TØI report 1286/2013

Lasse Fridstrøm

Institute of Transport Economics
Norwegian Centre for Transport Research

Norwegian Transport Towards the Two-Degree Target: Two Scenarios

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ISSN 0808-1190
ISBN 978-82-480-1476-8 Electronic version

Oslo, December 2013

Title: Norwegian Transport Towards the Two-Degree Target: Two Scenarios

Tittel: Norsk samferdsel mot togradersmålet – to scenarioer

Author(s): Lasse Fridstrøm
Date: 11.2013
TØI report: 1286/2013
Pages 34
ISBN Electronic: 978-82-480-1476-8
ISSN 0808-1190
Financed by: Ministry of the Environment
Project: 3917 - Togradersmålet
Project manager: Lasse Fridstrøm
Quality manager: Ronny Klæboe
Key words: Greenhouse gases, Scenario, Transport

Forfattere: Lasse Fridstrøm
Dato: 11.2013
TØI rapport: 1286/2013
Sider 34
ISBN Elektronisk: 978-82-480-1476-8
ISSN 0808-1190
Finansieringskilde: Miljøverndepartementet
Prosjekt: 3917 - Togradersmålet
Prosjektleder: Lasse Fridstrøm
Kvalitetsansvarlig: Ronny Klæboe
Emneord: Klimagass, Samferdsel, Scenario

Summary:
A scenario analysis has been done assessing the potential reduction of CO_2 emissions from domestic Norwegian transport within the 2050 horizon. Under strongly optimistic assumptions, a 60 per cent decrease compared to the 2010 level may be envisaged. By far the most efficient climate policy instrument so far applied to Norwegian transport is the CO_2 graduated component of the vehicle purchase tax, coupled with the very substantial tax exemptions and privileges applicable to battery electric cars. While the continued and sharpened application of these tax incentives may possibly come a long way towards eliminating CO_2 emissions from private cars, greenhouse gas abatement in the freight sector is seen as considerably more challenging.

Sammendrag:
Ved å kombinere grunnprognosene i Nasjonal transportplan 2014-23 med et sett optimistiske anslag over mulige forbedringer i transportmidlenes energieffektivitet og utslippsrater har vi beregnet et 'lavutslippsscenario' for samferdselen i 2020, 2030, 2040 og 2050. Vi sammenlikner dette hypotetiske framtidsbildet med et 'referansescenario' basert på gjeldende trender og kjente utviklingstrekk. Lavutslippsbanen forutsetter til dels drastiske forbedringer i utslippsratene. CO_2-utslippet pr personkilometer er innen 2050 forutsatt å synke med 97 prosent for personbiler og med 74 prosent for fly. På godstransportsiden forutsettes 80 prosents utslippsreduksjon fra tunge kjøretøy og 35 prosents reduksjon fra skip, regnet per tonnkilometer.

Language of report: English

This report is available only in electronic version.

Rapporten utgis kun i elektronisk utgave.

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Preface

In 2012, the Swedish Commission on Fossil-Free Road Transport commissioned a review of the greenhouse gas (GHG) abatement policy in the Norwegian transport sector, focusing on fuel and vehicle taxation, biofuel, electrification, and vehicle energy efficiency. The results of this study were summarised in working paper 50277 from the Institute of Transport Economics (TØI). Emphasis was put on the concrete policy measures implemented on the road passenger transport side, and on their apparent results.

In 2013, the Norwegian Ministry of the Environment commissioned a paper on the perspectives and prerequisites for a low emissions scenario in Norwegian transport by 2050, compatible with the two-degree target for global warming. The aim of this analysis was to elucidate possible paths towards the two-degree scenario, interpreted as an 85 per cent emissions reduction between 2010 and 2050, rather than to describe the most likely course of development.

In preparing this paper, which was presented during the Low Emissions Seminar in Arendal on 8 August 2013, TØI was able to draw heavily on the work already done for the Swedish Commission on Fossil-Free Road Transport, as well as on several reports previously published by the Institute.

The present report is an updated, corrected and reedited version of these two papers. The most important correction made relates to the initial amount of CO_2 emitted from domestic travel in 2010, which had been set at too low a level in the previous analyses.

The costs of reediting have been covered mainly by the TEMPO project on sustainable transport (see www.transportmiljo.no).

Thanks are due to Per-Andre Torper of the Ministry of Transport of Communications for providing data on the average CO_2 emission rate of new cars, to Bernt Reitan Jenssen of Ruter AS for providing data on public transport ridership, to Per Kågeson of the Swedish Commission on Fossil-Free Transport for his valuable comments, and to TØI's research partners under the TEMPO project, notably the Institute of Transportation Studies (ITS) at the University of California, Davis, and the CICERO Center for International Climate and Environmental Research, Oslo. Special thanks are due Lew Fulton and Joel Bremson of ITS, and to Borgar Aamaas of CICERO. At TØI, the following persons have been instrumental in providing background material and professional advice: Rolf Hagman, Ronny Klæboe, Erik Figenbaum, Jan Usterud Hanssen, Inger Beate Hovi, Anne Madslien and Harald Thune-Larsen. The quality assurance has been assumed by Ronny Klæboe.

Oslo, December 2013
Institute of Transport Economics

Gunnar Lindberg
Managing Director

Ronny Klæboe
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Summary:

Norwegian Transport Towards the Two-Degree Target: Two Scenarios

TØI Report 1286/2013
Author: Lasse Fridstrøm
Oslo 2013, 34 pages Norwegian language

The potential for reducing the CO_2 emissions from domestic Norwegian transport within the 2050 horizon has been analysed. Under strongly optimistic assumptions, a 60 per cent decrease compared to the 2010 level may be envisaged. By far the most efficient climate policy instrument so far applied to Norwegian transport is the CO_2 graduated component of the vehicle purchase tax, coupled with the substantial tax exemptions and privileges enjoyed by battery electric cars. While the continued and sharpened application of tax incentives may come a long way towards eliminating CO_2 emissions from private cars, greenhouse gas abatement in the freight sector is more challenging.

Climate policy goals for Norwegian transport

The Norwegian government has set ambitious targets for the reduction of greenhouse gas (GHG) emissions. By 2020, emissions are to be cut to a level 30 per cent below the 1990 benchmark. By 2050, full carbon neutrality is to be achieved. Two thirds of the cuts are to be made domestically, while the remaining third could be compensated for through international trading.

To comply with the two-degree target for global warming, GHG emissions must be cut by an estimated 85 per cent by 2050. In this report, we set out to examine whether this milestone is achievable as applied verbatim to the Norwegian transport sector. Some 32 per cent of the domestic Norwegian emissions are due to mobile sources, and some 26 per cent to transport proper, i. e. when we exclude fishing vessels, agricultural and construction machinery, etc.

To reduce emissions, the Stoltenberg government pledged, in its 2012 white paper on GHG abatement, to implement new, climate friendly technology and mobility patterns. Local governments are expected to reduce the future demand for transport by a coordinated land use and environmental policy. Public transport use is to be stimulated through direct subsidies as well as through urban densification. In all the major urban areas, any future growth in travel demand should be absorbed by public transport, bicycling or walking. By 2020, the average CO_2 emission rate of new passenger cars is not to exceed 85 g/km.

Fuel and vehicle taxation

Independently of climate policy considerations, Norwegian automobile ownership and use have long since been subject to important taxes. We may distinguish between (a) fuel tax, (b) vehicle purchase tax, (c) registration tax, (d) road toll, (e) scrap deposit tax, and (f) income tax on company cars. In terms of revenue, (a) and (b) are by far the more important. Taken together, they bring close to US$ 7 billion each year into the public treasury, i. e. almost $ 1 400 per capita.

Petrol is subject to 'road use' and 'CO_2' taxes amounting to US$ 0.93 per litre (as of 11 November 2013), or $ 3.53 per US gallon. Diesel taxes amount $ 0.72 per litre, i. e. $ 2.72 per gallon. On top of this, a general value added tax of 25 per cent is charged.

Vehicles are more heavily taxed in Norway than in almost any European country, with the possible exception of Denmark. Passenger cars are subject to purchase tax upon their first registration. Imported second hand cars are subject to a graduated purchase tax depending on the age of the vehicle.

In general, the purchase tax is made up by three important components, one depending on the vehicle's weight, a second depending on engine power (kW), and, since 2007, a third determined by the vehicle's 'certified' rate of CO_2 emission (g/km) as measured by the standardised EU testing cycle (NEDC).

From 2007 onwards, the CO_2 purchase tax component has given rise to an important shift in new car acquisitions, in the direction of cars with lower certified emission rates. Since CO_2 emission is directly proportional to fuel use, and since diesel engines are generally more energy efficient than those running on petrol, the relative purchase prices have shifted markedly in favour of diesel cars. From 2006 to 2007 the diesel engine share of new passenger cars registered rose from 48.3 to 74.3 per cent.

In the fiscal years following 2007, increasing weight has been put on the CO_2 component of the purchase tax, so as to strengthen the incentive to buy low emission cars. As of 2013, the following CO_2 purchase tax amounts apply (Table A).

Table A: CO_2 purchase tax component at selected levels of type approval CO_2 emission. November 2013

CO_2 g/km	0	50	100	150	200	250	300	350
US$	-15 834	-7 961	-1 327	5 006	17 135	34 430	57 926	81 423

Cars emitting more than 110 grams of CO_2 per km are subject to a progressively increasing tax rate, while cars releasing less than this actually obtain a subsidy, in the form of a certain deduction in the tax levied on weight and engine power.

From 2006 until 2012, the average rate of CO_2 emission among new cars had dropped by 27 per cent, to 127 grams per km (Diagram A). In October 2013, the rate had come down to 118 grams per km, helped to a large extent by the generous privileges granted to battery electric vehicles (BEVs). These cars are exempt of value added tax, vehicle purchase tax, road tolls and public parking charges. They benefit from strongly reduced annual registration tax and reduced ferry fares. Moreover, BEVs are allowed to travel in the bus lane and may be recharged for free in many public parking lots.

As a result, Norway probably has the largest share of electric vehicles of any country. As of 31 October 2013, there are more than 17 000 rechargeable vehicles on Norwegian roads, i. e. appr. 0.7 per cent of the passenger car fleet. BEVs constitute the overwhelming majority of rechargeable vehicles, only about 4 per cent being plug-in hybrids (PHEV). BEVs are in particularly high demand in the Oslo area, especially in the municipalities west of Oslo, from where the trunk road into the city (E18) is heavily congested during the rush hours. Using the bus lane, electric vehicles may travel at a speed several times higher than the ordinary car.

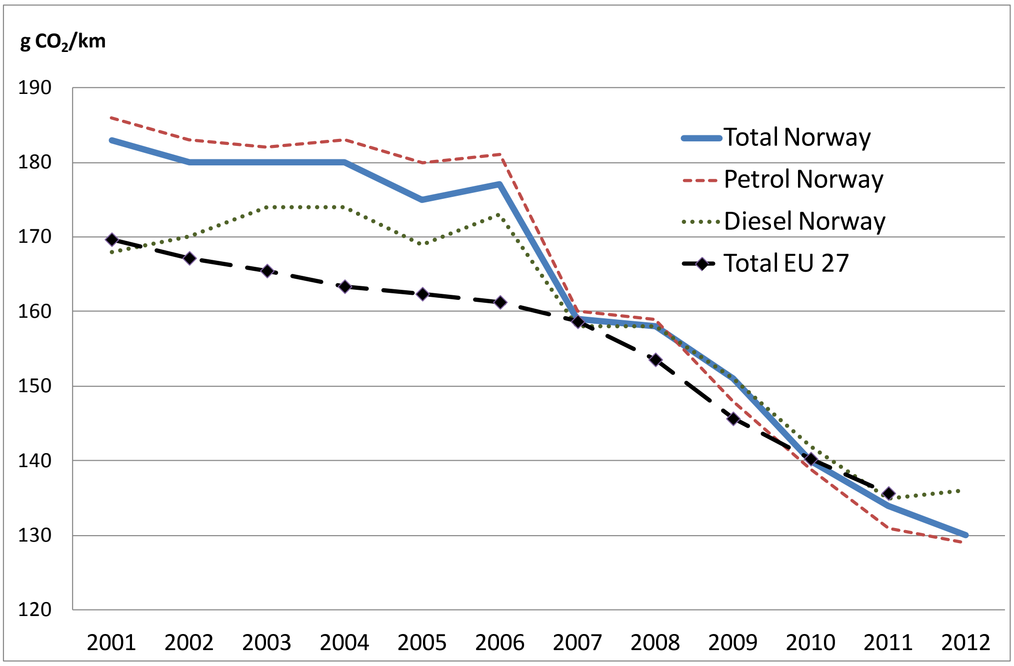


Diagram A: Average CO_2 emission from new cars registered in Norway, by fuel type, and in EU 27. Electric vehicles included in total.

Emission scenarios for the 2050 horizon

As an input to the Norwegian National Transport Plan 2014-23, the Institute of Transport Economics (TØI) has developed new, long term travel and freight demand forecasts (Madslien et al. 2011, Hovi et al. 2011). Moreover, an assessment of future energy use and greenhouse gas (GHG) emission rates has been authored by Thune-Larsen et al. (2009).

In the present report, we have combined input from these three publications to produce rough estimates of future GHG emission volumes under a 'reference scenario' as well as a 'low emissions scenario'.

The aim of this analysis has been to elucidate possible paths towards the two-degree scenario, interpreted as an 85 per cent emissions reduction between 2010 and 2050, rather than to describe the most likely course of development. Without disregarding the formidable political and technological challenges involved in achieving emissions reductions compatible with this highly ambitious scenario, we make projections under the hypothetical assumption that many of these difficulties will somehow be overcome.

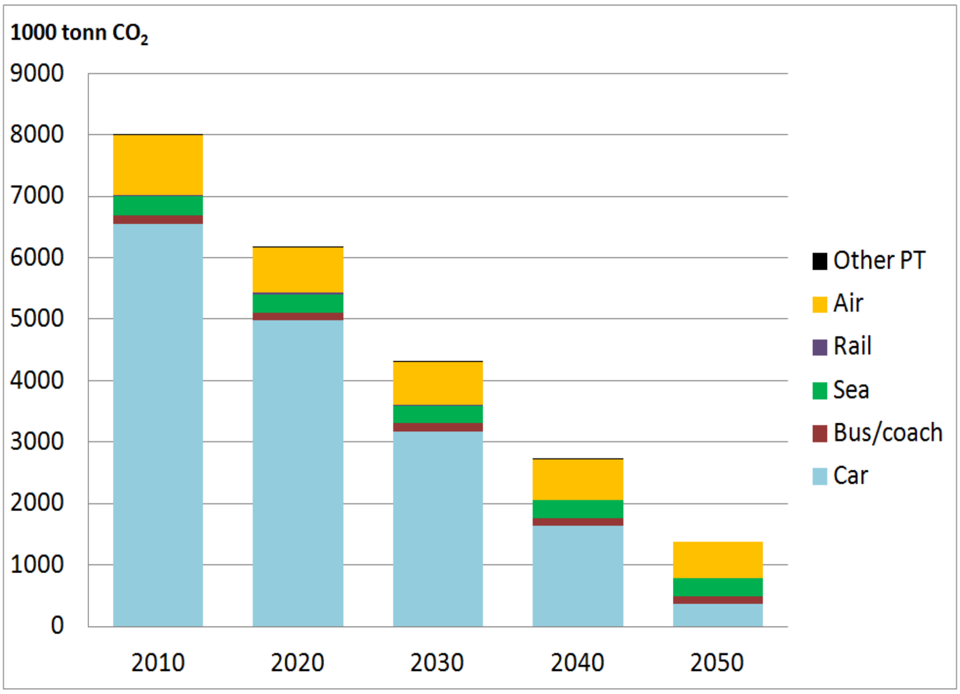


Diagram B: The low emissions scenario for domestic travel in Norway. Tonnes of CO_2.

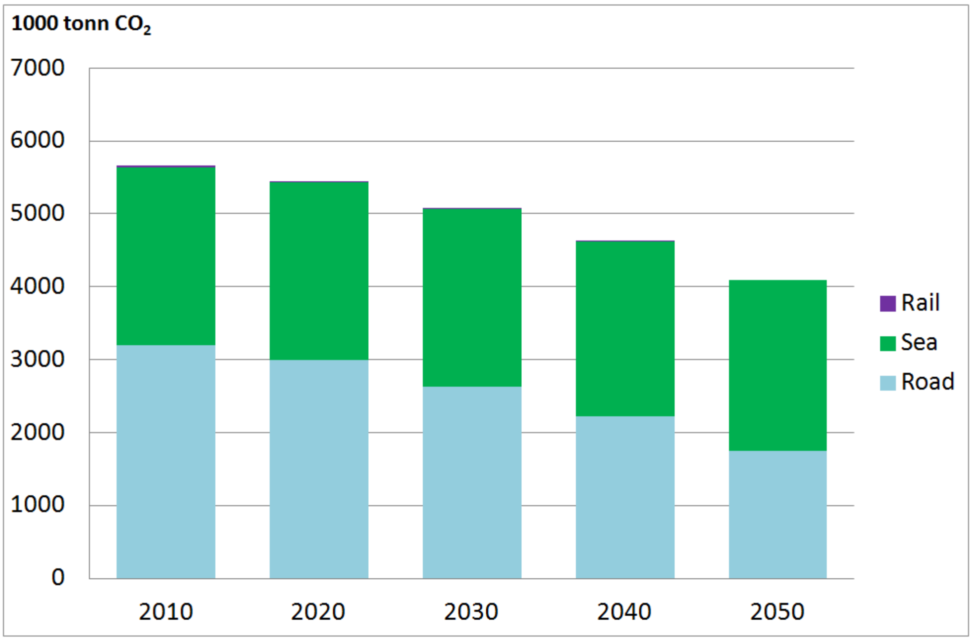


Diagram C: The low emissions scenario for freight transport on Norwegian territory. Tonnes of CO_2.

In the low emissions scenario, the CO_2 emission rate of private cars is assumed to come down by a full 97 per cent between 2004 and 2050. In road freight, an 80 per cent reduction in the emission rate per tonne km is envisioned, while in aviation a 74 per cent drop is regarded as feasible. Emissions from sea freight are assumed to come down by 35 per cent, as measured in terms of grams of CO_2 per tonne km.

These fairly drastic improvements will to some extent be offset by the projected, around 50 per cent increase in overall travel and freight demand. In Diagrams B and C we show projected, mode-specific absolute amounts of CO_2 emitted under the low emissions scenario.

In this scenario, emissions from domestic travel go down by a full 83 percent. On the freight side, a more modest, 28 per cent reduction is foreseen. Taken together, emissions from Norwegian transport – travel and freight – are, in the low emissions scenario, set to go down by 60 per cent between 2010 and 2050.

At the 2030 milestone, the low emissions scenario projects a 46 per cent emissions reduction from travel and 10 per cent from freight.

Policy discussion

Although substantial, these emission reductions do not meet the 85 per cent cut compatible with two-degree target for 2050, when interpreted as a uniform emission reduction requirement as applied to every sector of society. Yet, the assumptions underlying the low emissions scenario must be deemed to be fairly optimistic – indeed, some would say heroic.

There is an obvious danger inherent in the construction of such scenarios. While meant to show the potential results of a highly resolute, informed and persistent policy, they might be interpreted by some as a rather plausible image of the future. In such a case they might lead to complacency rather than to political action. This risk is particularly high as long as the scenario specification remains elusive in terms of what policy decisions are needed in order for the scenario assumptions to come true.

Given a roughly 50 per cent increased demand from here on to 2050, even a 33 per cent reduction in emission rates would leave us with a status quo as far as GHG emissions are concerned. To yield an 85 per cent reduction from today's level, emission rates would have to come down by 90 per cent by 2050.

Such a development would qualify as a major achievement in terms of *decoupling*, a term used by the OECD to characterize the breaking of the link between 'environmental bads' and 'economic goods'. If society is unwilling and/or unable to curb economic growth, sustainability must be achieved through pervasive decoupling. The policy of the European Union rests firmly on the paradigm of decoupling, as expressed in the Union's white paper, which states bluntly that 'Curbing mobility is not an option', since 'Transport is fundamental to our economy and society. Mobility is vital for the internal market and for the quality of life of citizens as they enjoy their freedom to travel. Transport enables economic growth and job creation....'

In a paper examining the roll-out requirements for advanced technology vehicles and fuels in the Nordic countries, Lew Fulton and Joel Bremson of the University of California, Davis, describe a set of possible pathways compatible with the two-degree scenario by 2050. Vehicles with conventional combustion engines will have to be entirely phased out, leaving the ground for hydrogen fuel cell vehicles, BEVs and PHEVs.

By far the most efficient GHG abatement measure applied so far in Norwegian transport is the CO_2 component of the vehicle purchase tax, coupled with the privileges and tax exemptions given to battery electric cars. The power of these policy instruments is conditioned by the very high initial levels of taxation applicable to private cars. Exemptions from these tax rules represent forceful indirect subsidies, without a single dollar having to be paid out by the public treasury.

While massive privileges apply to BEVs, the tax incentives directed at plug-in hybrid electric vehicles are more moderate. In order for these vehicles to obtain a satisfactory market uptake within the 2020 horizon, stronger incentives may be called for. Since, unlike BEVs, PHEVs do not present any 'range anxiety' problem, their long and medium term prospects for large scale market penetration is quite probably more promising than for BEVs. Most households are unlikely to acquire a vehicle with limited range other than as a second or third car.

In the longer term, hydrogen fuel cell technology could emerge as the solution to the electric vehicles' range problem. Massive infrastructure investment (refuelling stations) would, however, be required before this type of vehicles becomes attractive to the ordinary consumer.

If and when emission rates from private cars come down as envisioned in the low emissions scenario, effectively decoupling private car use from GHG emissions, the main climate policy argument for curbing private car use disappears.

The challenges to reduce emissions from aviation, and from road and sea freight, remain. Here, the set of policy instruments available to the national government seems, unfortunately, to leave a lot to be desired.

Sammendrag:

Norsk samferdsel mot togradersmålet – to scenarioer

TØI rapport 1286/2013
Forfatter: Lasse Fridstrøm
Oslo 2013 34 sider

Under svært optimistiske forutsetninger om energieffektivisering og avkarbonisering vil en kunne redusere CO_2-utslippene fra norsk innenlands samferdsel med 60 prosent innen 2050. Potensialet for utslippsreduksjon er klart størst på persontransportsiden, der det er mulig å se for seg en 83 prosents forbedring. En slik utvikling forutsetter imidlertid at en innen 2050 stort sett har faset ut personbiler med forbrenningsmotor og har erstattet disse med batteridrevne elektriske biler, ladbare hybridbiler eller brenselscellebiler drevet av hydrogen. Det klart mest virksomme klimatiltaket innen samferdsel hittil er CO_2-komponenten i engangsavgiften for personbiler, kombinert med avgiftsfritakene og de andre fordelsordningene for elbiler. Dersom en skal lykkes med å gjøre personbiltransporten tilnærmet utslippsfri, må disse skatteincentivene videreføres og forsterkes, trolig slik at fordelene etter hvert utjevnes noe mellom de ladbare hybridbilene og de rene elbilene.

I henhold til grunnprognosene i Nasjonal transportplan 2014-2023 vil både person- og godstransport vokse med grovt regnet 50 prosent innen 2050. Dersom en, i tråd med togradersmålet for global oppvarming, likevel skal redusere CO_2-utslippene fra samferdselen med 85 prosent, må utslippene per personkilometer og tonnkilometer synke med 90 prosent.

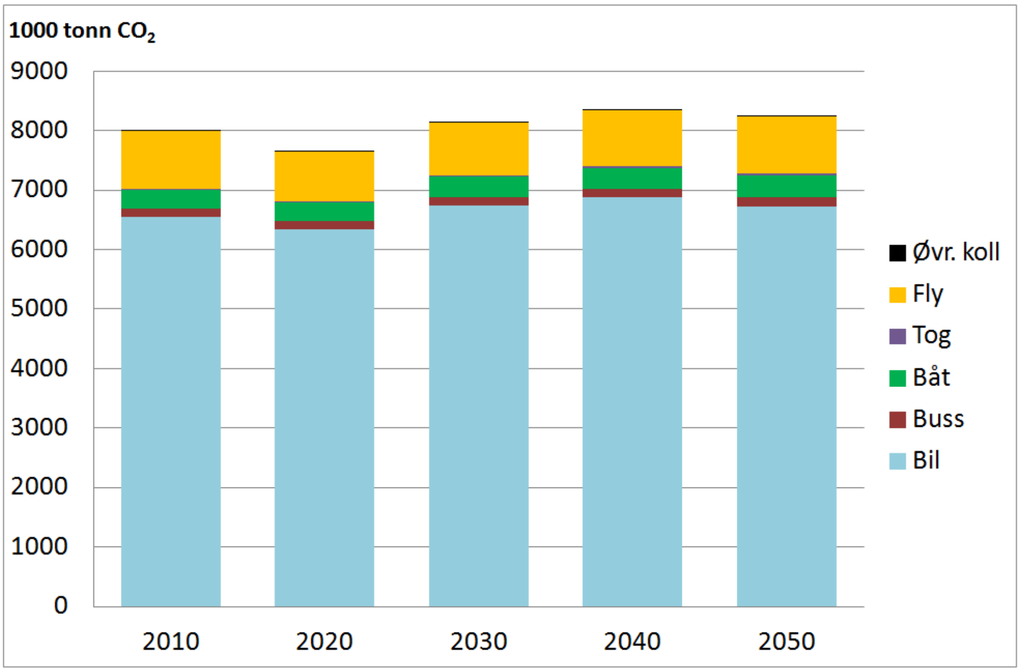
Ved å kombinere grunnprognosene med et sett anslag over mulige forbedringer i transportmidlenes energieffektivitet og utslippsrater har vi beregnet et 'lavutslipps-scenario' for samferdselen i 2020, 2030, 2040 og 2050. Vi sammenlikner dette hypotetiske framtidsbildet med et 'referansescenario' basert på gjeldende trender og kjente utviklingstrekk.

Lavutslippsbanen forutsetter til dels drastiske forbedringer i utslippsratene. CO_2-utslippet pr personkilometer er innen 2050 forutsatt å synke med 97 prosent for personbiler og med 74 prosent for fly. På godstransportsiden forutsettes 80 prosents utslippsreduksjon fra tunge kjøretøy og 35 prosents reduksjon fra skip, regnet per tonnkilometer.

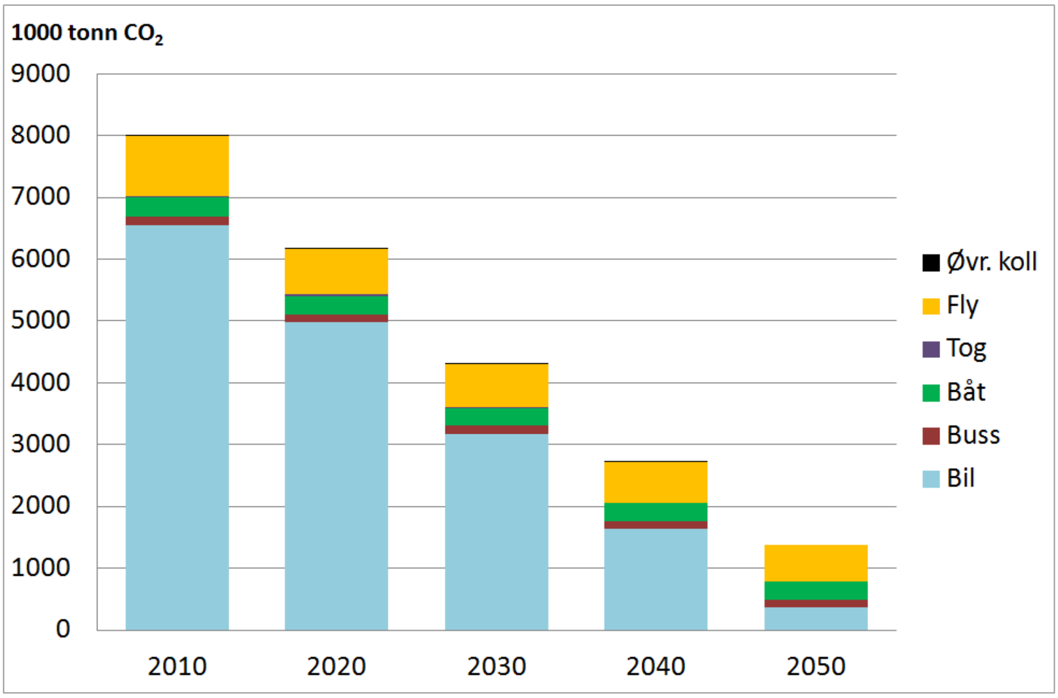
Utslippsutviklingen under referansebanen er vist i Figur 1 og 3, mens lavutslipps-banen er beskrevet i figur 2 og 4.

Utslippene fra persontransport går i lavutslippsscenariet ned med 83 prosent sammenliknet med utgangsnivået i 2010. For godstransport er nedgangen mer beskjeden: 28 prosent. Alt i alt reduseres CO_2-utslippene fra norsk innenlands samferdsel med 60 prosent fra 2010 til 2050.

Per 2030 er reduksjon 46 prosent for persontransport og 10 prosent for godstransport.



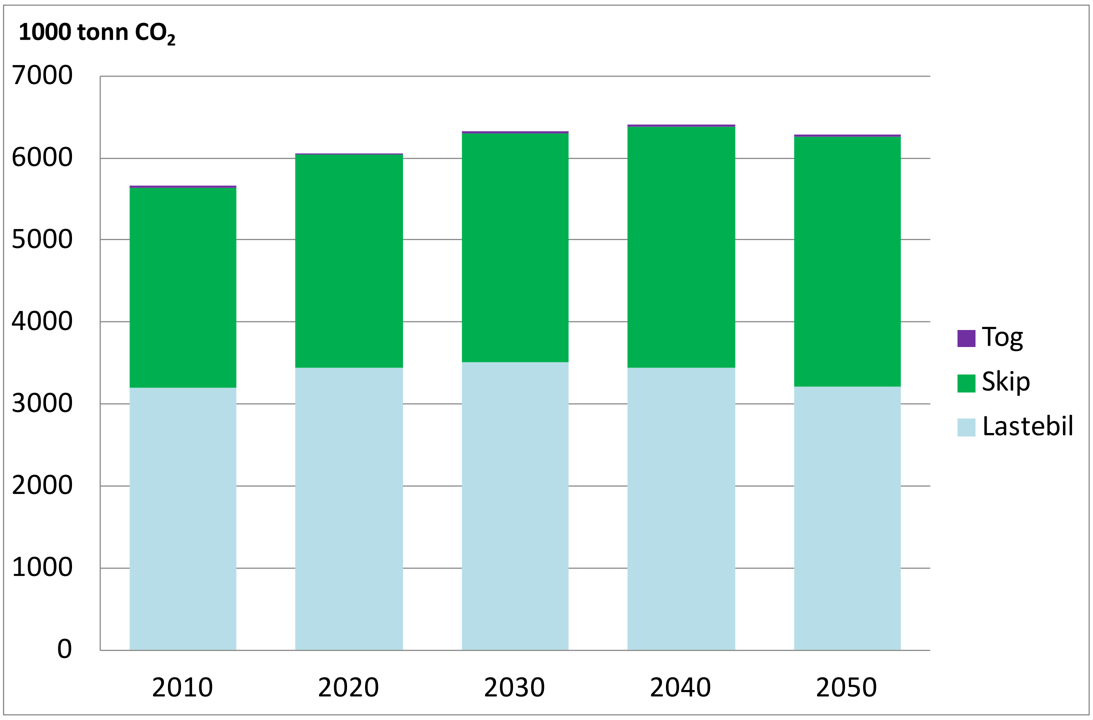
Figur 1: Referansebanen. CO_2-utslipp fra innenlands persontransport.



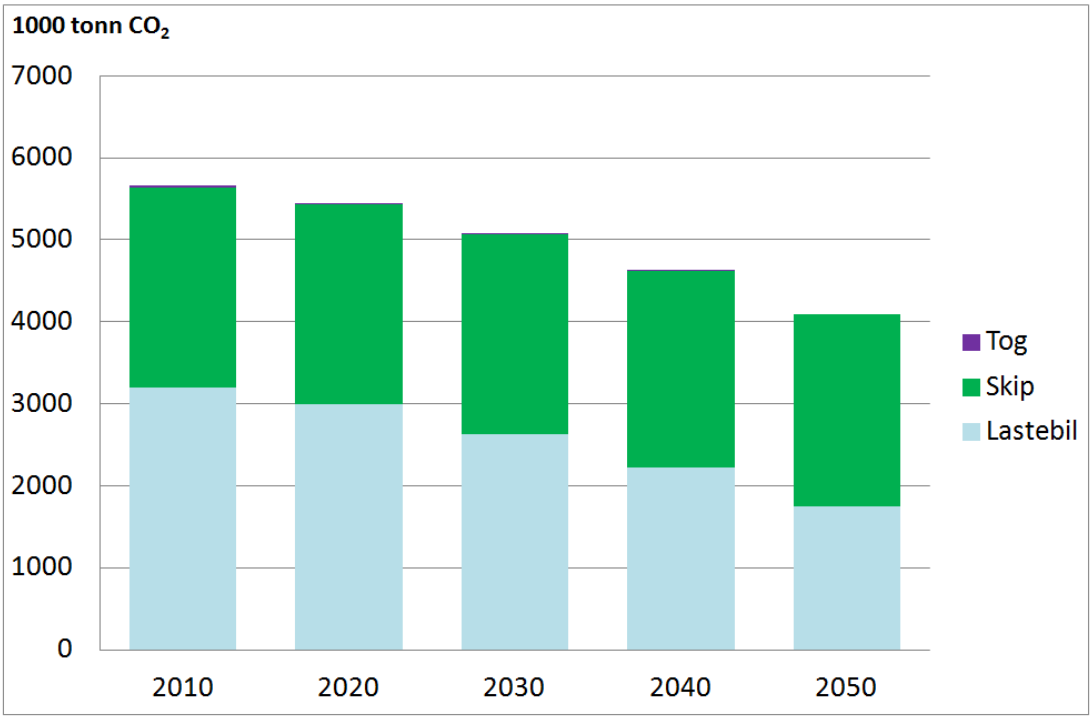
Figur 2: Lavutslippsbanen. CO_2-utslipp fra innenlands persontransport.

Forutsetningene under lavutslippsscenariet må sies å være svært optimistiske. Det er ikke klart hvilke virkemidler norske myndigheter kan anvende for å nå de utslippsmålene som er lagt til grunn, eller om slike virkemidler overhodet finnes.

Under referansescenariet – 'business-as-usual' – øker CO_2-utslippene fra innenlands samferdsel med anslagsvis 6 prosent fram til 2050, til tross for at en også her har forutsatt en viss reduksjon i utslippsratene regnet per personkilometer og tonnkilometer.



Figur 3: Referansebanen. CO_2-utslipp fra godstransport på norsk område.



Figur 4: Lavutslippsbanen. CO_2-utslipp fra godstransport på norsk område.

1 Current national policies

The Norwegian government's GHG abatement policy has defined the following overall goals:

- To not only meet the target set for the first period of the Kyoto protocol, but to surpass it by 10 per cent.
- By 2020, to commit Norway to cut global GHG emissions by an amount corresponding to 30 per cent of the country's emissions in 1990.
- By 2050, to achieve total carbon neutrality.
- As part of a possible, ambitious global agreement, to commit the country to national carbon neutrality by 2030 already.

It is, however, understood that not all the cuts in emission need to be made 'at home', i. e. domestically. Up to one half of the cuts could be achieved through the purchase of internationally tradable carbon credits. Deliberations in the Parliament have since sharpened this target, suggesting that no more than one third of the emission cuts should be achieved by international trading.

Emissions from domestic mobile sources (including fisheries, mobile oil rigs and agricultural and construction machinery, but excluding international air and sea transport) amounted to 17.3 million tonnes of CO_2 equivalents in 2010, representing some 32 per cent of Norway's total greenhouse gas (GHG) emissions. Between 1990 and 2010, GHG emissions from transport rose by 29 per cent. Road transport represents some 59 per cent of the transport emissions.

To reduce these emissions, the central government has pledged, in its 2012 white paper on GHG abatement (Meld. St. 21, 2011-2012), to implement new, climate friendly technology and facilitate a gradual transfer to public transport, walking and bicycling. Local governments are expected to reduce the demand for transport by a coordinated land use and environmental policy. Public transport use is to be stimulated through direct subsidies as well as through urban densification.

Among the targets laid down, the following are perhaps the most concrete and verifiable:

- In all the major urban areas, any future growth in travel demand should be absorbed by public transport, bicycling or walking.
- By 2020, the average CO_2 emission rate of new passenger cars should not exceed 85 g/km.

In the National Budget for 2011, GHG emissions from transport are, in the business-as-usual scenario, projected to rise to 18.7 million tonnes in 2020 and to 18.9 million tonnes in 2030. Road transport would represent 11.9 million tonnes in 2020.

In the so-called 'Klimakur 2020' study (KLIF 2010), the technical GHG reduction potential in the transport sector (including fisheries) was estimated at 2.5–4.5 million tonnes at the 2020 horizon. Viewed as a target, this translates into a roughly 15-25 per cent abatement ambition compared to the 2010 level.

1.1 Fuel and vehicle taxation

Independently of climate policy considerations, Norwegian automobile ownership and use have long since been subject to important taxes. We may distinguish between (a) fuel tax, (b) vehicle purchase tax, (c) registration tax, (d) road toll, (e) scrap deposit tax, and (f) income tax on company cars.

a. Fuel tax

As of 2013, petrol is subject to a 'road use' tax amounting to NOK[1] 4.82 per litre, a 'CO_2' tax of NOK 0.91 per litre and a general value added tax (VAT) of 25 per cent. Diesel is subject to corresponding tax rates of NOK 3.80, NOK 0.60 and 25 per cent VAT. Needless to say, one NOK of 'road use' tax has exactly the same GHG abatement effect as one NOK of 'CO_2' tax, regardless of how the two are labelled. The purpose of the 'road use' tax is, however, fiscal rather than environmental.

Biodiesel is subject to a 'road use' tax of NOK 1.87 per litre. No 'CO_2' tax is levied on biofuel.

The petrol and diesel tax rates have been fairly stable over the last 10 years. They do not differ markedly from standard European rates of fuel taxation, although they belong in the upper range.

b. Vehicle purchase tax

Vehicles, on the other hand, are more heavily taxed in Norway than in almost any European country, with the possible exception of Denmark. Private cars meant for passenger transport[2] are subject to purchase tax ('engangsavgift') upon their first registration. Imported second hand cars are subject to a graduated purchase tax depending on the age of the vehicle.

Since 2007 the structure of the purchase tax has undergone considerable change, with the purpose of stimulating the acquisition of low carbon vehicles. Up until the fiscal year 2006, the purchase tax consisted of the following three components:

- An amount determined by the weight of the vehicle (kilograms)
- An amount determined by the engine power (kW)
- An amount determined by the engine cylinder volume (litres)

From 2007 on, the cylinder volume component was replaced by a CO_2 component, determined by the vehicle's type approval rate of CO_2 emission (g/km) as measured by the standardized EU testing cycle (NEDC). As new types of engine technology were starting to appear in the market (hybrid and electric cars), it was no longer

[1] As of 11 November 2013, NOK 1 = US$ 0.163 = € 0.122.

[2] Cars with only two seats and a large cargo room (max 300x190 cm) are classified as vans. For these vehicles, which carry green license plates, the purchase tax rates have been set at 22-25 % of those applicable to passenger cars. Cars registered as taxis are charged 60 per cent of the purchase tax. After three years they can be resold as private cars without penalty.

practical to levy a tax that was not technology neutral, but relevant only for 'old-fashioned' combustion engines.

The CO_2 tax curve introduced was progressive, rising more steeply at higher levels of CO_2 emission per km. It gave an immediate shift in the composition of new car acquisitions, in the direction of lower average certified emission rates. Since CO_2 emission is directly proportional to fuel use, and since diesel engines are generally more energy efficient than those running on petrol, the relative purchase prices shifted markedly in favour of diesel cars. From 2006 to 2007 the diesel engine share of new passenger cars registered jumped from 48.3 to 74.3 per cent.

In the fiscal years following 2007, gradually increasing weight has been put on the CO_2 component of the purchase tax, so as to steadily strengthen the incentive to buy low emission cars. By 2011, the average rate of CO_2 emission among new cars had dropped by 24 per cent since 2006, and by 2012 by nearly 27 per cent. In the 27 EU countries, the rate dropped by 16 per cent between 2006 and 2011 (Diagram 1).

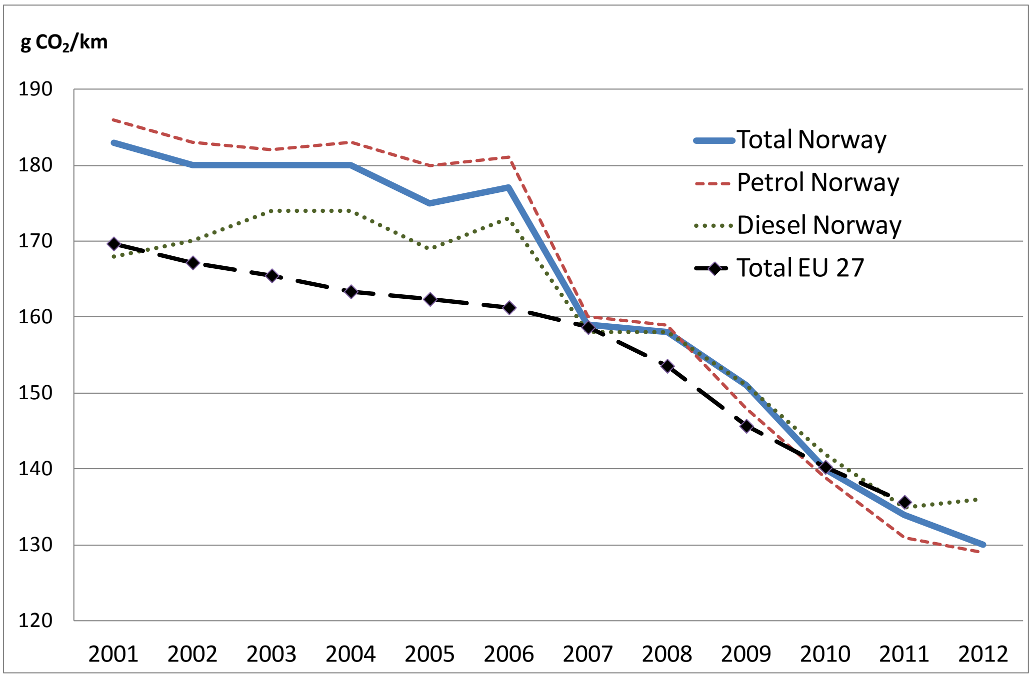


Diagram 1: Average CO_2 emission from new cars registered in Norway, by fuel type, and in EU 27. Electric vehicles are included in total. Source: Fridstrøm (2012), based on input from the Norwegian Ministry of Transport and Communications, OFV and www.eu.europa.eu.

In 2013, cars releasing less than 110 grams of CO_2 per km actually obtain a subsidy, in the form of a certain deduction in the tax levied on weight and engine power. The deduction is NOK 814 per gram CO_2 from 110 to 50 gram, increasing to NOK 966 per gram below 50 gram.

In a study to assess the feasibility of the 85 g/km target for 2020, Figenbaum et al. (2013) conclude that it is indeed achievable, at least under certain favourable assumptions regarding the international market uptake of battery electric (BEV) and plug-in hybrid electric vehicles (PHEV). It will, however, be hard to reach the target without BEVs and PHEVs obtaining considerable market shares. As the main instrument to reach the target, Figenbaum et al. (2013) suggest a progressively sharpened CO_2 graduated purchase tax, as exhibited in Diagram 2.

Note, however, that the CO_2 tax is only one out of four purchase tax components, including the recently introduced, but small NO_x component.

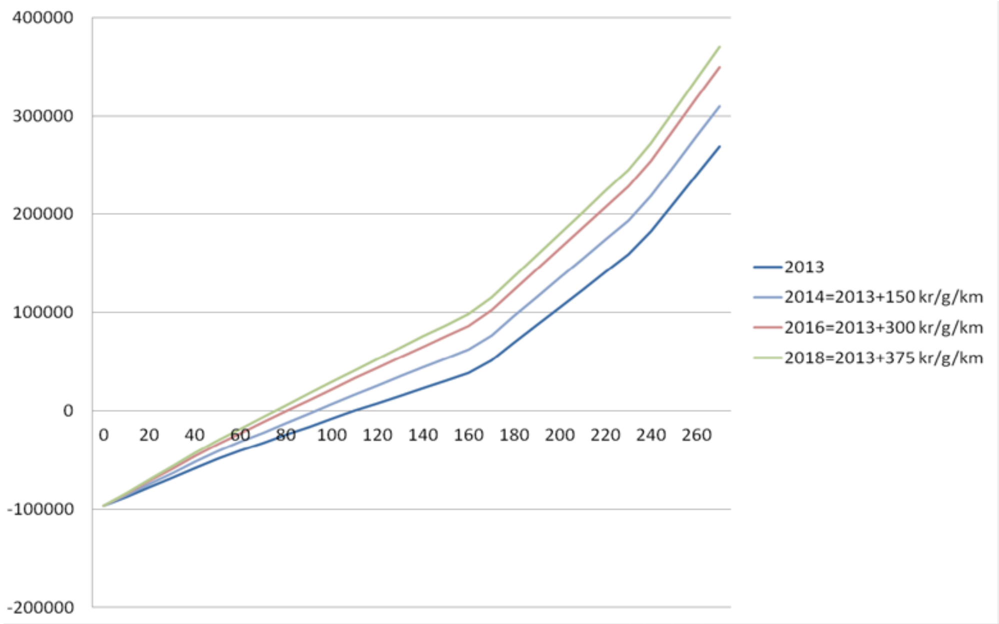


Diagram 2: Present and proposed vehicle purchase tax on certified CO_2 emission rates (g/km). Source: Figenbaum et al. (2013)

As of 2013, for a vehicle weighing 1 000 kilos with an engine of 75 kW, the weight component amounts to NOK 37 590 and the engine power component to NOK 2 750. For a vehicle weighing 2 000 kilos with an engine power of 150 kW, the corresponding tax amounts are NOK 175 409 and NOK 77 675.

The NO_x component is set at NOK 35 per mg NO_x/km. The maximally allowed NO_x emission rate according to the EURO V standard is 180 mg/km, resulting in a maximal one-time tax of NOK 6 300.

Since the abolition of the technology dependent cylinder volume tax component, hybrid vehicles have been subject to basically the same tax scheme as vehicles with traditional combustion engines. However, the weight of the electric motor and the battery pack are said not to be subject to purchase tax, whereby a standard 15 per cent deduction (10 per cent prior to 1 July 2013) is applied when calculating the hybrid vehicle's weight. Similarly, the effect of the electric motor is not counted in when calculating the engine power component. In 2012, some 4.5 per cent of new passenger cars registered were hybrid vehicles, up from 2.8 per cent in 2011. In October 2013, BEVs reached a marked share of 7 per cent.

Vehicles running on at least 85 per cent ethanol are given a lump-sum NOK 10 000 purchase tax deduction. However, few petrol stations in Norway offer E85 fuel.

Electric and hydrogen powered vehicles are exempt of purchase tax as well as VAT. Any vehicle with an auxiliary combustion engine for extended range is not considered electric, but as a hybrid.

No purchase tax applies to heavy duty vehicles.

c. Registration fee

Another element of vehicle taxation is the annual registration fee. As of 2013, vehicles weighing less than 3 500 kg and equipped with a license plate are generally charged NOK 2 940 per year. Diesel driven vehicles without a factory mounted particle filter are charged NOK 3 425, while motorcycles are charged NOK 1 800, and electric and hydrogen vehicles only NOK 415.

Whenever a vehicle is resold and reregistered, another lump-sum tax is due. Varying between NOK 1 530 and NOK 19 602, the reregistration fee for passenger cars depends on the vehicle's class, age and weight. The fee decreases with age and increases with weight. There is thus a significant fiscal 'penalty' on reselling cars younger than 12 years.

Heavier vehicles are subject to annual registration fees which depend on the vehicle's weight, suspension system, and number of axles. As of 2013, these fees range from NOK 420 per annum for the smallest vehicles up to NOK 10 384 for the largest. In addition, an environmental fee is charged depending on vehicle weight and emission standard (EURO I-VI). These fees range from NOK 84 per annum, for a EURO VI vehicle between 7.5 and 12 tonnes, to NOK 7 194, for a EURO I vehicle above 20 tonnes.

d. Road toll

According to the Road Act, tolling may be implemented by decisions by the local government for the purpose of funding road construction or improvement. A large number of tolling projects (some 70) are currently in operation. Although these tolls are not meant as GHG abatement measures, they do serve to increase the cost of travelling by car. In the example given by the newspaper VG on 13 December 2012, a motorist travelling the 857 km from Kristiansand to Trondheim would have to pay appr. NOK 250 in toll, probably adding some 30-50 per cent on top of the fuel cost.

Few tolling schemes are used for congestion charging or for any other form of marginal cost pricing. The cordon toll ring in Trondheim is the most well-known example, where charges are twice as high (NOK 20 vs. 10) during the rush hours. Congestion charging is an efficient way of combating congestion, but carries – under Norwegian conditions – no more than a marginal potential for reducing GHG emissions. This is so because a relatively small share of the vehicle kilometres travelled take place under congested conditions. A marginal cost pricing scheme differentiating between vehicles according to their emission rates would have a considerably larger GHG abatement potential.[3]

e. Scrap deposit

When a new car is registered, the buyer is charged a 'Vehicle Scrap Deposit Tax' reimbursable when the car is delivered to an authorized vehicle scrapping facility. The deposit is meant as an incentive not to leave car wrecks in the street or in the open environment. As of July 2013, the deposit payable on new cars was NOK 2 400. The 'reimbursement' collected at scrapping was, however, NOK 3 000.

[3] Steinsland & Madslien (2007) calculated that doubled toll rates around the five major cities would reduce the national CO_2 emissions by 1.3 per cent. Congestion charging would probably have a smaller impact.

The scheme came into effect in 1978. For the single calendar year 1996 the 'reimbursement' was temporarily increased from NOK 1 000 to NOK 6 000, in an attempt to achieve a faster renewal of the car fleet. A total of 227 000 vehicles[4] were scrapped in 1996, against 61 000 in 1995. In the following years, however, the turnover was correspondingly lower, so the effect on the fleet's average age was almost as temporary as the policy itself. Demands to repeat the experiment, or to raise the scrap deposit tax more permanently, are being put forward from time to time. Although these policies are being 'marketed' as GHG abatement measures, their potential towards this target is quite limited. Since the average CO_2 emission rate of new cars is steadily diminishing, the best one can achieve by intensified scrapping is to move this descending curve a bit to the left, allowing us to reach a certain improvement one year earlier than would otherwise be the case (Fridstrøm et al. 2013). When account is taken of the extra CO_2 emission spurred by increased car manufacturing, the sign of the net effect, at best, questionable.

f. Income tax on company cars

The private use of company owned cars is subject to ordinary income tax. This means that the tax burden incurred by any single beneficiary depends on his/her marginal income tax rate. In Norway, the maximal marginal tax rate on a person's salary is 47.8 per cent. Anyone earning more than NOK 509 600 per annum net of deductions will pay at least 44.8 per cent tax on the margin. Below NOK 509 600, the marginal tax rate is 35.8 per cent.

As of 2013, the annual benefit of using a company owned car is, generally speaking, valued at 30 per cent of the (new) vehicle's list price up to NOK 275 200, and at 20 per cent of the price exceeding NOK 275 200[5]. However, for cars more than three years old as of 1 January, or if the annual distance travelled in the company's service exceeds 40 000 km, the taxable benefit is reduced by 25 per cent. Also, for electric vehicles the taxable benefit is reduced by 50 per cent.

Out of the 4.7 million passenger cars changing hand during 2003-2011, only 1.03 million, i. e. 22 per cent, were new. In Norway, around 40 per cent of all new cars are bought by companies. Taken together, these statistics mean that six out of seven Norwegian households buy their cars second hand (or third, fourth, etc.). The average age of cars scrapped in Norway is 19 years. Hence the annual cost of depreciation and interest incurred by the average car owner is probably not higher than 10 per cent of the list price, in many cases lower, and the total private cost of car ownership is perhaps only half as high as assumed in the tax regulation. In this perspective, having 'free' access to a company car is by no means free. The beneficiary's incremental income tax could easily approach, perhaps even exceed, the out-of-pocket cost of private ownership to a similar, but significantly older vehicle.

Since the marginal rate of valuation drops from 30 to 20 per cent per annum as the price exceeds NOK 275 200, it may seem that costly company cars are somewhat less heavily taxed than cheaper ones. However, to qualify this one must take into account

[4] Of which only 177 000 were actually removed from circulation, having been carrying license plates in 1995.

[5] The median price of new cars sold in Norway exceeds NOK 275 200. The VW Golf 2.0 TDI 140 HP would, e. g., sell for around NOK 300 000 in a 'stripped' version. As of today, few company cars are cheaper than NOK 275 200.

the strongly progressive purchase tax due, especially the CO_2 component, which serves to render large, energy consuming cars unusually expensive. The current tax rules make it quite costly for employees to receive the benefit of access to such a car.

As of today, few, if any, companies offer their employees electric cars for private use. However, the 50 per cent 'discount' given on electric company cars, which comes on top of the VAT, road toll and purchase tax exemptions, could work as a rather powerful incentive, given that electric cars are otherwise seen as attractive company vehicles. With the market entry of more sophisticated or prestigious models, electric company cars could be facing a rather steep rise in demand during the next couple of years.

1.2 Biofuels

Since 1 April 2010, fuel merchants must ensure that at least 3.5 per cent of the fuel sold for road transport purposes is biofuel.

Merchants may comply by this regulation by mixing a 3.5 per cent share of biofuel into all the fuel they sell, or by mixing a correspondingly higher share into certain parts. In Norway, most petroleum companies achieve the target by mixing up to 7 per cent rapeseed methyl ester (RME) into the diesel sold. Statoil also blend a low share of bioethanol into their petrol.

Up until 2009, biodiesel was exempt of the 'road use' tax payable on fossil diesel (NOK 3.20 per litre in 2009). This had led certain large hauliers to implement a programme for massive biodiesel use in their lorries, and a factory in south-eastern Norway had started producing and marketing the fuel. In their budget proposal for 2010, however, the government announced that biodiesel would no longer be exempt from the tax, on the grounds that vehicles travelling the road by means of biofuel would not meaningfully be exempted from a 'road use' tax.

This proposal sparked a quite heated debate, some reactions[6,7,8] being extremely critical. Certain researchers, however, gave support to the government's argument,[9,10] while also criticizing the government for giving out mixed signals to whatever private investors might be willing to commit themselves to innovative, climate friendly solutions.[11] In the end, the Parliament decided that biodiesel would be subject to half the 'road use' tax levied on fossil fuel.

1.3 Electrification

Norwegian legislation and taxation provide powerful incentives for the acquisition and use of battery and hydrogen fuel cell electric vehicles. These vehicles are exempt of value added tax, vehicle purchase tax, road tolls and public parking charges. They benefit from strongly reduced annual registration tax (see section 1.1 c above) and reduced ferry fares (at most equal to those payable for MCs). Moreover, they are

[6] http://www.bellona.no/nyheter/nyheter_2009/Jens_misforstar

[7] http://www.dinepenger.no/regler/biodieselavgift-er-et-dolkestoet-i-ryggen/569033

[8] http://www.vg.no/nyheter/innenriks/norsk-politikk/artikkel.php?artid=592378

[9] http://www.aftenposten.no/meninger/kronikker/article3390006.ece

[10] http://www.ssb.no/emner/01/04/10/rapp_201044/rapp_201044.pdf

[11] http://www.dagbladet.no/2009/11/23/nyheter/innenriks/miljo/miljogifter/statsbudsjettet_2010/9164228/

allowed to travel in the bus lane and may be recharged for free in many public parking lots.

As a result, Norway probably has the largest share of electric vehicles of any country. As of 31 October 2013, there are more than 17 000 rechargeable vehicles on Norwegian roads, i. e. appr. 0.7 per cent of the passenger car fleet. BEVs constitute the overwhelming majority of rechargeable vehicles, only about 4 per cent being PHEVs. BEVs are in particularly high demand in the Oslo area, especially in the municipalities west of Oslo, from where the trunk road into the city (E18) is heavily congested during the rush hours. Using the bus lane, electric vehicles may travel at a speed several times higher than the ordinary car.

Certain stakeholders, among them the public transport companies, whose bus lanes are becoming crowded, have been concerned about the fast multiplication of the electric vehicle fleet. Stakeholders on the electrification side, such as Grønn bil and ZERO, have, on the other hand, been asking for stable and foreseeable incentives and regulation. To strike a balance between these demands, the Parliament has decided that the present regulation will persist until 2018, or until there are 50 000 electric vehicles registered, whichever comes first. ZERO, while admitting that BEVs' access to the bus lane will have to be closed in a few years' time, advocates a prolongation of the tax incentives until 2020-22 (Asheim 2013).

1.4 Other national policy instruments

The government has launched as its explicit target that, in all the major urban areas, any future growth in travel demand should be absorbed by public transport, bicycling or walking. To the extent that public transport consumes less energy per passenger kilometre than private cars, this intention could be seen as a plan to enhance energy efficiency. It is, however, uncertain whether the set of policy instruments available or foreseen would be sufficient to meet the goal.

At the level of the central government, the most important set of incentives in operation is the so-called '*reward scheme for public transport*' ('belønningsordningen'), established in 2004. Its explicit aim is to relieve congestion and improve the urban environment and health by slowing the growth in motorized traffic and increasing the number of bicyclists, pedestrians and public transport users at the expense of private cars. Counties fulfilling the criteria are entitled to subsidies from the central government. In the fiscal budget for 2012, a total of NOK 411 million was set aside for this purpose. As of November 2012, NOK 290 million had been awarded to four different counties, for their efforts to improve public transport in the Bergen, Drammen/Kongsberg, Kristiansand and Trondheim areas, respectively. In the fiscal budget for 2013, the budget was increased to NOK 673 million. In the National Transport Plan 2013-24 (Meld. St. 26 2012-2013), it is foreseen that this reward scheme be replaced by more extensive 'urban environment programmes' totalling NOK 26.1 billion over the 10-year period.

Another set of instruments to curb automobile use and encourage the use of public transport is *parking regulation*. Many employers offer free parking for their employees. In principle, this fringe benefit is taxable, but in practice, taxing the individual use of parking space is considered too cumbersome. The Ministry of Transport and Communications has proposed a law that would allow cities and municipalities to require that all property owners with more than 10 parking spaces must charge for parking. This would compel large employers to charge their employees and shopping malls to charge their customers. The proposal has met fierce opposition from the business community. One major counterargument is that it would distort competition between neighbouring municipalities, if one of them decides to make use of the provision and the other one does not. Apparently only a nationwide regulation of the sort would work.

Some contend that there is an obvious asymmetry present, in that, while free parking is not taxed, any employer offering his personnel free monthly passes on public transport is required to declare the cost as a taxable part of their salary. Proposals have been made to remedy this by allowing such fringe benefits to be exempt of income tax. But the Ministry of Finance invariably opposes this on the grounds that it would entail a large drop in income tax revenue.

Efforts are, however, being made to restrict the availability of public as well as private parking in urban centres. In the four largest cities[12], maximal norms for parking space are being imposed on all new office and industrial buildings.

1.5 Private and local government initiatives

a. Trondheim

The most publicized local government initiative is the so-called environmental package ('miljøpakken') of the city of Trondheim. It consists of road and tunnel construction as well as public transport improvement, road safety measures, noise abatement and bicycle facilities. The total budget amounts to NOK 9 656 million, of which NOK 6 642 million will be collected through tolling, while the central government is expected to contribute NOK 1 730 million. The rest would come from the city budget, the county budget and/or through the government reward scheme (see section 1.4).

Some NOK 2 030 million have been set aside for public transport enhancement and NOK 1 300 million for bicycle lanes, paths, parking and other facilities. The largest budget share, NOK 4 126 million, is, however, assigned to road infrastructure improvement, mainly to improve the traffic flow around the urban centre.

b. Oslo area

In Oslo and Akershus (the surrounding county), public transport ridership has increased markedly over the last few years, while private car use in Oslo has stagnated (light blue line in Diagram 3). This development is due to a complex set of factors, the most important of which are probably the following:

- In 2007, the counties of Oslo and Akershus created a common public transport procurement agency, called Ruter, with the purpose of coordinating, improving and simplifying the public transport supply in the greater Oslo area. A number of improvements and simplifications have already taken place, such as the introduction of a common, electronic fare system.
- The Oslo metro has been upgraded through a complete replacement of the rolling stock. Punctuality has improved and frequency has increased on certain lines. This also applies to the tramway. More bus lines have been put in place. The local railway lines, which had been marred by weak regularity, have

[12] Oslo, Bergen, Trondheim and Stavanger.

undergone important technical renewal work, improving regularity and punctuality.

- Another set of tolling stations have been set up on the western corridor, increasing the total toll to enter the city from the west by 50 per cent.
- The price structure has been amended within the public transport system as well as in the toll ring. Since 1 July 2008, it has not been possible to buy monthly or annual passes for the Oslo toll ring. Every passing is now subject to a marginal cost, although only inbound traffic is charged. Since February 2013, light vehicles pay NOK 27 if equipped with an AutoPASS transponder, heavy vehicles are charged a triple rate. In public transport, an almost opposite change took place at almost exactly the same time (1 August 2008): The price of the monthly pass was reduced sufficiently that most commuters choose to buy it, meaning that for a large share of the users, the marginal cost of public transport use is now zero. These one-time changes, introducing a marginal cost for motorists, while abolishing it for many public transport users, have probably served to restrain car use and boost public transport demand.
- Increased congestion, especially on the main arteries into the city, is making it less and less attractive to commute by car.
- The financial crisis, although not felt as severely in Norway as in other European countries, may have contributed to the reduction in car traffic observed from 2008 to 2009.
- Reurbanization: since 2000, central parts of Oslo have experienced considerable population growth, while suburban growth has been tapering off.

Diagram 3: Development in public transport ridership, private car use and population size in the Oslo and Akershus counties[13]*. Source: Ruter AS*

c. Cities of the Future

[13] Kollektivtransport = Public transport (PT); vognkm=PT vehicle kilometres; befolkning=population; biltrafikk=car traffic flow.

13 of the largest cities in Norway have formed a cooperation programme called Cities of the Future ('Framtidens byer'). Its purpose is 'to reduce greenhouse gas emissions and make the cities better places to live'. The main idea is expressed like this:

> 'Cities of the Future are densely built. This means we can walk and cycle instead of using cars, reducing pollution. Fewer cars and roads make more room for bike paths and parks. This makes the cities prettier and makes us healthier. The parks will also help absorb the increasing rainfall expected in the future. […] The Cities of the Future programme will help city municipalities to share their climate friendly city development ideas with each other and with the business sector, the regions and the Government.'

The programme is supported by the Ministry of the Environment.

d. HyNor/HYOP

The HyNor hydrogen highway was established in 2003 as part of the Scandinavian hydrogen highway partnership. The highway runs between Oslo and the port of Stavanger. It is part of the Norwegian hydrogen infrastructure, and several hydrogen refuelling stations have been built along the 580-kilometre route.

Norway's first hydrogen fuelling station was opened in 2006 near Stavanger, the second in Porsgrunn in 2007, and two stations were opened in Oslo and Lier in 2009. The official opening of HyNor took place on 11 May 2009 in Oslo.

Originally operated by Statoil, the hydrogen fuelling pumps were taken over by HYOP AS in May 2012.

1.6 Pending proposals

In January 2012, the high-speed rail study commissioned by the Norwegian Rail Administration ('Jernbaneverket') was presented. A network of high-speed rail (HSR) lines serving the cities of Oslo, Trondheim, Bergen, Stavanger and Kristiansand, possibly also connecting to Stockholm and Gothenburg, was designed, and its costs of investment, maintenance and operation were calculated. The carbon footprint was also given attention, with the interesting conclusion that the carbon debt accumulated during construction would take an estimated 60 years to pay back.

In the National Transport Plan 2014-23 (Meld. St. 26 2012-2013), the idea of building a high-speed rail network is not pursued. Priority is given to the so-called Intercity (Rail) Triangle, connecting the cities of Skien/Porsgrunn (southwest), Halden (southeast) and Lillehammer (north) to Oslo, through a radically improved and faster rail service. The calculated cost, although much smaller than for the HSR network, is such as to presuppose a dramatically enlarged government budget for transport investment during the next couple of decades.

Another large scale proposal for infrastructure development is the so called ferry-free coastal highway (E39) between Stavanger and Trondheim. No less than eight ferry crossings would be replaced by bridge or tunnel.

2 A scenario analysis for the Nordic countries

Building on the IEA (2013) study on Nordic energy technology perspectives, Fulton and Bremson (2013) discuss the roll-out requirements for advanced technology vehicles and fuels with a view to reach the 2050 targets compatible with the IEA two-degree scenario (2DS).

Under the two-degree scenario, no more than 73 per cent of new light vehicles sold in 2020 would be equipped with conventional engines for fossil fuel combustion, decreasing to 41 per cent in 2030, 8 per cent in 2040, and practically zero in 2050 (Diagram 4). It is foreseen that hybrid vehicles with or without plug-in possibilities would make up 25 per cent of the market in 2020 and almost 50 per cent in 2050. Hydrogen fuel cell and battery electric vehicles are assumed to constitute more than half the market in 2050.

In the even more ambitious rapid transition scenario (RTS), only rechargeable vehicles are sold in 2040, while by 2050 a full 84 per cent of new vehicles sold rely exclusively on hydrogen or electric energy.

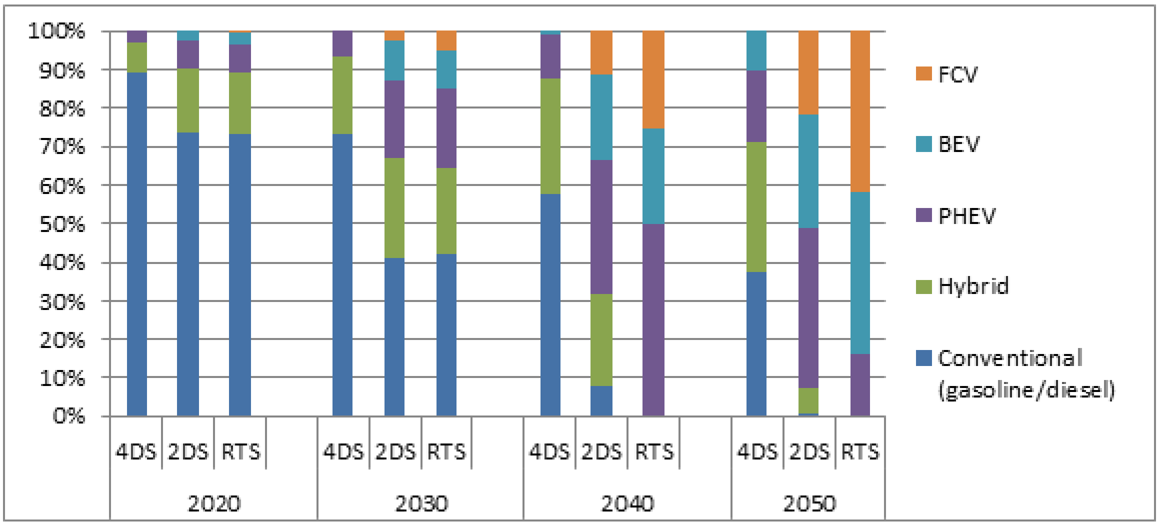


Diagram 4. New Light Duty Vehicles (LDV) sales shares in the Nordic countries, under a 4-degree (4DS), 2-degree (2DS) and rapid transition scenario (RTS)[14]. Source: Fulton and Bremson (2013).

The path towards the two-degree scenario is shown in Diagram 5. Note that this diagram depicts the annual flow of new vehicles sold, not the stock of vehicles at any given point. It takes about 20 years until (almost) the entire car fleet has been renewed.

[14] FCV= Fuel Cell Vehicle; BEV= Battery Electric Vehicle; PHEV= Plug-in Hybrid Electric Vehicle

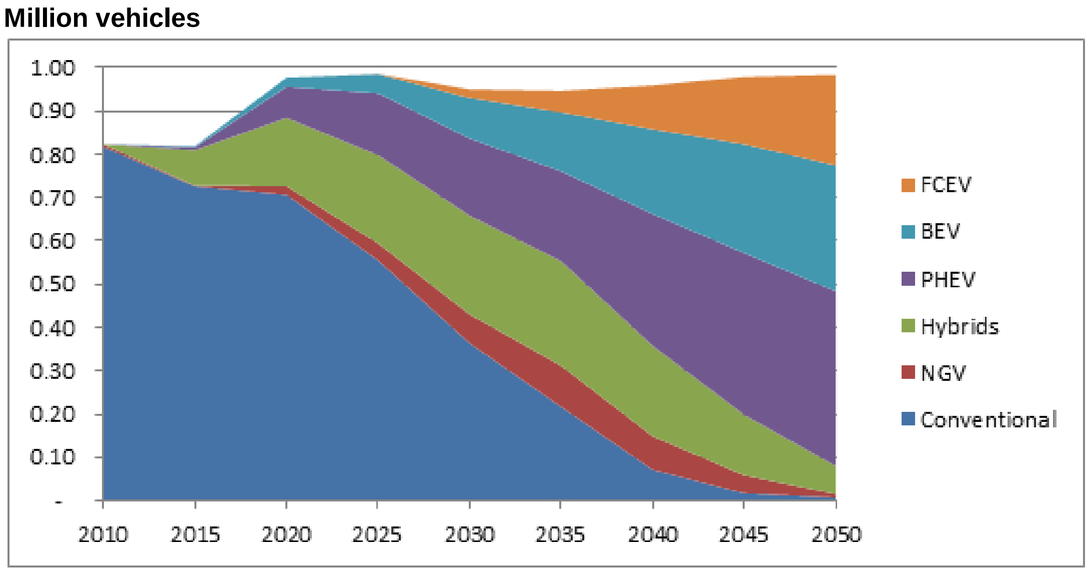


Diagram 5. The 2-degree scenario (2DS). Annual light-duty vehicle sales by technology type in the Nordic countries[15]. Source: Fulton and Bremson (2013)

In terms of technological development, Norway – and even the Nordic region – is too small a market for national incentives and regulation to have much impact on the international auto industry. However, Fulton and Bremson (2013) argue that

> 'The five Nordic countries (Denmark, Finland, Iceland, Norway, and Sweden) have an opportunity to become world leaders in the deployment of plug-in electric vehicles (PEVs), including battery electric, plug-in hybrid and hydrogen fuel cell vehicles. The benefits of rapid deployment of these technologies would include not only the direct energy savings and CO_2 reductions they would provide, but also the possibility to accelerate a global transition to very low carbon vehicles and fuels.
>
> ...
>
> Overall, there are good reasons why Nordic countries should seize the day and move toward a rapid transition to advanced technology vehicles. Some key polices are in place in each of the countries. A sustainable funding mechanism to help lower the price of PEVs over perhaps the next 10 years so they are attractive to consumers without further support is probably the greatest requirement, and this can be achieved through policies such as CO_2-based vehicle taxation systems. These are now in place to varying degrees in the different Nordic countries and in some cases may just need to be fine-tuned over time. Other incentives such as roadway and parking priority access, and installation of recharging infrastructure are also in place in various ways in the different countries, and such incentives have proven valuable, but must be managed carefully, particularly as the PEV car stock grows. Further work on optimizing policy packages, and ensuring sustainable funding streams (while preserving government revenues), is needed. But the basic elements are already in place, particularly in Norway.'

An interesting point made by Fulton and Bremson (2013) relates to cost. As the manufacturing of PEVs reaches critical mass and beyond, the costs of operating such vehicles will converge to those of conventional cars (Diagram 6).

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[15] NGV= Natural Gas Vehicles

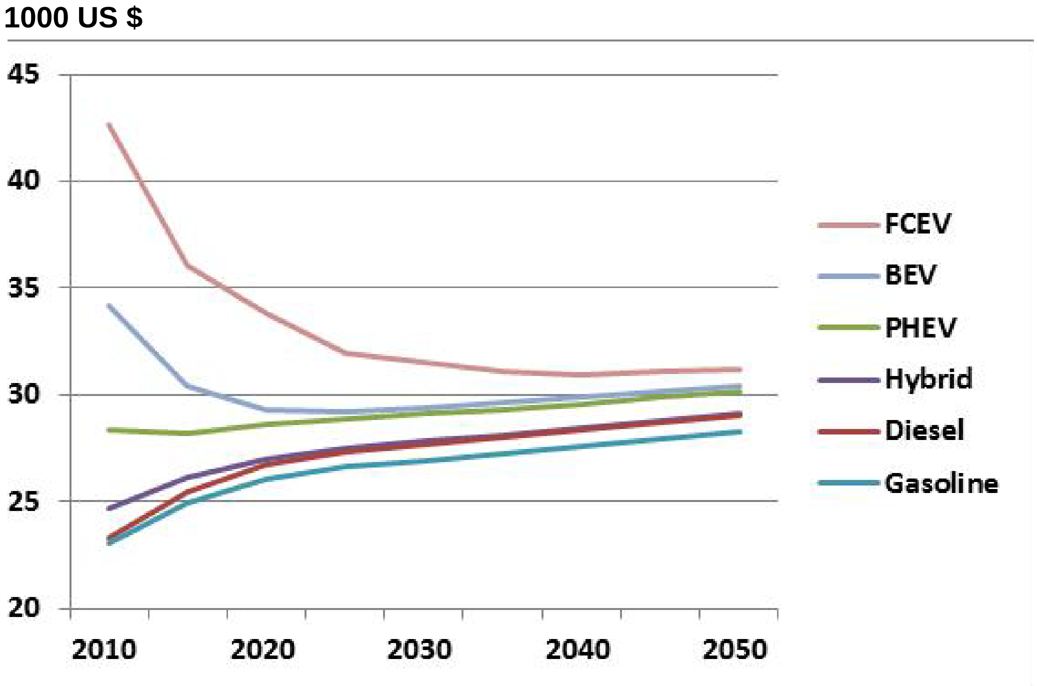

Diagram 6: Cost-based price of a representative light-duty vehicle by technology type. Source: Fulton and Bremson (2013), based on IEA vehicle cost projections.

According to Fulton and Bremson (2013),

> 'This approach captures all spending on new car purchases, along with fuel purchases for all cars on the road, in each year. It does not include the non-fuel cost of operating cars (such as maintenance and insurance) – these are assumed to be similar for all vehicle types so are not expected to vary across scenario. In fact, this approach underestimates the fuel savings from PEVs in a given year since it includes the cost of all PEVs sold in that year but only the fuel savings associated with them in that year, whereas they will continue to provide fuel savings for many more years.'

There are three basic reasons for this convergence. First, on account of economies of scale, the costs of advanced technology vehicles drop over time as their sales volumes increase. Second, the energy consumption of advanced technology vehicles is likely to drop as these vehicles become gradually more efficient. And third, fossil fuel being a depletable resource, its price is likely to rise over time, while – according to Fulton and Bremson – the opposite development can be foreseen for hydrogen and electricity. One cannot rule out the possibility that, by 2050 or before, the total economic cost of acquiring and operating an advanced technology vehicle has become lower than that of conventional vehicles.

3 Long term projections for transport demand and emissions

As an input to the Norwegian National Transport Plan 2014-23, the Institute of Transport Economics (TØI) has developed long term travel demand forecasts based on the models NTM5 (for long haul trips) and RTM (for local trips) (Madslien et al. 2011). Similarly, freight demand forecasts have been developed by Hovi et al. (2011).

An assessment of future energy use and greenhouse gas (GHG) emission rates from Norwegian transport was commissioned by the Ministry of Transport and Communications and authored by Thune-Larsen et al. (2009).

In the present report, we have combined input from these three publications to produce rough estimates of future GHG emission volumes under a 'reference scenario' as well as a 'low emissions scenario'. The aim of this analysis has been to elucidate possible paths towards the two-degree scenario, interpreted as an 85 per cent emissions reduction between 2010 and 2050, rather than to describe the most likely course of development. Without disregarding the formidable political and technological challenges involved in achieving emissions reductions compatible with this highly ambitious scenario, we make projections under the hypothetical assumption that many of these difficulties will somehow be overcome.

Compared to the preliminary projections presented in Fridstrøm (2013d), some corrections and adjustments have been made. The initial (2010) level of CO_2 emissions from the various travel and freight modes have been adjusted so as to coincide with the most reliable statistical sources, as summarized by Hovi and Madslien (2008: table 7.2). This recalibration has the effect of boosting the CO_2 emissions from the travel modes, set at too low a level in Fridstrøm (2013d), while lowering the emissions estimates for freight.

3.1 Defining reference and low emissions scenarios

Our reference and low emissions scenarios correspond roughly to the equally labelled scenarios developed by the Norwegian 'Commission on Low Emissions' (Lavutslippsutvalget, NOU 2006:18). Some more detailed information on the content of our scenarios is summarized in Diagrams 7 through 10.

In the low emissions as well as in the reference scenarios, CO_2 emission rates go down for two main reasons: (i) improved energy efficiency as reckoned per transport unit, and (ii) reduced CO_2 emission rates per energy unit. The former could be due either to sheer technical improvements or to better capacity utilization. The latter development is due to the gradual market penetration of alternative energy carriers, such as electricity, biofuel, or hydrogen.

In Diagrams 9 and 10, we show how much reduction is attributable, in the low emissions scenario, to each of these two developments.

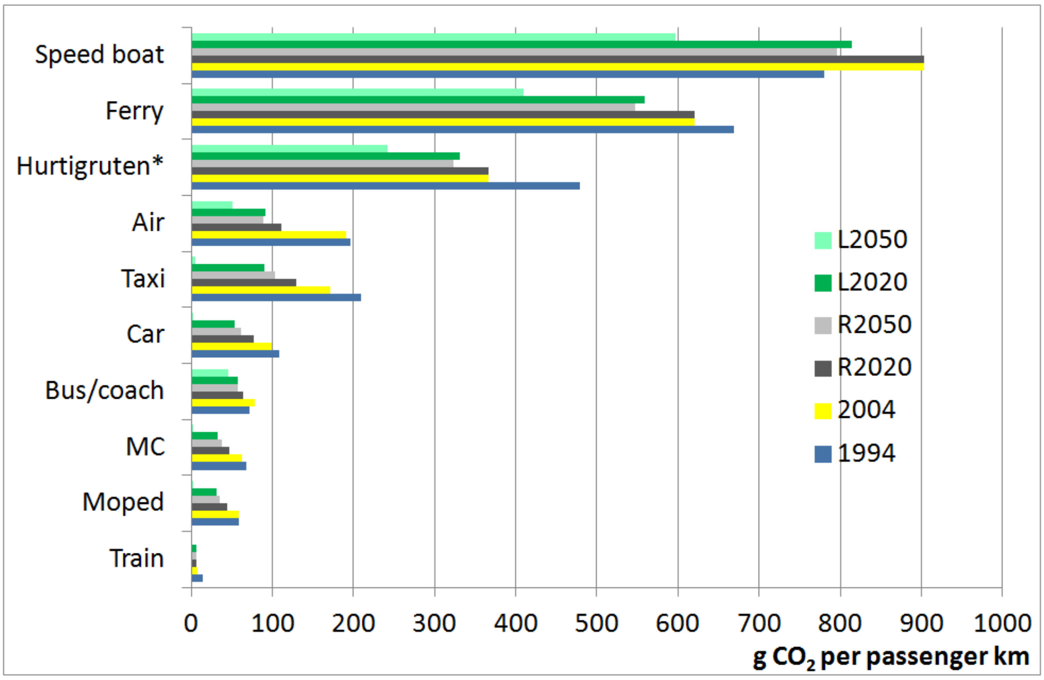

*Diagram 7: CO_2 emission rates for domestic Norwegian travel * in 1994, 2004 and under the reference (R) and low emission (L) scenarios 2020 and 2050. Source: Thune-Larsen et al. (2009).*

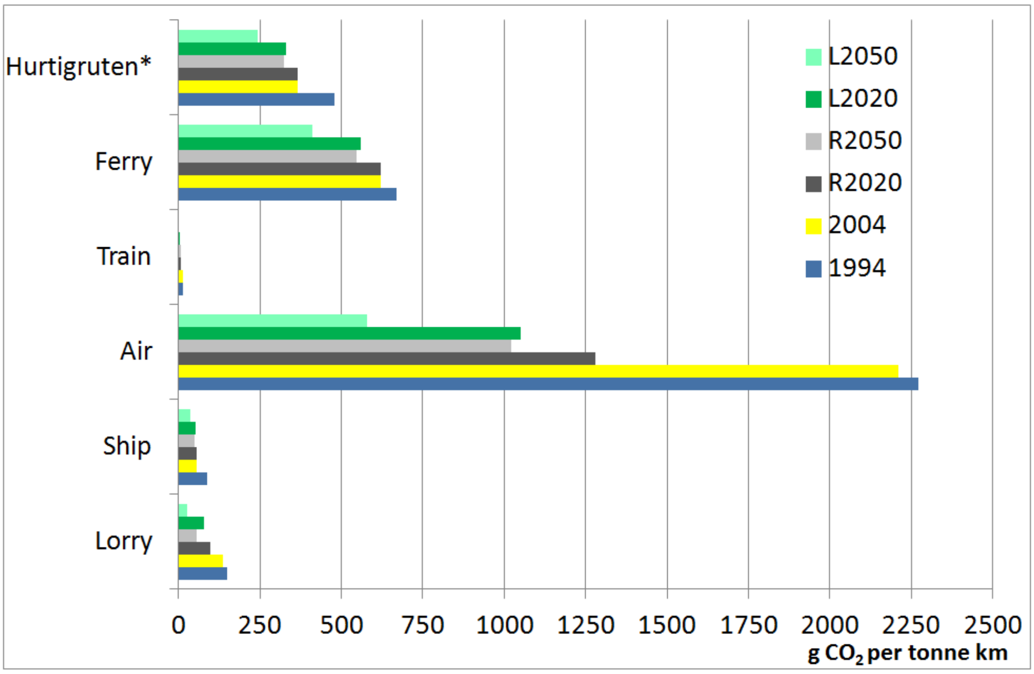

Diagram 8: CO_2 emission rates for freight on Norwegian territory in 1994, 2004 and under the reference and low emissions scenarios 2020 and 2050. Source: Thune-Larsen et al. (2009).

In aviation, a 47 per cent drop in both energy use and CO_2 emission rates is assumed between 2004 and 2020, and a 74 per cent drop is envisioned by 2050. In other

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* ‘Hurtigruten’ refers to the daily passenger and freight shipping service along Norway's western and northern coast.

words, the entire improvement is supposed to come from more energy efficient aircraft or from better capacity utilization.

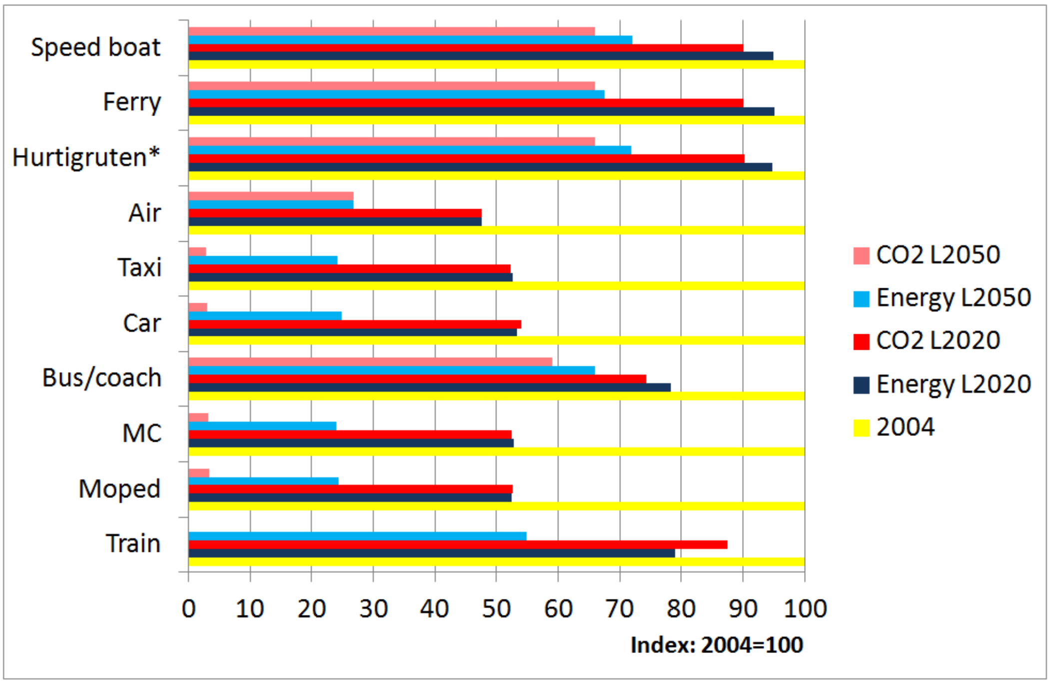

Diagram 9: Assumed relative, per passenger km energy use and CO_2 emission rates for domestic Norwegian travel under the low emissions scenario 2020 and 2050. Source: Thune-Larsen et al. (2009).

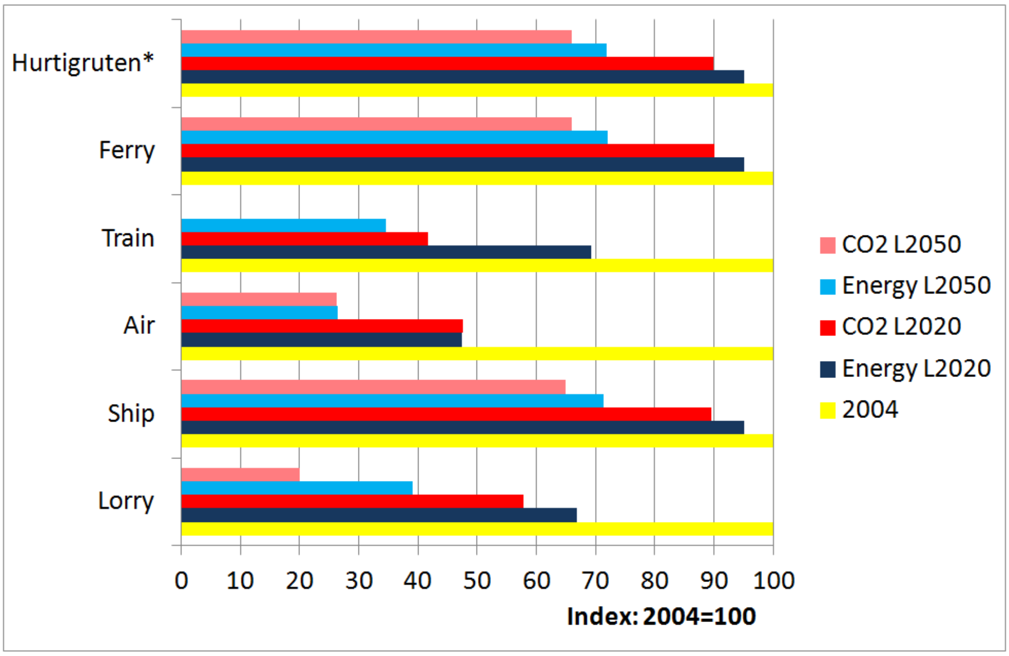

Diagram 10: Assumed relative, per tonne km energy use and CO_2 emission rates for freight on Norwegian territory under the low emissions scenario 2020 and 2050. Source: Thune-Larsen et al. (2009).

Private cars are, again in the low emissions scenario, required to become 47 per cent more energy efficient by 2020 (compared to 2004), and 75 per cent more efficient by 2050. In addition, new energy carriers should add another 22 percentage points improvement in CO_2 emission rates by 2050, bringing the average emission rate down to 3 per cent of the 2004 level.

In the road freight arena (Diagram 10), energy efficiency is assumed to improve by 33 per cent by 2020 and 61 per cent by 2050. CO_2 emission rates come down by a corresponding 42 and 80 per cent, meaning that in 2050, less carbon intensive energy carriers are assumed to almost halve the emission rate compared to the situation with (almost) only traditional, fossil fuels.

In sea freight, energy savings are assumed to account for a 5 per cent improvement by 2020 and a 29 per cent drop by 2050. New energy carriers bring the improvement in terms of CO_2 emission rates to 11 and 35 per cent in 2020 and 2050, respectively.

As shown in Diagrams 7-8, the seagoing modes have high emission rates when it comes to passenger transport, but low rates when it comes to freight. Luckily, the sea mode has a very much higher share of the freight market than of the travel market (Diagrams 11-12).

3.2 Transport demand forecasts

In Diagrams 11 and 12, we show forecasts for travel and freight demand, respectively, as well as market shares for 2008/2009.

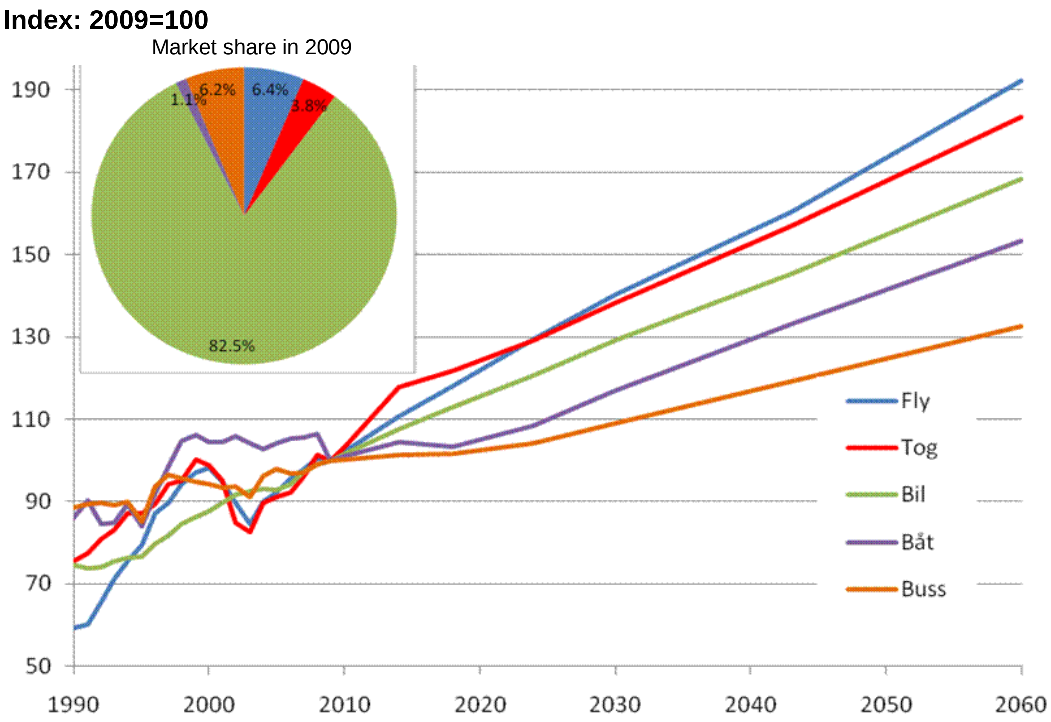

Diagram 11: Travel demand by mode 1990-2009 and forecasts to 2060. Person kilometres travelled relative to 2009. Source: Madslien et al. (2011)[16]

[16] Fly=Air; Tog=Rail; Bil=Car; Båt=Sea; Buss= Bus/coach

Travel demand is expected to grow by more than 50 per cent between 2009 and 2050. The strongest growth is foreseen for air travel, followed by rail and private cars.

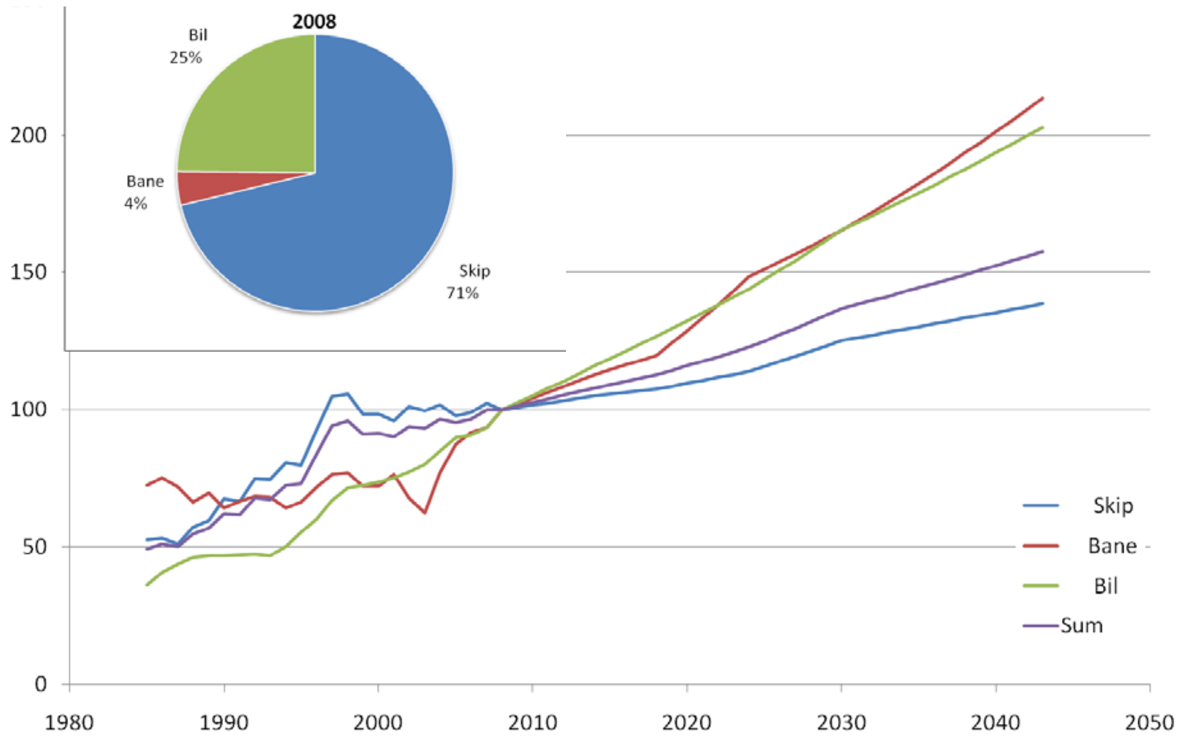

Diagram 12: Freight demand by mode 1985-2008 and forecasts to 2043. Tonne kilometres hauled relative to 2008. Source: Hovi et al. (2011)[17]

Freight demand by rail and road is expected to more than double, while sea freight is likely to grow by less than 50 per cent. All modes taken together, freight tonne kilometres in Norway are projected to grow by more than 50 per cent by 2050.

3.3 CO_2 emission forecasts

In Diagrams 13-16, we have combined these forecasts with reference and low emissions scenario rates of CO_2 emissions, respectively, to produce emission forecasts. Since the forecasting milestones used by Madslien et al. (2011) and Hovi et al. (2011) do not coincide, we have resorted to linear interpolation to obtain common snapshots for 2020, 2030, 2040 and 2050.

In the reference scenario, foreseen technological improvements are insufficient to offset the projected growth in transport demand, resulting in a 3 per cent increase in CO_2 emissions from domestic travel and an 11 per cent increase due to freight, both reckoned as of 2050 compared to 2010.

In the low emissions scenario, however, emissions from domestic travel go down by a full 83 percent. On the freight side, a more modest, 28 per cent reduction is

[17] Skip=Sea; Bane=Rail; Bil=Road; Sum=Total

foreseen. Taken together, emissions from Norwegian transport – travel and freight – go down by 60 per cent between 2010 and 2050.

At the 2030 milestone, the low emissions scenario projects a 46 per cent emissions reduction from travel and 10 per cent from freight.

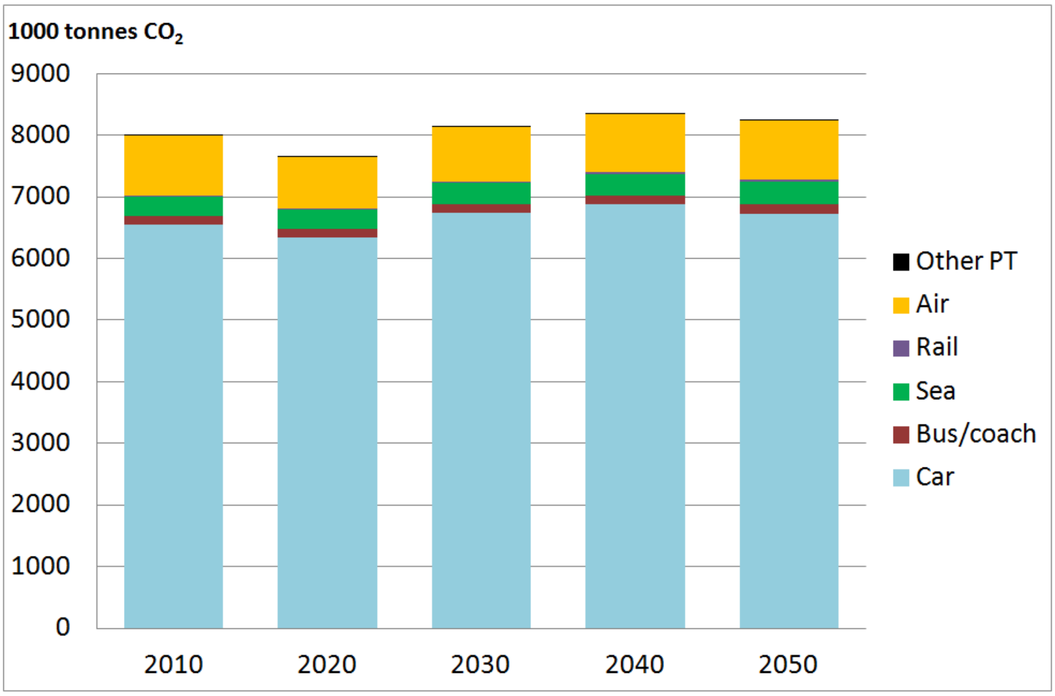

Diagram 13: The reference scenario for domestic travel in Norway. Tonnes of CO_2.

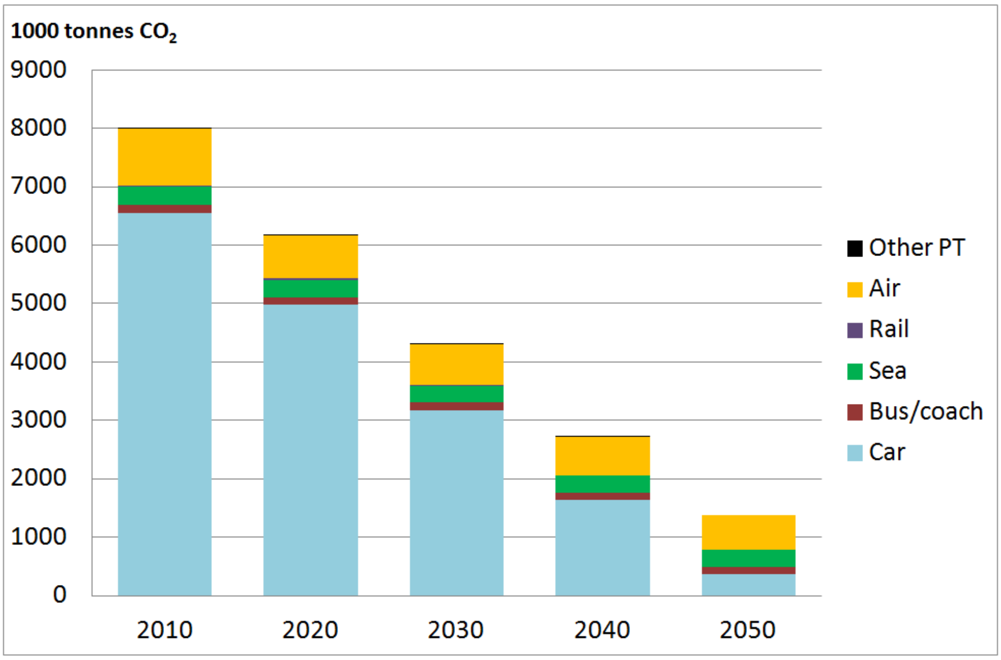

Diagram 14: The low emissions scenario for domestic travel in Norway. Tonnes of CO_2.

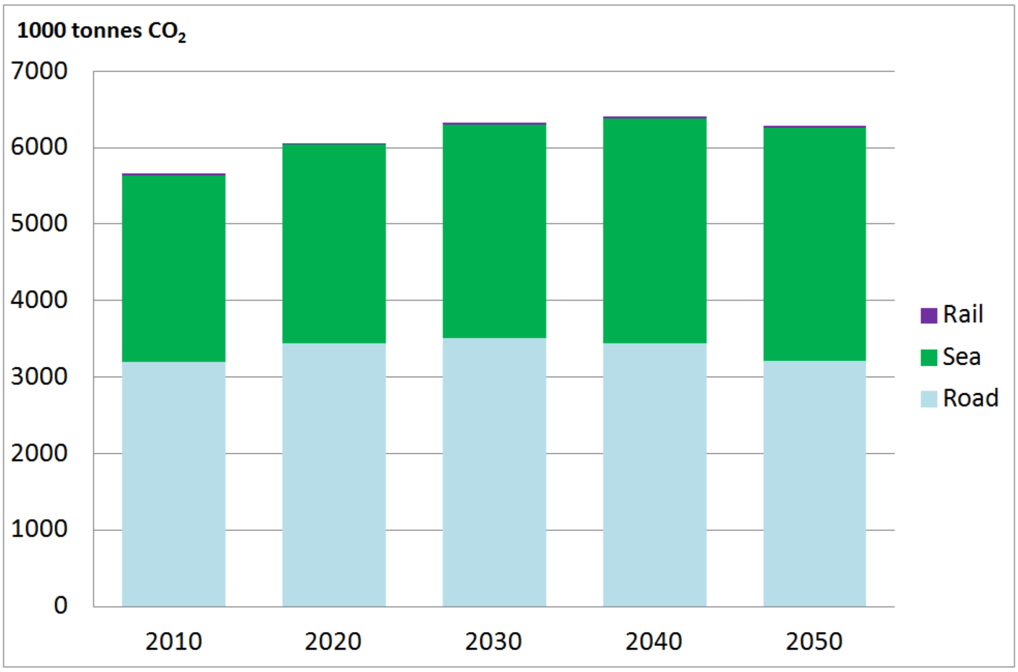

Diagram 15: The reference scenario for freight transport emissions on Norwegian territory. Tonnes of CO_2.

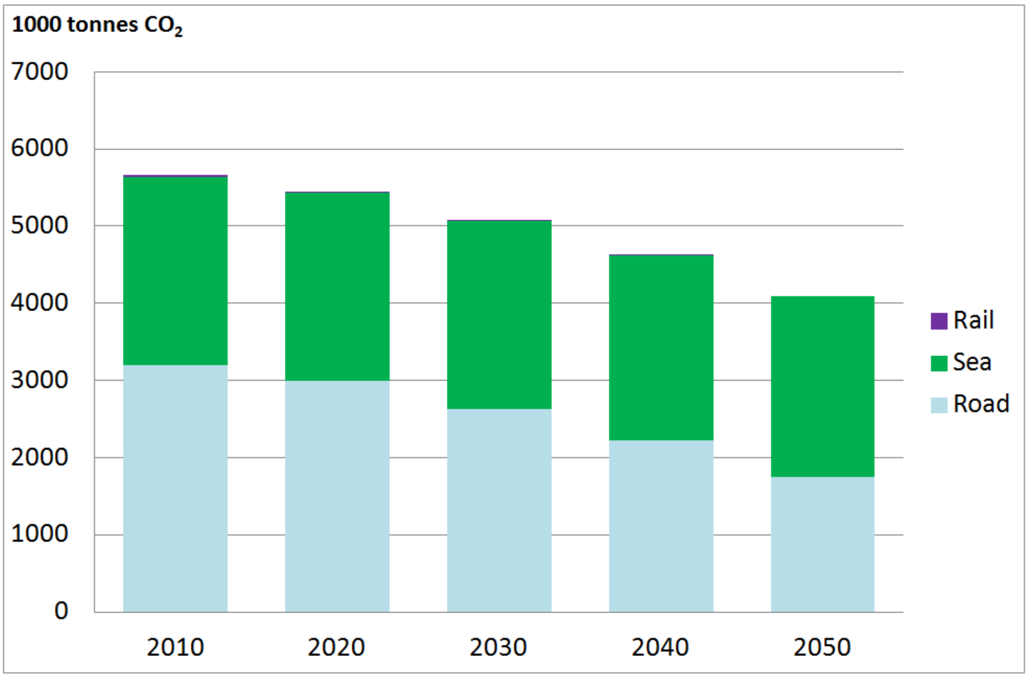

Diagram 16: The low emissions scenario for freight transport on Norwegian territory. Tonnes of CO_2.

4 Policy discussion

The Commission on Low Emissions (NOU 2006:18) identified four general sets of policy measures as a basis for their low emissions scenario for the transport sector:

1. Introduction of low and zero emission vehicles, such as BEVs, PHEVs, FCVs, hybrids and light diesel engine vehicles
2. Introduction of CO_2 neutral energy carriers such as bioethanol, biodiesel, biogas and hydrogen
3. Reduced transport demand through improved logistics and urban planning
4. Development and introduction of low emission sea vessels

We shall discuss some of these suggestions in light of the scenario analyses and projections presented above.

4.1 Low and zero emission vehicles

Up until 2013, the most promising GHG abatement measure applied in Norwegian transport is no doubt ***the CO_2 component of the vehicle purchase tax***. From 2006 to 2012, the average CO_2 emission rate of new passenger cars sold dropped by 27 per cent. Although this entire improvement cannot readily be attributed to the CO_2 tax, since several other 'drivers' have been at play simultaneously[18], it is interesting to note that since 2006 the rate of emission from new cars in Norway has been improving at an about 50 per cent faster pace than in the 27 EU countries.

The average emission rates of the existing car fleet has, of course, so far dropped by only a fraction of the 27 per cent recorded for new cars. However, as new cars continue to replace old ones, the effect will gradually penetrate the entire automobile population. By 2020, close to half the private car fleet of 2012 will have been replaced, and by 2030 almost all of it. As far as private cars are concerned, we can therefore expect an at least 27 per cent improvement by 2030.

An even stronger improvement is foreseeable if the CO_2 tax component continues to receive an incessantly larger weight in the vehicle purchase tax. Indeed, even in the reference scenario presented herein, average emission rates from private cars have come down 28 per cent in 2035 and 39 per cent in 2050. In the low emissions scenario, the corresponding figures are 79 and 97 per cent.

There is, however, a hurdle. Given that consumers respond to the CO_2 tax as intended, by buying steadily more climate friendly and less heavily taxed cars, the revenue from the purchase tax will shrink. If the government insists on maintaining the level of revenue, it could become an obstacle to a continued sharpening of the CO_2 tax instrument. Or, on the contrary, it could necessitate a quite aggressive policy of gradually 'tightening the bolts'. If and when the target CO_2 emission rate of 85

[18] Notably the EU regulation mandating car manufacturers to bring the average CO_2 emission rate of new cars down to 95 g/km by 2020.

g/km is achieved, as averaged over all new cars, it would represent a more than 50 per cent drop from the 2006 level.

While the impact of the CO_2 purchase tax component is, in a sense, improving automatically over time, the same is obviously not true of ***the privileges and tax exemptions given to battery electric cars***.[19] When these cars become too numerous, their right to use the bus lane will have to be abolished. Those who acquire BEVs primarily to gain access to the bus lane will become drastically fewer as the end of this privilege draws nearer. Barring a technological breakthrough that would allow BEVs a range comparable to that of petrol or diesel cars, it remains uncertain how competitive electric cars will be from the point where they lose any one of their privileges: bus lane access, VAT exemption, purchase tax exemption, road toll exemption, free parking and/or free public recharging. Will the larger variety of models marketed, the improved performance and the price fall due to larger economies of scale be sufficient to outweigh the gradual elimination of subsidies? If not, chances are that the sales of electric cars will taper off as the fleet size approaches 50 000 registered vehicles, corresponding to about two per cent of the car fleet. This may limit the GHG abatement potential of electric cars in the short and medium term.

While massive privileges apply to BEVs, the tax incentives directed at ***plug-in hybrid electric vehicles*** are more moderate (see section 1.1 above). In order for these vehicles to obtain a satisfactory market uptake within the 2020 horizon, stronger incentives may be called for. Since, unlike BEVs, PHEVs do not present any 'range anxiety' problem, their long-term prospects for large scale market penetration is quite probably more promising than for BEVs. Most households are unlikely to acquire a vehicle with limited range other than as a second or third car.

The first generation plug-in hybrids that were recently tried out in the Nordic countries came out with an average CO_2 emission rate (78 g/km) well below[20] the NEDC target set for new cars in 2020 (Hagman & Assum 2012). Still, their CO_2 abatement potential (compared to non-rechargeable hybrids) hinges probably on their electric range being large enough for owners to take the trouble of recharging them whenever possible. There appears, at present, to be two possible directions of technological development – one targeting electric ranges of 20-30 km, the other aiming for 50-80 km. The latter has a clearly higher CO_2 abatement potential. With an electric range of 20 km, the maximal fuel savings obtained per recharging is of the order of one litre, at a cost of NOK 10-15. To many consumers, this incentive might be too small for climate friendly habit formation. An electric range of at least 50 km would be more likely to elicit such behaviour.

Thus, when designing more forceful tax incentives directed at PHEVs, there is reason to encourage the purchase of vehicles with a particularly large electric range more than what might follow from a 'technology neutral' consideration.

In the longer term, ***hydrogen fuel cell technology*** could emerge as the solution to the electric vehicles' range problem. Massive infrastructure investment (fuelling stations) would, however, be required for this type of vehicles to become attractive to the ordinary consumer. Also, as pointed out by Fulton and Bremson (2013), FCVs

[19] See Hagman et al. (2011) for a more extensive discussion.

[20] The difference is of the order of 20-40 per cent, when considering the fact that emission rates in real traffic are typically at least 10-30 higher than in the NEDC testing cycle.

are just as carbon intensive as the source of their hydrogen. Given, however, the abundance of hydropower available in Norway, chances are that electrolytically produced hydrogen would come out with a fairly low well-to-wheel carbon intensity.

Certain objections have been raised against the electrification subsidies on the grounds that, on the margin, their energy is being generated by thermal plants in Denmark, Germany or Poland. Assuming, however, that the European Union's Emission Trading Scheme (EU ETS) works as intended, there is an unequivocal gain to transport electrification, in that a GHG emission generating activity – travelling – that was previously unchecked, is now brought into the trading scheme. Since the cap on GHG emissions remains the same, no extra GHG unit is emitted as another electric vehicle is allowed to enter the road.

The net gain will, nevertheless, depend on what kind of activity is replaced by the use of an electric car. If bicyclists or public transport users convert to electric cars, or if the privileges enjoyed by electric cars induce additional travel demand, the net GHG abatement gain could turn out to be rather small. There is little solid knowledge on this behavioural issue.

Bicycles equipped with an auxiliary electric motor are becoming popular in several parts of the world. Such vehicles might help overcome the topographical handicap of cities like Oslo and Bergen, as compared, e. g., to the 'bicycle Meccas' of Copenhagen and Amsterdam. Now, a large scale penetration of ***electric bicycles*** into the Norwegian market probably presupposes some fairly conspicuous, introductory subsidies.

While the prospects for bringing down the emission rates of light duty vehicles may appear quite promising, the same does not apply in equal measure to ***heavy freight vehicles***. Here, the projected reduction in emission rates at the 2050 horizon – 60 per cent since 2004 in the reference scenario, and 80 per cent in the low emission case – is more uncertain, and less open to intervention by the Norwegian government, as it would depend on international (EU) regulation and on technological developments on the manufacturing side. One interesting possibility exists, however, in the form of electrified highways.

The role of ***biofuel*** in Norwegian GHG abatement policy is so far a modest one (a 3.5 per cent mandatory share of fuels sold for road transport), and its future role remains uncertain. With the possible advent of new and unquestionably sustainable types of biofuel, the issue may be up for reconsideration.

If freight vehicle emission rates are to come down as projected, climate neutral bioenergy will probably have to play a considerable role. For private investors to commit themselves to bioenergy solutions, it is imperative that the fiscal and regulatory conditions be foreseeable.

Another pitfall relates to the problematic combination of economic and regulatory policy instruments. Hoel (2013) makes the point that if a regulation is already in place inducing merchants to blend a percentage share of biofuel into all or parts of the road fuel sold, subsidizing the biofuel would only make the blend cheaper, boosting demand and emissions.

The possible fabrication and use of biofuels based on boreal Norwegian forest biomass has become an issue of heated debate, within the scientific community as well as publicly. Some argue that since it takes 70 to 100 years for a boreal forest to grow back after harvesting, the use of biofuel based on such biomass is by no means carbon neutral in the short and medium term.[21,22,23] Considering the fact that the need to reduce the GHG emissions globally is an urgent one, the time horizon does matter. Only plants with a relatively short rotation period would qualify as carbon neutral sources of biofuel. Yet, the albedo effect linked to the harvesting of boreal forests may tip the balance in favour of fuel based on such a source: Surfaces that are covered by snow large parts of the year would reflect more sunshine after the forest has been harvested.[24,25] Obviously, the last word has not been said on this fairly complex issue.

While the use of unconventional fuels for private (car) transport is unlikely to become fully competitive in the short term, on account of the costly new infrastructure needed, public transport companies refuelling their vehicles at certain mass points may be in a better position to take advantage of such opportunities. Thus, Ruter – the Greater Oslo public transport procurement agency – has implemented a programme for biogas driven buses in and around the city. Also, a small number of hydrogen fuel cell vehicles are currently operating.

4.2 Modal shift and reduced transport demand

An 'obvious' way to cut back on emissions is to enhance the use of public transport. Some qualifications are, however, in order.

Unless powered by climate neutral energy, public transport also generates GHG emissions. The climate effect of increased public transport ridership will depend on whether the additional passenger is due to (i) induced demand, (ii) reduced walking and bicycling, (iii) reduced use of private vehicles with a combustion engines, or (iv) reduced use of zero/low emission vehicles such as BEVs or PHEVs. It also depends on whether the increased ridership can be accommodated by the existing public transport supply, or if additional vehicles are needed.

In a model simulation for the city of Bergen, Kwong and Madslien (2013) calculate the effect of ***doubling the frequency of public transport departures***. They find that private car use goes down by merely 1 per cent, while pedestrian trips drop by 2 per cent and bicycling by 5 per cent. Overall CO_2 emissions increase by about 7 per cent.

Similarly, a 25 per cent ***cut in public transport fares*** results in a less than 1 per cent reduction in car use, a 1 per cent increase in public transport use, a 2-3 per cent reduction in walking and cycling, and a less than 1 per cent cut in CO_2 emissions.

More intelligently designed improvements in public transport supply do, however, have the potential of curbing car use and emissions in the larger urban areas. One must, however, focus on quality developments, i. e. enhanced frequency, punctuality, speed, comfort, and information, rather than on fare reductions. As shown by Jara-

21 http://www.transportmiljo.no/aktuelt/klimaeffekt-av-biobrensel/

22 http://link.springer.com/article/10.1007%2Fs10584-011-0222-6

23 http://www.frisch.uio.no/cree/publications/Popular_scientific_articles/Debat_SamfOk_Skog_Klima_Holtsmark/Debatt_SamfOk_Skog_BiO_Klima_Holtsmark_2012.pdf

24 http://www.transportmiljo.no/aktuelt/aapent-landskap-reflekterer-varme/

25 http://pubs.acs.org/doi/abs/10.1021/es201746b

Díaz and Gschwender (2003) there are large benefits to be reaped from an efficiently subsidized and consumer oriented public transport system.

Now, it is debatable whether the ***incentives to enhance public transport, bicycling and walking*** are strong enough to reach the target of absorbing all travel demand increase in and around the cities. It remains to be seen if local governments will make decisions in line with this goal. Several recent cases suggest otherwise[26]. The government's ***reward scheme for public transport*** does, however, probably pull in the intended direction, despite the fact that in some of the packages 'rewarded', a large share of the budget is allocated to road construction and improvement, thus facilitating private car use.

The development of the ***Intercity Rail Triangle*** around Oslo may seem like a crucial step towards combating the long term increase in private car use – foreseeable on account of population and income growth. However, few investments will be worthwhile until the capacity of the ***central railway tunnel*** through downtown Oslo has been substantially expanded. There is growing consensus that priority must be given to removing this bottleneck.

Attractive public transport does not necessarily mean rail. In a number of urban areas worldwide, the concept of ***Bus Rapid Transit (BRT)*** is gaining foothold. While travelling on fast, dedicated 'busways' inside the central urban area, the BRT vehicles can also make use of the ordinary road network and hence serve a large number of destinations in the suburban region. Coming closer to the door-to-door quality of the private car, they may be more likely than rail to attract commuters that would otherwise go by car. BRT infrastructure development typically comes out less expensive and more manageable than does the alternative railway solution.

While drastically improving accessibility along its route, the ***ferry-free coastal highway*** may not, at first sight, seem compatible with the aim of transferring road transport to sea or rail. Such a road would allow heavy road vehicles to outcompete the coastal ship routes for most origin-destination pairs along the corridor. Also, a fairly large amount of new transport demand is likely to be induced. On the other hand, the coastal highway may facilitate the establishment of a large central harbour near Stavanger, which, in combination with road vehicles, could conveniently serve most of western Norway. This might mean shortened transport routes by sea as well as by road, since shipments no longer need to pass through some harbour in the Oslo fiord or in Sweden.

Urban densification is another key factor in the longer run. Although not marred by urban sprawl in quite the same way as the United States, Norway certainly has a more spread-out population the most other European countries. This generates considerable travel demand and grants the private car a competitive advantage versus public transport, walking and bicycling. A more centralized residential pattern would help achieve climate policy goals, be it at the urban, regional or national level.

Kwong and Madslien (2013) study the introduction of ***congestion charging*** and of generally increased rates in the Bergen cordon toll ring. The former measure, specified as a tripled toll rate during rush hours, results – according to the model

[26] In planning new hospitals meant to serve two neighbouring cities, rather than locating the hospital near the public transport hub of one or the other, it has become common to choose a location that is 'equally bad' for both, i. e. in an almost uninhabited area between the two urban centres, not easily served by public transport.

simulation – in a 2 per cent cut in local CO_2 emissions, brought about by small changes in modal split. A somewhat larger effect is obtained through a doubling in the general toll rate: 3 per cent less CO_2 emissions.

Although congestion charging has only a very small potential to reduce CO_2 emissions at the national level, it is, in fact, a highly cost efficient measure. By effectively relieving congestion, it is socially profitable even before considering its CO_2 abatement effects.

Congestion is only one out of several important negative externalities generated by car use, the other ones being road wear, noise, emissions, and accidents. When all of these are internalised in a comprehensive ***marginal cost pricing*** scheme, considerable social benefits ensue, as shown in the AFFORD project for the European Commission (Fridstrøm et al. 1999, 2000). Thus, if all tolling stations in Norway were equipped to charge according to each particular vehicle's road wear, noise and gas emissions, external accident risk and contribution to congestion, much larger effects could be achieved than from congestion charging alone. Such a scheme could also be used to control the emission of local pollutants under unfavourable atmospheric conditions. Better still, a generally applicable GPS based system, charging motorists everywhere in the network, not only those passing certain tolling points, could come fairly close to internalising all externalities generated by road use.

Raising the ***fuel tax*** is another measure that is frequently put forward by environmentalists. Some economists give support to this, saying that it makes sense to tax automobile use rather than ownership. While this may appear like a sound theoretical argument, proponents tend to forget the very close link between car ownership and use, which makes it almost immaterial which of the two is taxed. In fact, on account of consumer myopia, a one-time (purchase) tax charged upon the acquisition of the vehicle is likely to affect choices more strongly than a corresponding amount of (fuel) tax amortized over the lifetime of the vehicle. The immediate out-of-pocket expenditure is perceived as more tangible and definite than the uncertain prospect of higher monthly costs in some distant future.

A drastic increase in the fuel tax would, surely, restrain demand[27], however with the politically regrettable knock-on effect of also curbing tourism – a rather important source of income in rural Norwegian communities. Other parts of trade and industry would suffer as well. Large increases in the fuel tax is, therefore, only conceivable as part of a joint European initiative.

Improved freight logistics, as advocated by the Commission on Low Emissions (NOU 2006:18), is somewhat of a conundrum. What is meant by 'improved'? Recent trends, driven by the fact that transport is cheaper than storage, go in the direction of fewer, centrally located storehouses, direct deliveries, and smaller and more frequent shipments. This 'improvement', as seen by the businesses and their clients, is unlikely to leave a weaker climate footprint. The opposite is more plausible.

In ***local urban distribution***, certain interesting developments are, however, taking place, such as the cargo hoppers operating in Gothenburg and Utrecht, the electric vans operating in Oslo, or the consolidation centres that are being tried out in certain European cities, under the STRAIGHTSOL project.

[27] Steinsland & Madslien (2007) calculated that a doubled fuel price, corresponding roughly to a tripled fuel tax, would restrain the car kilometres travelled by about 19 per cent and the CO_2 emissions by 12 per cent.

4.3 Climate friendly rail and sea freight

Despite the general consensus about the need to transfer freight from road to sea or rail, few policy instruments are in place, and recent trends actually point in the opposite direction. Two particularly strong hurdles are the limited reliability of rail services and the insufficient capacity and efficiency of major cargo handling terminals, especially the one at Alnabru, Oslo. These problems force shippers and forwarders to choose door-to-door solutions for their cargo, i. e. the road mode. Some operators also choose to develop their own cargo handling facilities, rather than relying on the central terminal at Alnabru.

Rail freight is, nowadays, practically synonymous with intermodality. The last (few) mile(s) will almost always have to be accomplished on the road. This means that if rail freight is to obtain a noticeably higher market share in years to come, ***efficient cargo handling terminals*** are indispensable. Priority must be given to the development of such infrastructure.

Another infrastructure improvement needed is ***increased track capacity***. Most railway links in Norway are single track lines. Double track lines have, roughly speaking, ten times the capacity. A less costly option than building continuous double track lines would be to multiply and/or extend the existing passing sections to accommodate longer trains and more frequent passing. Electrification of the Røros line could open a *de facto* double track line on most of the distance between Oslo and Trondheim, improving resilience and reliability. Another efficiency enhancing measure is the accelerated installation of automatic traffic management systems.

A third possible measure is to enhance the ***priority given to freight versus passenger trains***. Quite possibly, the climate impact of transferring freight from road to rail will exceed the negative effect of reduced frequency of long distance passenger trains.

The CO_2 ***emission rates of ships*** are expected to come down by 12 and 35 per cent in the reference and low emissions scenarios, respectively. Developments in this area rely heavily on technological innovation, although the Norwegian transport authorities may play a role by procuring gas driven or electrically powered vessels for the ferry services. Since the lifetime of seagoing vessels is fairly long, the market penetration of new technology is a slow process.

4.4 Aviation

The fuel efficiency of aircraft has improved steadily over the last few decades, and is likely to continue to do so. This also impacts favourably on their GHG emission rates.

Under the reference and low emissions scenarios for 2050, the CO_2 emission rate per air passenger kilometre will have fallen by 53 and 73 per cent, respectively, since 2004. This improvement is sufficient to outweigh the expected growth in domestic air travel demand, even in the reference scenario. In the low emissions scenario, CO_2 emissions from domestic aviation goes down by 41 per cent between 2010 and 2050.

Unfortunately, this is not the whole story, for two reasons: (i) it does not take account of other greenhouse gases than CO_2, and (ii) it does not take account of international aviation.

While CO_2 is the dominating greenhouse gas emitted by road vehicles, diesel locomotives, and ships, it is responsible for only just about half the global warming potential of aircraft. Contrails and cirrus formation, taken together, seem to play an almost equally important role.

Moreover, the climate impact of Norwegians' international travelling by air is far larger than that of domestic aviation. This is so on account of the much longer distances flown abroad. Based on the national Norwegian travel survey, Aamaas (2013) calculates the climate impact of our international air trips. He finds this impact to be similar to that of travelling by car, in fact it surpasses the GHG emissions from private cars by some 20 per cent.

Fierce competition and the advent of low cost carriers have brought down the cost of air trips to a level affordable by a steeply increasing share of the global population. Certain concerned environmentalists have advocated the introduction of ***jet fuel tax*** similar to that payable by European motorists. For such a tax to become effective, or for an aviation emission trading system to work, it would have to be quite generally enforced internationally.

For aviation to drastically reduce its climate footprint, ***biofuel*** seems like the most promising solution. Avinor – the Norwegian airport operator – has been studying this option carefully, having commissioned a report on the issue from Rambøll (2013). Here, two possible industrial processes for producing sustainable aviation biofuel from Norwegian feedstock are identified, (i) the thermo-chemical Fischer-Tropf (FT) process based on biomass and waste, and (ii) the Alcohol-to-Jet (AtJ) process based on macroalgae cultivation. These are calculated to result in 81 and 65 per cent GHG emissions reductions, respectively. Under favourable fiscal and financial conditions, these options might become feasible within the 2020-2025 horizon.

5 Synthesis

5.1 Scenario interpretation: a warning

In this report, we have presented 'reference' and 'low emissions' scenarios for Norwegian transport up to the 2050 horizon. In the low emissions scenario, CO_2 emissions from transport go down by 60 per cent from 2010 to 2050, in spite of an about 50 per cent projected increase in total transport demand. As reckoned per unit of transport, emission rates are supposed to come down by almost three quarters.

Although substantial, these emission reductions do not meet the 85 per cent cut compatible with two-degree target for 2050, when interpreted as a uniform emission reduction requirement as applied to every sector of society. Yet, the assumptions underlying the low emissions scenario must be deemed to be fairly optimistic – indeed, some would say heroic.

There is an obvious danger inherent in the construction of such scenarios. While meant to show the potential results of a highly resolute, informed and persistent policy, they might be interpreted by some as a rather plausible image of the future. In such a case they might lead to complacency rather than to political action. This risk is particularly high as long as the scenario specification remains elusive in terms of what policy decisions are needed in order for the scenario assumptions to come true.

In our case, the reference and low emissions scenarios being based on previous, not-too-explicit policy formulations, it is not technically possible to quantify, measure by measure, the partial and cumulative contribution of each policy decision to the target CO_2 emissions reduction. We shall, however, attempt to identify the single most promising/effective/crucial policy instruments available, with the understanding that none of them will suffice in itself. Only a combination of several, highly effective policy instruments applied in conjunction can bring us near the two-degree target.

5.2 An inventory of policy instruments

5.2.1 Travel

On the passenger transport side, the following policy measures would probably qualify as most effective:

- Continuously sharpened CO_2 component in the vehicle purchase tax
- Subsidies or tax relief for plug-in hybrid vehicles, especially those with high electric range
- Vehicle recharging facilities in residential areas, as well as on the job
- Subsidies and infrastructure directed at electric bicycles
- Result-oriented support schemes for public transport, encouraging, e. g., BRT and the construction of ordinary bus lanes
- Enhanced use of renewable fuels in public transport
- Strongly increased capacity in the Oslo rail tunnel
- Strongly increased capacity and coverage in the Oslo metro network

- Double track railway lines in the inner intercity triangle around Oslo (i. e., Skien-Hamar-Fredrikstad)
- Regulation obliging taxis to use cutting-edge, low emission technology
- Strict parking regulation in urban centres
- Attractive park-and-ride facilities at public transport nodes
- Marginal cost pricing at tolling points, or through a generally applicable GPS based system, charging for road wear, noise, emissions, accidents, and congestion
- Climate friendly procurement of public transport and ferry services, favouring electrically powered or (bio)gas driven vehicles and vessels

5.2.2 Freight

Given the international character of freight, and the commitments made by Norway through the EEA agreement, the list of policy options open to Norwegian authorities on the freight side is much shorter:

- Enhanced railway and cargo handling capacity with indiscriminate access for all operators
- Enhanced priority for freight trains in existing network
- Electrification of the Røros line between Oslo and Trondheim
- Improved rail service regularity through enhanced avalanche and rockslide protection
- Improved connections to European railway network
- Foreseeable, gradually sharpened biofuel regulation, ensuring predictability for private investors
- Support for transfer of shipments from road to sea or rail
- Support for common freight distribution trial schemes in major cities

5.2.3 General

In essence, transport is about overcoming distance. Certain general patterns of demography and economic activity have a large bearing on the demand for transport, both travel and freight, simply on account of geographic distance. Measures to leave people with more options (for jobs, shopping, schooling, etc.) in their near surroundings might reduce the demand for transport, or allow a larger share of trips to be made by slow modes (walking, bicycling), or by public transport, thereby also reducing emissions.

To be specific, the following policy measures seem relevant:

- Urban densification: more dwellings in city centre; more jobs and dwellings near public transport nodes; no new health institutions, public agencies, shopping malls, business locations or residential housing unattached to public transport nodes
- Rural densification: urbanization around major railway stations and other public transport hubs, if necessary overruling the protection of agricultural land
- Regional and national centralization: could be spurred by a reorganisation of the municipalities into a drastically smaller set

5.3 Decoupling – and beyond

The analyses presented herein have taken the travel and freight demand forecasts developed by Madslien et al. (2011) and Hovi et al. (2011) for granted. Given a roughly 50 per cent increased demand from here on to 2050, even a 33 per cent reduction in emission rates would leave us with a status quo as far as GHG emissions are concerned. To yield an 85 per cent reduction from today's level, emission rates would have to come down by 90 per cent by 2050.

Such a development would qualify as a remarkable achievement in terms of ***decoupling***, a term used by the OECD (2002) to characterize the breaking of the link between 'environmental bads' and 'economic goods'. If society is unwilling and/or unable to curb economic growth, sustainability must be achieved through pervasive decoupling. The policy of the European Union rests firmly on the paradigm of decoupling, as expressed in the Union's white paper (EU 2011), which states bluntly that

> 'Curbing mobility is not an option',

since

> 'Transport is fundamental to our economy and society. Mobility is vital for the internal market and for the quality of life of citizens as they enjoy their freedom to travel. Transport enables economic growth and job creation....'

Paradoxically, the European financial crisis has led to such a reduced growth in mobility and energy demand that CO_2 emission allowances are being traded at a fraction of the price foreseen when the European Union's Emission Trading Scheme (ETS) was established. Under 'normal' economic growth, allowances would have become scarce and expensive, and the cap would have become effective, indirectly curbing mobility and other fossil fuel use.

Given the standard of living enjoyed by today's Norwegian population, one might question the need for – and perhaps also the realism in – a further 50 per cent increase in the mobility of people and goods. Could our transport markets be approaching saturation? Automobile use may seem to be tapering off, at least in and around the cities. Should we 'hope' for slower or more sustainable economic growth, and are there politically palatable ways to achieve it?

On the other hand, if and when emission rates from private cars come down as foreseen in the low emissions scenario, effectively decoupling private car use from GHG emissions, the main climate policy argument for curbing private car use disappears. The challenge to reduce emissions from aviation, and from road and sea freight, remains.

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