric tons of annual CO_2 emissions from Norwegian road transport under ultra-low emission scenario, by vehicle category. Emissions from biofuel combustion are included. Source: Fridstrøm & Østli (2016).

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. 6.2).

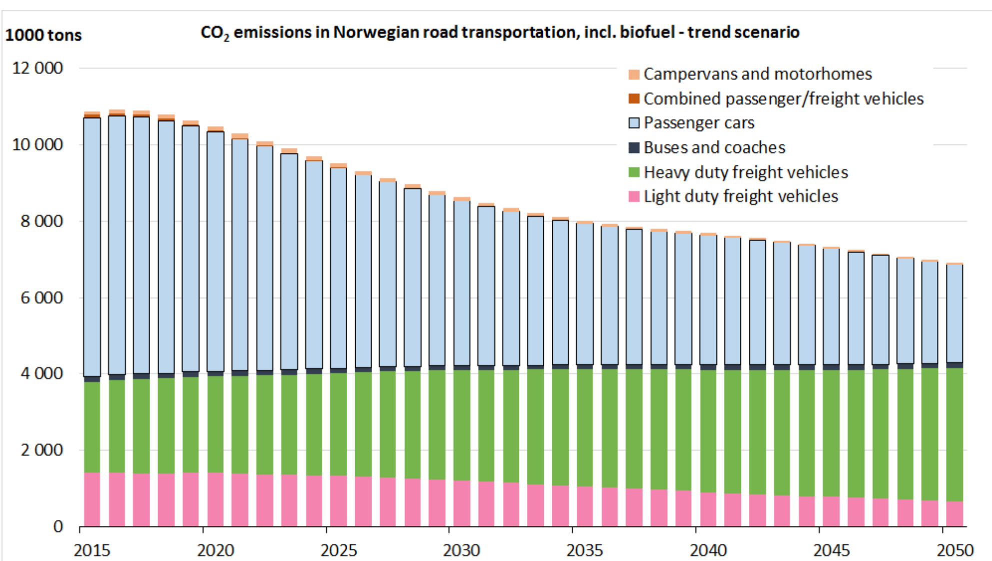

Fig. 6.2. Projected metric tons of annual CO_2 emissions from Norwegian road transport under trend scenario, by vehicle category. Emissions from biofuel combustion are included. Source: Fridstrøm & Østli (2016).

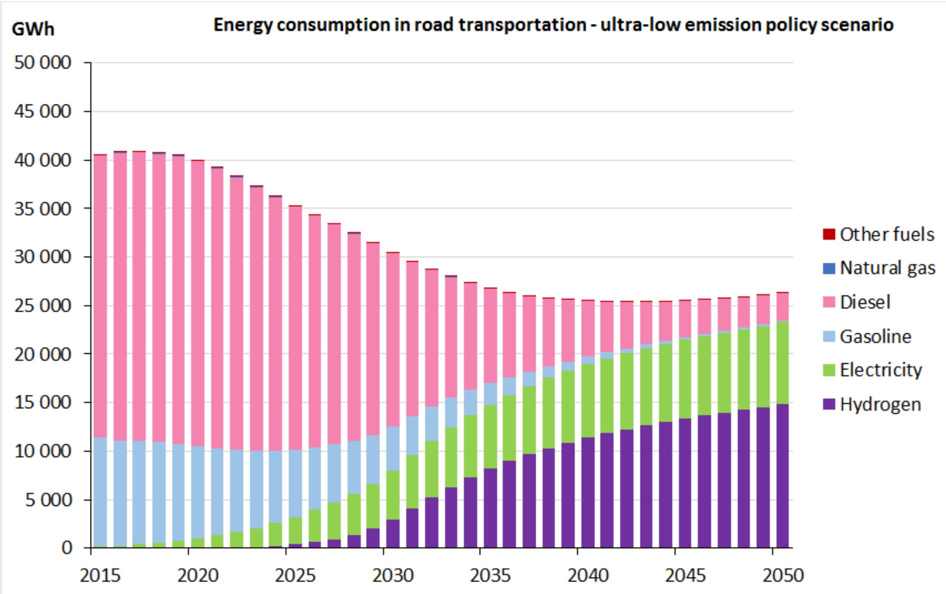

Fig. 6.3. Projected energy consumption in road transport under ultra-low emission policy path, by energy carrier. Biofuel combustion is included. Campervans, motorhomes and combined passenger/freight vehicles are left out. Source: Fridstrøm & Østli (2016).

As evidenced by the BIG stock-flow model, there is considerable inertia in vehicle fleet developments. It may take 5 to 15 years for innovations affecting the flow of new vehicles to penetrate similarly into the stock[35] . 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.

Fig. 6.3. shows 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% in 2015 to 26% in 2030 and 89% 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% 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

Road transport towards zero emission

Road transport will play a major role in decarbonization towards 2030. If the transport sector 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 analyses 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 on their own.

[35] Fridstrøm, L. (2017a). From innovation to penetration. Calculating the energy transition time lag for motor vehicles. *Energy Policy*, 108: 487-502.

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. 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, except for biofuel regulations and increased railway investment. Apparently, the market potential for transferring freight from road to rail is very limited.[36]

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[37], and road freight vehicles are becoming steadily larger and hence more energy efficient per ton kilometre.[38] The volume of freight transport and the accompanying energy use and GHG emissions have increased.

International air travel by Norwegians

International air travel by Norwegian residents is not included in official GHG emissions. Plane travel abroad by Norwegian residents was estimated to 24 billion passenger-kilometres (pkm) in 2006 and grew by 37% to 32.96 billion pkm in 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.[39] 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 fulfilment of Norway's climate policy obligations comes at a cost. 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. 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 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

Given the interrelationships between GHG emissions, energy use, car ownership and transport behaviour, it has been argued that the most important principle to reduce transport demand is 'non-ownership of cars'.[40]

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[36] Marskar, E.M., Askildsen T. C., Presttun T., Markussen G. (2015). *NTP Godsanalyse. Hovedrapport*. Statens vegvesen, Kystverket and Jernbaneverket, Oslo.
[37] Walnum H.J., Hille, J. and Aall, C. (2015) *Driver response model Norwegian road freight transport 1993-2013, WNRI report nr. 5. 2015*
[38] Fridstrøm L. (2017b). Bilavgiftenes markedskorrigerende rolle. *Samfunnsøkonomen*, 131(2): 49-65.
[39] Aamaas, B., Peters G. P. (2017). The climate impact of Norwegians' travel behaviour. *Travel Behaviour and Society*, 6: 10-18.
[40] Gilbert, R. & Perl, A. (2008). Transport Revolutions: Moving People and Freight without Oil. New Society Publishers, Gabriola Island, Canada.

Where people do not have access to a private car, transport volumes will decline. There is strong evidence that transport choices can be influenced in favour of bicycle and public transport, particularly in city contexts.

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. Similar trends have been noted in France, Germany and Australia. However, in Norway, this trend has been reversing since 2007.

If future automated cars were to make driver's licenses unnecessary, 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 several developing countries. With various measures in place to increase cycling shares in Norwegian cities, cycling will likely become 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)

Smartphones have made public transport far more navigable. 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 increasingly well-adjusted to passenger expectations, with many buses or trains now offering wireless Internet access, usually free of charge. 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 because of its contribution to non-car ownership principles. In 2010, car-sharing systems were already available in 1100 cities in 26 countries, and most large cities in Europe now have several competing 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.

While car-sharing schemes are susceptible to reduce car use within families that would otherwise possess their own private car, they also make cars available to more families, and at a lower fixed cost. It is 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 they 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 also suggests that cars will be able to use road space more efficiently (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, there would also be considerable rebound effects in terms of transport demand. 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.

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 are 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 a more intensive use of vehicles (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

As described in 2.2. and shown in figure 2.1, greenhouse gas emissions from transport can be cut in five 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

Option 1 is unattractive to the extent of being politically infeasible in democratic societies. To obtain a 1% cut in Norwegian GHG emissions through a proportional (i.e. 1%) 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).

Option 2 runs counter to the very ideas of trade, integration, freedom of movement and division of labour – the 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.

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.

Option 3, understood as a transfer from petrol 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 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. Even diesel driven buses and coaches may represent an improvement compared to the private car, since 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 in the freight as well as in the travel market. Very powerful incentives are needed 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 can bring about the emission cuts 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.

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 of several decades.

To minimize the risk of lock-in effects, incentives and regulations ought to be technology neutral. Manufacturers are better prepared for the necessary risk assessment than any government agency.

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

In some cases, 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. BEVs and FCEVs 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 the 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.

There are various instruments available to public policy makers:

(i) fiscal instruments
(ii) regulatory measures
(iii) public investment and procurement
(iv) organizational and institutional measures
(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, 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 since 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% 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 has an immediate effect on the GHG emission accounts. This illustrates the merit of technology neutral policies: When powered by biofuel, ICE vehicles are less 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 a low carbon society. The term 'fossil cars' is meaningless, since modern cars run on both renewable fuel and 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 *future* system – for instance satellite based – for general road pricing could 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 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. When the entire vehicle fleet is electrified, a crucial national source of emission is 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% biofuel during 2018, of which at least 4% is to be suited for petrol engines and a minimum of 3.5% is to be '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 blending in 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 the 50% emission reductions target, 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 BEVs. 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 considerable 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 that 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 and will 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, the government can make a big difference towards the long-term goal of carbon neutrality. Climate assessment studies should estimate the GHG abatement consequences of the investment options.

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 spillovers 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 of 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 crucial 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. 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 investments 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, all sectors of transport and communication in Norway are regulated and organized in different ways. In the mobile telephone sector, for example, the dominant company, Telenor, owns and operates its own network 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. 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 partly explains 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 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, quite limited. One cannot achieve the GHG mitigation goals by appealing to the conscience and goodwill 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

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 were derived from a goal of maximizing welfare.

However, when 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% by 2030. The policy challenge is no longer to find a path towards first-best economic resource allocation, but to identify the second-best combination of policy measures achieving the mitigation goals at minimum economic cost.

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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