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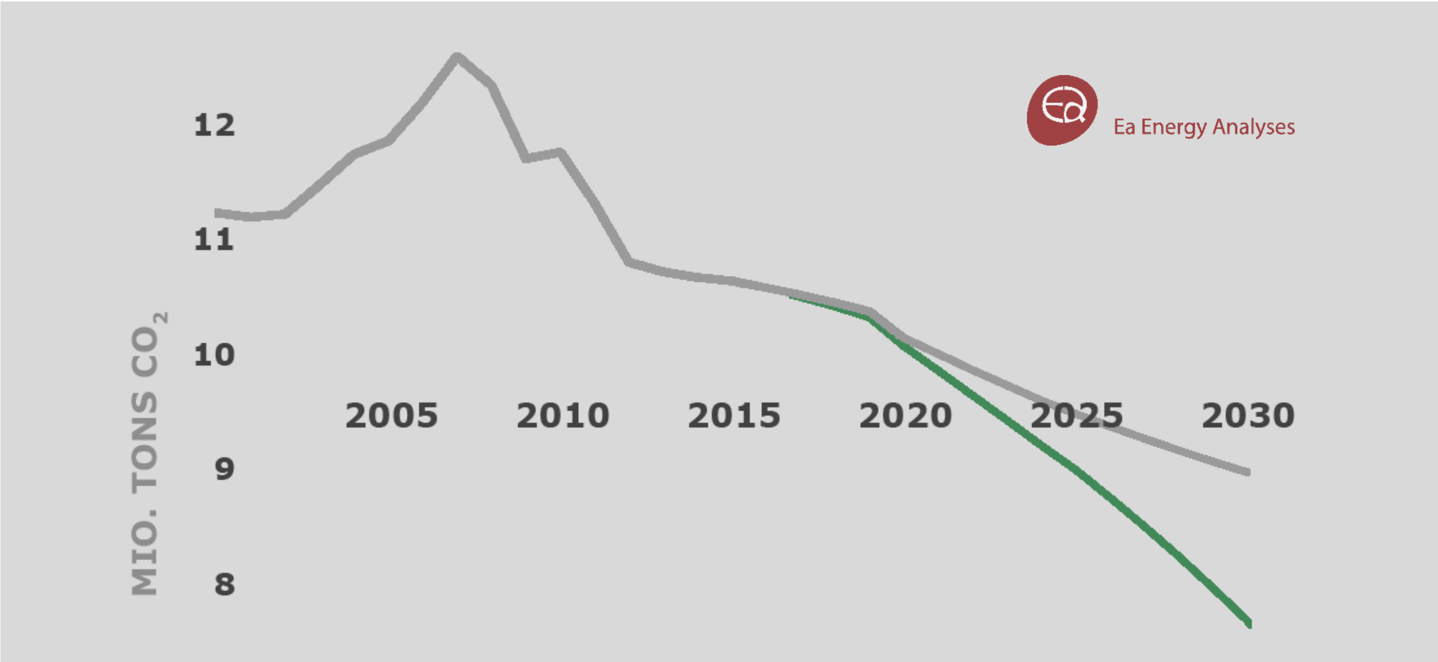
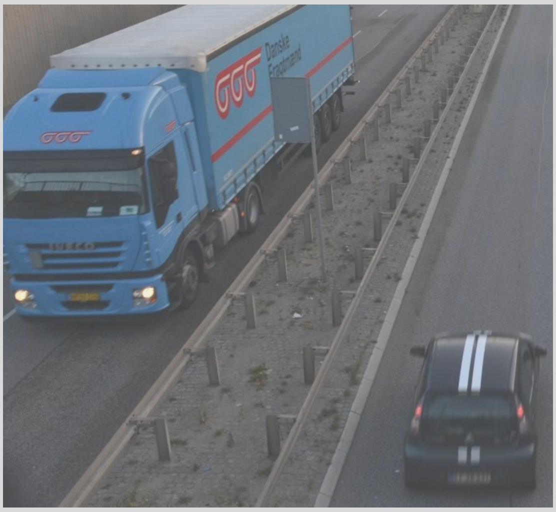


GREEN ROADMAP 2030

SCENARIOS & TOOLS FOR A CONVERSION OF DANISH TRANSPORT’S ENERGY CONSUMPTION

January 2016



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1 FOREWORD, CONCLUSIONS AND RECOMMENDATIONS

Denmark has a long-term goal to be independent of fossil fuels by 2050. This has consequences for our transport sector, which is primarily based on oil. At the same time, society is completely reliant on an efficient network for goods and personal transport.

2050 may seem in the distant future, but a conversion in the transport sector cannot be done from one day to the next. It is therefore important to have milestones along the way, thus avoiding a situation where development quickly has to be accelerated, and thereby risking higher costs.

Denmark is also committed to the goals established by the EU, including the decision that the non-ETS sector shall reduce its CO_2 emissions by 30% in 2030. The largest portion of the emissions in this sector comes from transport and agriculture. Each EU member will receive a binding target for reductions in the non-ETS sector. The specific objectives will not be known until 2016, but Denmark is expected to receive a binding target involving emission reductions of 35%-40% compared to 2005.

The aim of the "Green Roadmap 2030" is to present ideas on how road transport can contribute its proportionate share of the expected Danish reduction commitment in 2030, i.e., at least 35%.

Green Roadmap 2030 presents a concrete mix of technologies (electric vehicles, plug-in hybrids, biofuel blending, gas, etc.) and means that can be employed, taking into account the technologies' maturity, development potential, and societal costs. The study comprises a main scenario (35% CO_2 reduction), three technology scenarios that build further on this 35% scenario towards a CO_2 40% reduction, and a reference scenario.

The scenarios are based on an accelerated phasing in of electric vehicles for passenger transport, increased blending percentages in biofuels for all vehicles, and the introduction of biogas (primarily for heavy transport), relative to a situation without new national initiatives. The roadmap presents the socioeconomic costs of the different scenarios.

A premise of the project is that the technologies and tools identified are also expected to play a role after 2030. The project is based on the expectation that electricity will play a crucial role in transport towards 2050, both in the EU political spectrum and Danish energy policy. As the focus of the roadmap is 2030, the project has not encompassed potential technological breakthroughs after 2030 in alternative technologies such as fuel cells, advanced biofuels, etc.

Green Roadmap 2030 is initiated and financed by the Energy Fund in order to provide an informed input to the debate on how we can gradually and cost-effectively reduce road transport CO_2 emissions in a way that will ensure a continuous transition to the effort that must be made in the period after 2030.

The project is organised via a steering committee consisting of representatives from the sector. The report and the analyses were undertaken by Ea Energy Analyses in cooperation with the analysis department of the Danish Energy Association, whom assisted with professional sparring.

The scenario analyses and analysis of the Danish road transport taxation system were presented at two workshops, which saw participation from a wide range of experts and interested stakeholders. The aim of the workshops was to receive feedback from a broad spectrum of actors in regards to the project assumptions, analysis approach, and preliminary results.

We would like to take this opportunity to thank the many who have actively participated in the two workshops. They have contributed valuable feedback, and as a result of this feedback, we can with a greater certainty present the analysis results that were generated in the project.

It is our hope that the analyses and the steering committee's conclusions and recommendations can contribute to an overall picture of possible pathways to the decarbonisation of road transport, and to create a well-documented basis for both national policies, as well as Denmark's efforts in the EU towards 2030.

STEERING COMMITTEE'S CONCLUSIONS

Based on the analyses undertaken in "Green Roadmap 2030", the steering committee would like to highlight a number of *conclusions* that it endorses as essential in the process of gradually making the transport sector CO_2 neutral – with the first step geared towards 2030.

1. It is possible to reduce greenhouse gas emissions from road transport by 35 to 40% by 2030 by relying on a mix of technologies and fuels that are considered available.

2. A 35-40% reduction will not be realised without political action in Denmark and the EU.

3. The socioeconomic cost of reaching a 35% reduction is, even with the current low oil prices, low compared to the previous government's catalogue of climate mitigation instruments from 2013.[1]

4. It is socioeconomically cheaper (in DKK/tonne terms) to proceed from a 35% reduction to a 40% CO_2 reduction, than to achieve the first 35%.[2]

5. Blending of biofuels is the cheapest way to reduce greenhouse gases in the initial part of the period, while the phasing in of more electric/low emission vehicles is expected to be more cost-effective when approaching the end of the period towards 2030.

6. The analyses concluded that EU regulation is central to achieving the roadmap goals, and it is particularly important that:
    a. The regulation of passenger and commercial vehicles' efficiency continue after 2021, and are made more stringent towards 2030.
    b. Efficiency requirements should also be implemented for lorries and buses.
    c. It becomes mandated that all new gasoline vehicles can run on E20 by 2020 at the latest.
    d. Targets are set for the increased use of advanced biofuels during the 2020-2030 period.

7. At the national level, the report highlights that:
    - A specific effort is required in order to promote biogas in heavy transport.
    - The current taxation system for personal vehicles should be reformed if it is to contribute significantly in motivating consumers to select vehicles with low CO_2 emissions. The steering committee has not taken a stance regarding the specific taxation changes proposed in the report.
    - An externality-based taxation system would place a disproportionally high burden on heavy transport.

---

[1] Catalogue of Danish Climate Change Mitigation Measures – Reduction potentials an costs of climate change mitigation measures (Inter-ministerial working group, 2013)

[2] This may seem counterintuitive but is because the additional CO_2 reductions undertaken in the 40% reduction scenarios primarily take place near the end of the scenario period, when the CO_2 reduction costs are lowest.

STEERING COMMITTEE'S RECOMMENDATIONS

1. The analysis has substantiated that a significant part of the Danish reduction commitments in the non-ETS sector can be realised in the transport sector. This can be done by utilising a mix of cost-effective technologies and measures. The analysis suggests that the cost of reducing road transport CO_2 emissions is lower than those indicated in the previous government's catalogue of climate mitigation instruments, and that a 35% emissions reduction will be cost neutral with a marginal CO_2 price of 1,000 DKK/tonne.

2. *Within the EU, Denmark should* work actively for:
   - More stringent efficiency requirements for passenger cars and vans after 2021, when the current agreement expires.
   - Implementation of efficiency requirements for lorries and buses in a manner that reduces emissions from cross border bus and truck transport without distorting competition.
   - Requirements mandating increased blending of advanced biofuels after 2020.
   - Requirements mandating that all new gasoline passenger vehicles shall be capable of running on E20 by 2020.

3. *Via supplementary national policies, Denmark should* ensure that road transport contributes with its proportionate share of non-ETS sector emissions reductions, including:
   - A special effort being undertaken to promote biogas in heavy transport.
   - A reform of the current taxation system for personal vehicles so that it contributes significantly in motivating consumers to select vehicles with low CO_2 emissions.
   - The establishment of a comprehensive strategy for how emissions from heavy transport can be reduced, with emphasis on EU regulation.

Copenhagen 16 November 2015:

Anne Grete Holmsgaard, BioRefining Alliance (Coordinator for the Energy Fund and Chairman)

Kristine van het Erve Grunnet, Danish Energy Association (Coordinator for the Energy Fund)

Lærke Flader, Danish Electric Vehicle Alliance

Ove Holm, Danish Transport and Logistics Association

Peter Stigsgaard, Danish Oil Industry Association

Torben Lund Kudsk, Federation of Danish Motorists

2 Main conclusions

EU climate targets

The EU Commission has stated that relative to 1990, total greenhouse gas emissions must be reduced by 85% - 90% by 2050. This includes the transport sector, where CO_2 emissions should be reduced by approximately 60% compared to 1990. More recently, the EU has set new targets for 2030, which include a 40% cut in greenhouse gas emissions compared to 1990 levels, a minimum 27% renewable share in energy consumption, and at least 27% energy savings compared with the business-as-usual scenario.

Danish commitments

Denmark has committed to making significant greenhouse gas emission reductions both in the ETS and non-ETS sectors. The largest portion of emissions in the non-ETS sector come from agriculture and transport, and under a new EU framework, it is expected that Denmark will be obligated to reduce its non-ETS emissions by 35-40% relative to 2005.

CO_2 emission reductions from Danish road transport

Within this project, five concrete scenarios for potential road transport development towards 2030 have been established and assessed: a 35% scenario depicting a path to a 35% CO_2 reduction by 2030 (relative to 2005), and three 'technology' scenarios, each of which result in a 40% CO_2 reduction by 2030. The technology scenarios are an electric scenario, a biofuel scenario and a gas scenario. The fifth and final scenario is a reference scenario.

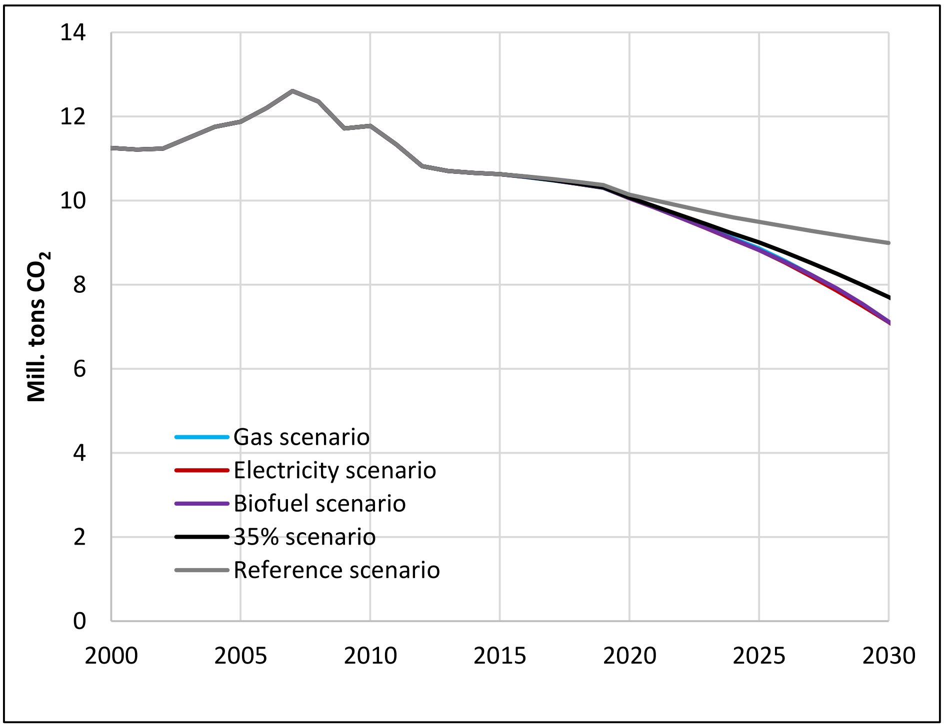

Figure 1: CO_2 emissions in the five scenarios. *CO_2 emissions encompass emissions from road transport from 2000 to 2030.*

In all five scenarios, new vehicle efficiency continues to improve, a development that is primarily based on anticipated decisions taken by the EU and automotive industry. This means that CO_2 emissions in the reference scenario also decrease. In fact, improved fuel economy contributes with roughly half of the total CO_2 reductions realised in the 35% scenario in 2030 (see Figure 2). Electric vehicles, gas vehicles, and biofuels combine for the other half of the CO_2 emissions reductions.

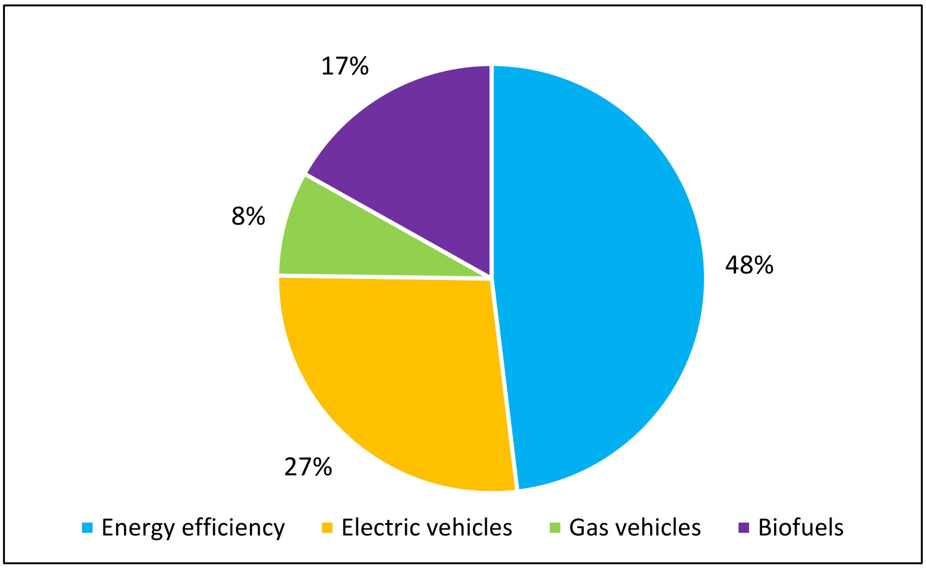

Figure 2: Contribution to CO_2 emissions reduction in the 35% scenario.

Socio-economic cost calculations

Socio-economic cost calculations were undertaken for each of the scenarios. The total discounted cost of implementing the 35% scenario is slightly over four billion DKK, with an undiscounted average of 400 million DKK annually.

The socio-economic cost calculations are sensitive to price changes in key parameters such as oil, batteries, biofuels and biogas. It should be noted that the approach utilised in this study does not include distortionary losses related to the policies and measures implemented (i.e. taxation, subsidies, etc.).

Since Denmark is committed to CO_2 reductions in the non-ETS sector, reductions here have a socio-economic value. As such, the costs of the scenarios are displayed given three different CO_2 values. If, for example, the alternative cost of reducing CO_2 emissions outside of the ETS sector in Denmark is 1,000 DKK/tonne, then the 35% scenario is roughly cost neutral for Denmark.

Billions of DKK NPV 2015-2030	35% scenario 0 DKK/tonne	35% scenario EU ETS price	35% scenario 1,000 DKK/tonne
Main findings	**4.1**	3.4	0.0
Sensitivity analyses on key assumptions			
Oil prices			
+20%	-1.1	-1.1	-1.1
-20%	+0.9	+0.9	+0.9
2015-level	+2.0	+2.0	+2.0
Biofuel prices			
+10%	+0.3	+0.3	+0.3
-10%	-0.3	-0.3	-0.3
Biogas price			
+10%	+0.2	+0.2	+0.2
-10%	-0.1	-0.1	-0.1
Battery prices			
+10%	+0.4	+0.4	+0.4
-10%	-0.3	-0.3	-0.3

Table 1: Costs for main scenario. *Total additional costs for the period 2015-2030 with a 4% discount rate. The main results vary dependant on the CO_2 price (first row), as well as the sensitivity analysis (first column). Sensitivity results (rows 2-10) are relative to the main findings (row 1).*

Once investments in achieving a 35% emissions reduction have been undertaken, the additional costs of increasing this emissions reduction to 40% via the three technology scenarios ranges from 1.1 to 1.4 billion DKK. The average CO_2 displacement cost of doing so varies between 925 to 1,000 DKK per tonne. With a CO_2 price of 1,000 DKK/tonne, both the electricity and biofuel scenarios result in lower additional costs (measured on a per tonne of CO_2 basis) by increasing from a 35 to 40% emissions reduction.[3]

Billions of DKK NPV 2015-2030	***0 DKK/tonne CO_2***	***EU ETS price***	***1,000 DKK/tonne CO_2***
35% scenario	*4.1*	*3.4*	*0.0*
Technology scenarios - Additional cost (NPV) relative to 35% scenario:			
Electricity scenario	*+1.2*	*+1.0*	*-0.4*
Gas scenario	*+1.4*	*+1.2*	*-0.0*
Biofuel scenario	*+1.1*	*+0.8*	*-0.4*

Table 2: Costs for the 35% scenario and the three 40% technology scenarios*. Total NPV costs for the period 2015-2030 with a 4% discount rate, given three different CO_2 values. For the technology scenarios, the table displays the additional cost of extending from a 35% emissions reduction to a 40% emissions reduction.*

[3] This may seem counterintuitive but is because the additional CO_2 reductions undertaken in the 40% reduction scenarios primarily take place near the end of the scenario period, when the CO_2 reduction costs are lowest.

Policies and measures (taxation)

Policies and measures

When looking outside of the ETS sector, a 2013 catalogue of climate mitigation instruments published by the Danish government found that alternatives to CO_2 emission reduction measures from the transport sector are primarily to be found in the agricultural sector. As a general rule, it stated that new policies and measures focused on the agriculture sector were on the cheap end of the mitigation instruments scale, while transport initiatives were to be found at the higher end. For example, when looking at measures with a cost of under 2,500 DKK/tonne, the agricultural sector could contribute with total emissions reductions of over 3.6 million tonnes, while the transport sector could only contribute with 0.5 million tonnes. (Inter-ministerial working group, 2013).

Transport related policies and measures included in the catalogue included: increases in fuel taxes, higher blending requirements for biofuels, the promotion of gas in heavy transport, as well as a mileage-based road tax. As such, it is many of the same types of policies and measures that are investigated in the current analysis, but where this study finds significantly lower CO_2 emission reduction costs. The higher emission reduction costs found in the catalogue are partly due to the inclusion of distortionary losses, including for example the anticipated loss of state revenues due to increased cross-border trade.

If transport sector CO_2 emissions are to be reduced at the lowest possible cost to society, it is important that distortionary effects are minimised. Low distortionary effects are achieved if the societal costs associated with road transport are made visible to the user, i.e. the externality costs from transport (costs related to noise, air pollution, etc.) are internalised.

If such an externality principle was to be pursued fully, it would have a considerable influence on the purchase and usage cost of vehicles that private persons and business are currently experiencing. Particularly small cars and trucks would see significant price increases compared to today's level. The consequences for businesses and private persons must therefore be assessed closely before such a change in the taxation model could be recommended. Meanwhile, in order to ensure continued growth in the sales of low-emission vehicles (EVs), some form of transitional arrangement to the new taxation model would be required for at least 10 years (until EV battery costs can be expected to have reduced significantly).

The political agreement from October 9th, 2015 between the government (Venstre), the Social Democrats, the Danish People's Party and the Danish Social-Liberal Party established a phase-in process into the existing tax system for electric vehicles, plug-in hybrid vehicles, and fuel cell vehicles. Electric and plug-in hybrid vehicles will be phased in over a 5-year period starting in 2016, resulting in full taxation in 2020. Fuel cell vehicles will meanwhile start a 5-year phase-in period in 2019.

The price development of batteries assumed in this report indicates that a phase-in period of five years is likely not sufficient to ensure the growth in sales of low-emission vehicles. Furthermore, it is problematic that the vehicle taxation system was developed at a time when vehicles had poorer fuel economy than they have today. A slight adjustment of the tax system could comprise an update of the registration taxation calculations, for example having it based on litres per km, rather than the current km per litre. In addition, it would be assumed necessary to extend the phase-in period beyond the currently proposed 5 years.

For biofuels, the study finds that a continuation of the mandated blending targets is adequate, including those for 2nd generation biofuels, as they are considered to be effective policy instruments.

With respect to gas, the most effective instrument is deemed to be a combination of a lower tax on gas for transport, along with a partnership approach with relevant stakeholders. Relevant stakeholders in this context are gas companies, petrol station companies, municipalities and fleet owners.

3 EU goals and policies

EU: Long-term CO_2 & RE goals

In its roadmap for transitioning to a competitive low carbon economy in 2050, the EU Commission indicated that relative to 1990, total greenhouse gas emissions must be reduced by 85% - 90% by 2050. This includes the transport sector, where CO_2 emissions should be reduced by approximately 60% compared to 1990.

More recently, the EU has set new targets for 2030, which include a 40% cut in greenhouse gas emissions compared to 1990 levels, a minimum 27% renewable share in energy consumption, and at least 27% energy savings compared with the business-as-usual scenario.

EU: 2020 CO_2 & RE legislation

According to the EU's climate and energy package adopted in 2009, in particular the Renewable Energy Directive, member states must reach a target of 10% renewable energy (RE) in transport by 2020. The RE Directive sets out a number of sustainability requirements for biofuels, with these requirements to be tightened starting in 2018. In addition, the EU's Fuel Quality Directive states that suppliers of road transport fuels must reduce greenhouse gas emissions from these fuels by 6% no later than 2020.[4]

The two directives are quite complex, and in the period since 2012 there have been lengthy discussions and negotiations regarding a number of issues, including limiting the use of 1G biofuels[5], the importance of indirect land use change (ILUC)[6], the role of biofuels after 2020, etc.

EU: Alternative fuels

In October of 2014, the EU adopted a directive on the establishment of infrastructure for alternative fuels. Amongst other things, member States have committed to adopt national objectives and measures for infrastructure development, with one example being EV charging stations (European Commission, 2015a).

In 2015, the EU decided that the maximum amount of 1G biofuels that may count towards the 10% target shall be 7%. In addition, it established an

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[4] The percentage targets in both directives are on an energy basis. In the Fuel Quality Directive, the target is measured on a well to wheel's basis, i.e. the upstream emissions are also included.

[5] Biofuels based on corn and other edible crops are generally classified as first generation biofuels (1G). Biofuels based on residues from agriculture or industry are meanwhile classified as second-generation biofuels (2G) or advanced biofuels. 2G biofuels count double towards the RE Directive target of 10% renewable energy in transport, but not in the fuel quality directive

[6] Indirect Land Use Change can lead to so-called indirect greenhouse gas emissions.

‘indicative’ sub-target for advanced biofuels of 0.5%, as well as expressed a desire to see a greater role for advanced biofuels after 2020 (T&E, 2015a).

EU: CO_2 emissions

A key regulatory tool for the EU is mandatory emission reduction targets for passenger cars and vans. These are implemented via requirements for falling CO_2 emissions, measured in CO_2 per kilometre (g CO_2/km), towards 2021.

In October of 2014, the European Council agreed on a *2030 Climate and Energy Policy Framework*. The decision means that the non-ETS sector must reduce its greenhouse gas emissions by 30% by 2030 (relative to 2005). The 30% target has yet to result in individual national reduction targets, but there is a consensus that national goals will be in the range of 0% to 40%. Denmark can be expected to have a reduction target between 35% and 40%. (European Council, 2014).

The European Council also invites the EU Commission to “further examine instruments and measures for a comprehensive and technology neutral approach for the promotion of emissions reduction and energy efficiency in transport, for electric transportation and for renewable energy sources in transport also after 2020.” (European Council, 2014). In the subsequent communication regarding the Energy Union Package (February 25, 2015), the Commission outlined a need for the EU to increase the energy efficiency of vehicles, decarbonise the transport sector, increase the use of electricity in transport, undertake a gradual shift to alternative fuels, and further integrate energy and transport systems (European Commission, 2015b).

The EU has therefore set an overall goal of increasing the number of technologies and instruments that can be used in reducing emissions from transport, a sector that accounts for over 30% of EU final energy consumption. However, concrete policies and measures are not yet on the table.

The non-ETS sector in Denmark

Denmark: CO_2 emissions

In 2005, roughly 39 million tonnes of CO_2 were emitted in the non-ETS sector in Denmark, with a distribution as displayed in Figure 3.

As can be seen from the figure, 35% of these emissions came from the transport sector, 33% from agriculture, 10% from households and 22% from other sectors.

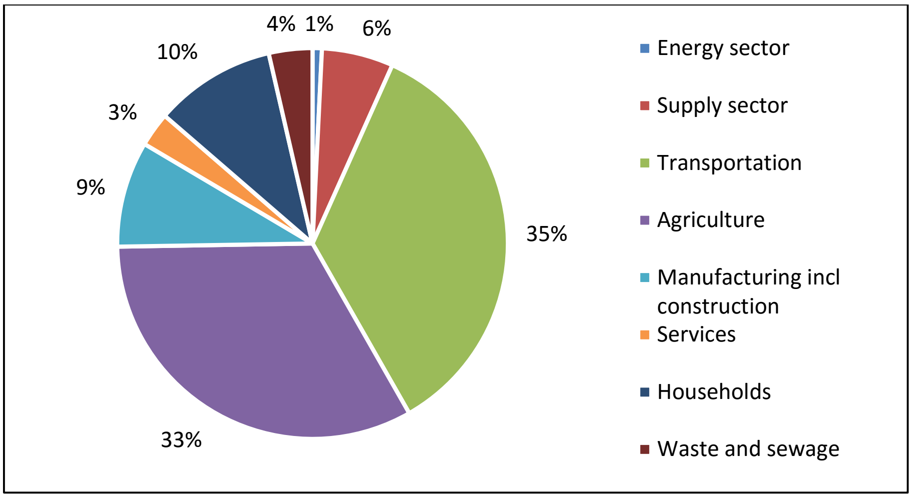

Figure 3: Distribution of greenhouse gas emissions in the non-ETS sector in Denmark in 2005.

With the new EU framework, Denmark will be obligated to reduce its non-ETS emissions by 35-40% relative to 2005, equivalent to a reduction of 13-15 million tonnes. There has already been some reduction since 2005, and in 2012, emissions had fallen to roughly 33 million, corresponding to a reduction of approximately 14%. This also means that distribution between sectors has changed, and as of 2012, the transport and agriculture shares had risen to 37% and 36% respectively. According to the Danish Energy Agency's baseline scenario from 2014 (see figure below), emissions from the non-ETS sector are expected to continue to decline towards 2025.

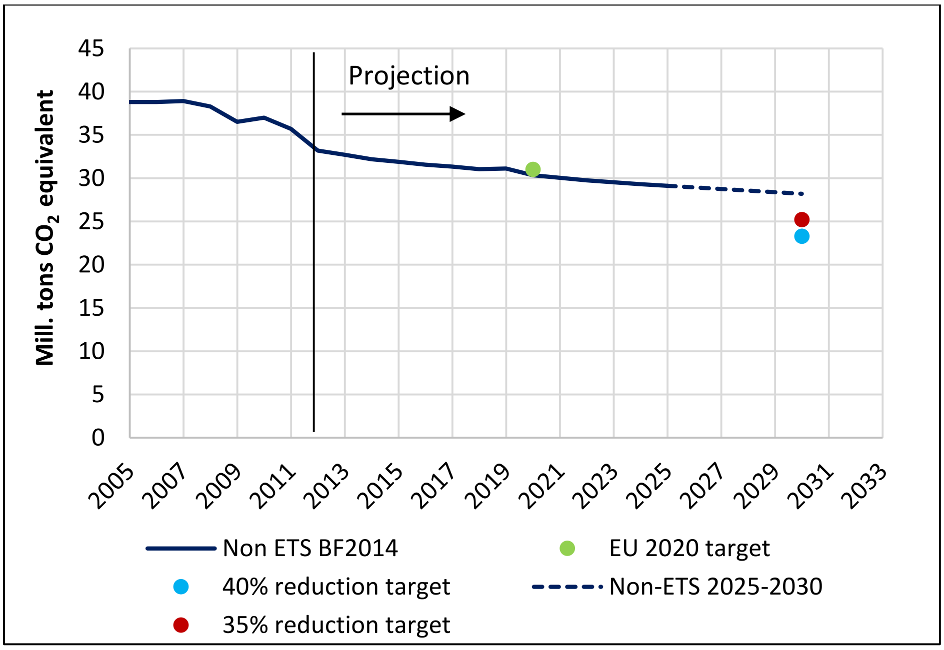

Figure 4: Danish greenhouse gasses in the non-ETS sector. *The projection from 2015-2025 is based on the Danish Energy Agency's baseline scenario 2014 (BF2014), while the projection from 2025-2030 is a linear extension of the 2015-2025 trend.*

4 Challenges and Opportunities

Transport's share of Denmark's total CO_2 emissions rose from 15% in 1990 to 26% in 2013. In 2013, road transport comprised 75% of the transport sector's total CO_2 emissions (92% when international aviation is not included).[7]

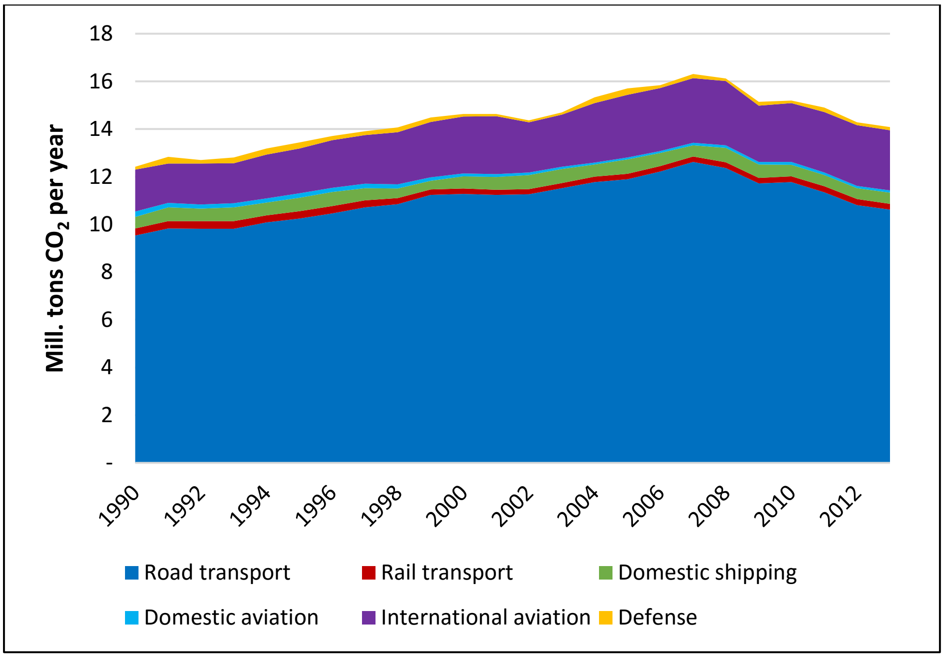

***Figure 5: Danish CO_2 emissions from transport, 1990-2013**. Source: Danish Energy Association, Energy statistics 2013 (ENS, 2014a)*

Danish CO_2 emissions from road transport peaked in 2007 at roughly 12.6 million tonnes, and have since decreased by approximately 2 million tonnes. Biofuel blending has reduced emissions by approximately 0.6 million tonnes. Other major factors have been a slowdown in heavy transport, and improved fuel economy prompted by stricter EU requirements. In addition, changes in the Danish car taxation system have provided incentives to purchase fuel-efficient cars and vans.

Although the actual CO_2 emissions from road transport have fallen in recent years, it is deemed a challenge to significantly reduce the transport sector's CO_2 emissions by 2030. This is due to several factors: Demand for transport services is expected to increase in the coming decades, there are technical limits on the efficiency that traditional internal combustion engines can reach, 2G biofuels from straw, wood, etc. are on the way, but they are still at an early developmental phase, and lastly, electric vehicles and plug-in hybrids

[7] CO_2 emissions from international aviation are not included in Denmark's reduction commitments in the non-ETS sector.

have gained considerable market shares in some countries, but still have significantly higher import costs relative to traditional vehicles.

Transport demand in the 'National transport model'

The *Landstrafikmodel* (National transport model) from 2014, developed by the transport department at the Technical University of Denmark (DTU), provides the starting point for the transport demand projections. These projections are based on historical data, combined with assessments of factors including future economic growth and demographic developments.

The GDP projection is based on the Danish Ministry of Finances' convergence program from 2013. During the period from 2010-2020 the average annual GDP growth is projected to be 1.6%, and after 2020 it is projected to be 1.2%. The population projection is based on analyses carried out by Statistics Denmark.

Figure 6 below displays the resulting projected demand for passenger transport, heavy transport, and light duty transport.

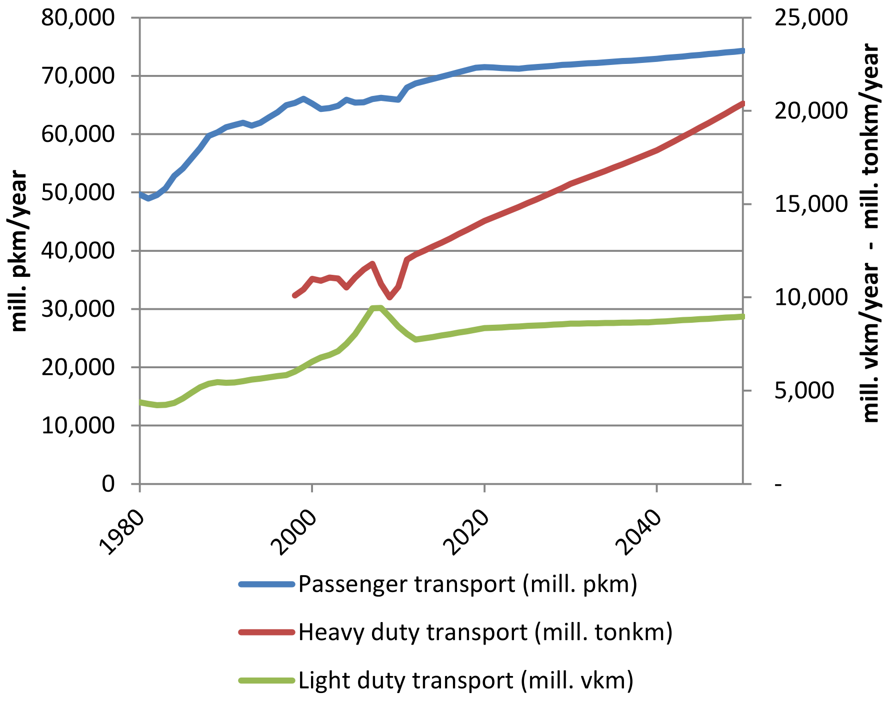

Figure 6: Projected transport demand. *(pkm – personal transport km, tonkm – tonne transport km, vkm – vehicle km). Source: Ea Energy Analyses based on statistics and projections from the National transport model.*

4.1 Energy efficiency and renewable energy

CO_2 emissions from road transport can be reduced via a number of different types of initiatives. Generally speaking, emissions can be reduced by:

1. **Switching from fossil fuels to renewable energy**
2. **Increased vehicle energy efficiency**
3. Reduction in transport demand
4. Shifting transport demand from private vehicles to bus, train or bicycle, and higher utilisation and/or occupancy rates of transport modes.

The current analysis has elected to focus on the first two points, and therefore does not investigate options for reducing transport demand or shifting transport demand to another mode (modal shift).

A shift to renewable energy (RE) includes the following options:

- Electrification of cars, vans and buses (the analysis calculations assume that the electricity used is produced from RE sources).
- Phasing in of gas vehicles in heavy transport (the analysis calculations assume that the gas used is biogas)
- Blending of liquid biofuels for use in conventional vehicles, with an eventual shift to 100% biofuel (it is assumed that all new petrol cars can run on E20 by 2020).

The technological and cost development potential of hydrogen and fuel cell vehicles have been investigated, but these vehicles are not included in the scenarios as there is great uncertainty regarding whether these vehicles can become economically competitive by 2030.

More energy efficient vehicles

Since 2007, the EU has implemented energy efficiency targets for passenger cars, starting with a fleet maximum of 130 g CO_2/km for new cars in 2015, and falling to 95 g CO_2/km for new cars in 2021 (and 147 g CO_2/km for new vans in 2021). These EU requirements have driven a significant reduction in CO_2 emissions from new passenger cars.

In Denmark, new cars emitted 25% less CO_2 per km in 2013 relative to 2007, even after taking into account the fact that car manufacturer's stated fuel economy figures continue to deviate more and more from actual real world consumption figures. As a result, the entire car fleet has already experienced a slight decline in the average g CO_2/km emissions (see figure below).

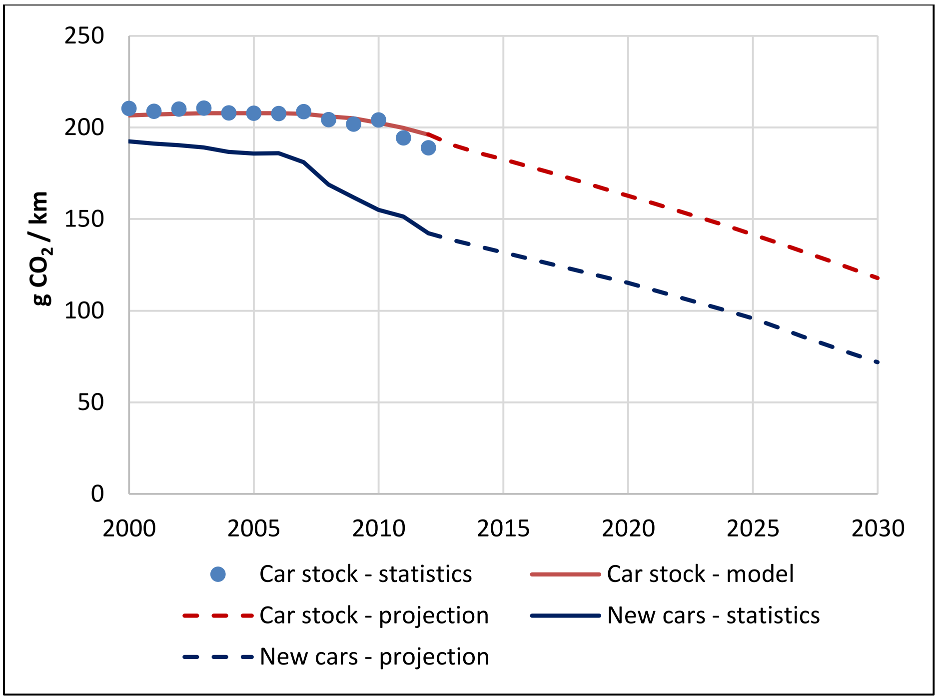

Figure 7: Energy efficiency development for all passenger cars in the 35% scenario*. The development is shown for both new cars, and the entire fleet of passenger cars. All types of passenger vehicles are included, and energy consumption from EVs are converted to CO_2 emissions using the same CO_2 factor as for petrol (73 g/MJ). For 2015-2020, fluctuations due to model calibration have been levelled out for new passenger cars.*

There are no EU targets for heavy-duty vehicle (HDV) transport similar to those for passenger cars and vans. However, on behalf of the European Commission, DELFT University has estimated that it is also possible to achieve considerable cost-effective emissions reductions for HDVs. The EU Commission is currently in the process of developing tools and systems for the measurement of new HDVs' fuel efficiency, the so-called Vehicle Energy Consumption Calculation Tool - Vecto.

The scenario calculations assume continued improvements in fuel efficiency for both light-duty and heavy-duty vehicles through to 2030.

Biofuels

Global biomass resources are significant, but also limited. In the long term, the International Panel on Climate Change (IPCC) has estimated that, on a global level, there are 100-300 Exajoule (EJ) of biomass that can be used for energy purposes, including transport. To put this into perspective, the total global energy consumption from the transport sector today is roughly 100 EJ. As a result, resource constraints will necessitate that biofuels can only be expected to be part of the solution within the transport sector, and these biofuels must therefore be prioritised in areas where it is difficult to find alternatives. Such areas include aviation, as well as parts of the shipping and HDV transport sectors.

Generally speaking, liquid biofuels are currently produced either from oil-based raw materials such as rapeseed, sunflower, soybean and palm oil (added to diesel), or from starch or sugar-based raw materials such as grain, maize and sugar cane (added to petrol). These are the so-called 1G technologies, which to some extent are in competition with food.

Biofuels can also be produced from waste products from agriculture and forestry, or based on organic waste from industry and households (2G biofuels). Some 2G technologies are well developed, including for example biofuels produced from used cooking oil and animal fat from slaughterhouses. These resources are however limited, and much of this potential is already being utilised. Therefore, the potential for increased production of 2G biofuel of this latter type is not deemed to be particularly large.

The so-called advanced 2G technologies include bioethanol production from straw and other plant residues, or biodiesel produced from forestry residues. These technologies have significantly higher raw material potentials, but they are still at a relatively early stage of development, either in the form of pilot or demonstration projects. At present, there are a handful of larger plants in Europe (Italy and Finland), the United States and Brazil, but economic and production data for these plants has not been available to this project.

A breakthrough for gasification is not expected prior to 2030

Although somewhat of an oversimplification, advanced 2G technologies can generally be categorised as either biological/enzyme based (bioethanol and biogas), or thermal gasification based (e.g. Fischer-Tropsch diesel).

The technical challenges associated with gasification have proven to be significant when the input material is biomass. An eventual commercial breakthrough therefore requires a dedicated and long-term development effort, one that is best borne via international cooperation. It is highly uncertain whether there will be significant commercial production of gasification-based biofuels by 2030.

2G bioethanol on the way

In recent years, considerable efforts have focused on developing 2G bioethanol plants, and there are plans to establish a full-scale plant in Denmark with straw as the raw material, and the by-products to be re-used in biogas and combined heat and power (CHP) production. Via integration with the biogas and CHP processes, the total energy output from the straw is expected to be significantly higher in comparison to energy output from a plant that solely produces bioethanol.

Benefits

The primary advantage associated with biofuels is that they can immediately displace fossil fuels across the entire vehicle fleet. This is because biofuels can be blended in petrol and diesel, which also means avoiding significant additional investments in new fuel distribution infrastructure.

Drawbacks

Challenges related to biofuels involve the limited available of sustainable biomass resources, and that a number of 2G technologies are still immature.

Green gas

Biogas technology is a well-known and mature technology in both Denmark and internationally. Biogas production in Denmark is largely based on residues from the agricultural and food industries, and is thus essentially a 2G technology. Due to improved support schemes, Danish biogas production is expected to grow significantly in the coming years. The majority of this biogas is expected to be purified, upgraded and injected into the natural gas grid. In addition, there is the possibility of increasing gas production by adding hydrogen, but due to the costs associated with hydrogen production, it is still uncertain to what extent this hydrogen upgrading will be utilised.

Other green gases include so-called SNG (Synthetic Natural Gas), which is based on the thermal gasification of biomass. However, as outlined above, the authors of the current report deem it unlikely that gasification technology will achieve a commercial breakthrough prior to 2030.

Benefits

In addition to biogas being a well-developed technology in Denmark, the majority of which is 2G biogas, another benefit of increased gas use in transport is that Denmark has a well-developed gas infrastructure. This reduces the distribution cost for gas used in transport, where gas vehicles also represent a well-known and mature technology.

Drawbacks

On the challenges side, the use of gas in transport requires investments in new filling infrastructure. In addition, there may be barriers related to encouraging the general public to purchase a new vehicle technology.

Electrification of the vehicle fleet

Electric vehicle technology in this report encompasses both pure battery-powered vehicles (EVs) and 'range extender' plug-in hybrid vehicles (PHEVs).

This type of PHEV is essentially an EV with an internal combustion engine (ICE) to power the battery when needed. As such, both of these vehicle types rely on an electric motor to power the wheels, and it is assumed that the vast majority (roughly 80%) of the PHEV km will be powered by electricity.

A PHEV in this context should not to be confused with a 'classic hybrid', which is a conventional car with an ICE, where an electric motor and battery have been integrated in order to increase the overall efficiency of the vehicle.

With an ever increasing portion of electricity production coming from renewables, in the future, electricity for use in the transport sector can be based on renewable energy.

Technological development

According to a number of estimates, including work carried out by the US Department of Energy (DOE), the period from 2010 to 2013 saw the cost of batteries reduced by nearly 50%, while at the same time, battery energy density has increased by nearly 50% (DOE, 2015). These trends are expected to continue, supported in part by DOE efforts, which in 2012 set a 10-year target of reducing battery prices to ¼ of their former price, and their weight and size by 50% by 2022. The latest update from 2014 indicated the price trend is on pace to meet these development goals (DOE, 2015).

EV sales

In Denmark, electric vehicles are exempt from registration taxation until the end of 2015. This tax exemption has driven EV sales of roughly 3,000 during the period from 2011-2014 (Dansk Elbil Alliance, 2015), and resulted in EVs representing approximately 0.8% of new vehicle sales in 2014. Internationally speaking, EV sales are also increasing, but these increases are typically seen in countries where EVs are supported by favourable framework conditions.

Benefits

Due to the very high efficiency of electric motors (85-95%), the energy losses in EVs are significantly lower than those from conventional vehicles, thus resulting in reduced driving costs. Another benefit of EVs relates to the integration of RE in the electricity sector, which is occurring at a rapid pace. With Denmark soon to surpass 50% of its electricity production coming from wind and solar, EVs can assist in the integration of this fluctuating production into the electricity system. Assuming that flexible charging options become viable, this could for example involve charging during the night.

Drawbacks

As is the case with gas vehicles, EV development requires the establishment of new infrastructure. Relative to conventional vehicles, another drawback relates to the higher upfront costs of EVs, which is largely due to the EV battery costs. In addition, EVs have a limited driving range, and even with rapid charging, take longer to refuel. As a result, particularly for longer trips, and for those with a large daily driving requirement, EVs are less attractive.[8]

4.2 Analysis methodology

The analysis involved the formation and evaluation of five different scenarios for potential road transport development towards 2030 (with CO_2 emissions reductions relative to 2005). The scenarios include a 35% scenario that illustrates the path to a 35% CO_2 reduction by 2030, three 'technology scenarios' that each deliver a 40% CO_2 reduction by 2030, and lastly, a reference scenario. By combining the main scenario 35% with contributions from one or more of the technology scenarios, Danish road transport CO_2 emissions can be reduced by 35-40% by 2030.

35% scenario

The 35% scenario is constructed given the following three criteria:

I. It must achieve a 35% reduction in CO_2 emissions from road transport in 2030 compared to 2005.
II. It must utilise a range of technologies that support a development towards 2050 (which is assumed to be dominated by electric mobility). Furthermore, the scenario shall be robust with regards to technology development and the potential for alteration of priorities along the way.
III. Minimisation of socioeconomic costs - given that I and II are fulfilled.

Three technology scenarios

The three technology scenarios go beyond the 35% scenario in each of their respective technology field: Increased electrification, increased use of liquid biofuels, or increased use of gas (biogas). Each of the three technology scenarios take their point of departure in the 35% scenario, and build further, so as to reach a 40% reduction in CO_2 emissions from road transport.

Reference scenario

In the reference scenario there is no shift to gas, sales of EVs stagnate, and biofuel blending levels at a level necessary to reach the 2020 RE targets are assumed, but they are not increased further.

Economics

The socioeconomic costs are determined by calculating the total road transport costs for each scenario. The total costs are comprised of four main components: Vehicle procurement, vehicle operation and maintenance, fuel

[8] There are also pure battery-electric vehicles with a longer range, but these cars are significantly more expensive due to the larger battery.

costs, and emissions and other externality costs. Externality costs include for example costs related to congestion, local pollution, road maintenance, etc.

Prices for each of these elements are measured in so called 'factor' or import prices, i.e., the cost of producing/importing the item. These prices don't include taxes and/or rebates etc., and should therefore not be confused with the consumer price, which is to a large extent determined by taxes.

In addition to projections for fuel and emission costs, for each vehicle segment (personal vehicles, LDVs, HDVs and busses) projections were made regarding technical data such as vehicle weight, engine efficiency, driving patterns and O&M costs for each drivetrain type.

4.3 Assumptions

Socioeconomic fuel prices

Fossil fuel price projects are based on the methodology used by the Danish Energy Agency in its socioeconomic fuel price assumptions, but using more recent price projections from the 2014 *World Energy Outlook* (IEA, 2014).[9]

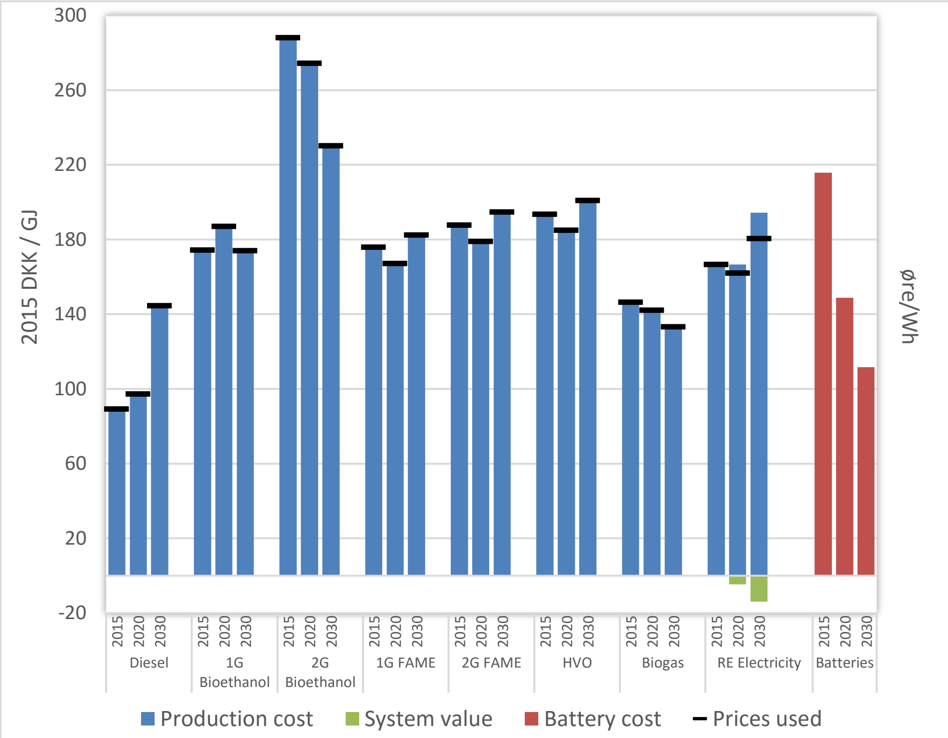

Figure 8: Socioeconomic prices of fuels and electric car batteries. *Costs are shown as import costs or at refinery/factory gate (2015 DKK/GJ). EVs electricity price includes a 'system value' that increases to 5 øre/kWh in 2030. Battery prices shown on the right axis (2015 øre/Wh)*

[9] Biogas prices are based on a report entitled: *Biogas i Danmark – status, barrierer og perspektiver med tillæg for positive sideeffekter beregnet af Institut for Fødevarer og ressourceøkonomi* (ENS, 2014b). A price fall of roughly 10% was assumed from 2015 to 2030.

Production costs for the various liquid biofuels are derived from calculations undertaken by Ea Energy Analysis based on a literature review. Calculations regarding fuel production, distribution and infrastructure costs are described in a separate report (Ea Energianalyse, 2015a). An important input for biofuel prices in this analysis are price projections of the respective raw materials (straw, wheat and rapeseed oil). Straw price projections are based on the DEA's most recent cost projections, while wheat and rape seed cost projections are based on a combination of forward prices and projections from the Food and Agriculture Organization of the United Nations (FAO).

In addition, the analysis calculations assume that there will always be a higher willingness to pay for green biofuels (biodiesel, bioethanol and biogas), compared to fossil fuels. As a result, the import price to Denmark (or alternatively the export price) for biofuels will always be higher than the corresponding fossil fuel price, regardless of the actual production costs derived in the analysis.[10] The level of this price premium is quite difficult to pinpoint, and the current analysis has elected to base it on the general willingness to pay for RE in Denmark (roughly 0.15 DKK/kWh electricity, or 40-60 DKK per GJ of heat). With this as a reference point, the price premium selected is just over 40 DKK/GJ for 2nd generation biofuels, and half of this for 1st generation biofuels. (This price premium only impacts the final results in sensitively analyses with high oil prices).

The electricity price utilised in this study is based on the costs associated with *new RE electricity* generation, including system costs. In 2015 it is assumed that the price of new RE is set via 50% onshore and 50% offshore wind, giving an average production and system cost of roughly 600 DKK/MWh. Meanwhile, the 2030 new RE price is assumed to be set by a combination of 60% offshore wind and 40% solar power, resulting in a price of roughly 700 DKK/MWh.

By 2030 it is also assumed that EVs will have a system value in the order of 50 DKK/MWh (i.e. via their ability to charge at times with low prices), thus bringing the RE cost utilised in 2030 to 650 DKK/MWh.

Infrastructure and distribution

In addition to the above wholesale prices, costs related to fuel infrastructure (i.e. refuelling) and distribution were also calculated and utilised (Ea Energianalyse, 2015a).

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[10] Given the assumption that biofuels are preferable to fossil fuels, then biofuels could be sold at a higher price than fossil oil products, regardless of production costs. At the same time, biofuels will displace the most expensive oil production, and thus should put downward pressure on oil prices.

For vehicles that use liquid fuel, the point of departure is the DEA economic assumptions, where the cost of distribution & refuelling for diesel and petrol are 28.7 and 34.8 DKK/GJ respectively.

For electric and gas vehicles, cost estimates for charging/fuelling stations were undertaken for each of the four vehicle segments. These cost estimates also factored in the anticipated utilisation rates of the fuelling infrastructure for each vehicle segment. As a result, the total fuel costs for both gas and electricity (in per GJ terms) are considerably higher during the first years compared to later in the period, when the infrastructure is assumed to have a higher utilisation rate. In determining the infrastructure costs for all fuel types, the depreciation costs of existing networks are considered to be 'sunk costs', and are therefore not included. For the electricity distribution net, this may result in the costs being slightly underestimated during the end of the study period when the large number of EVs could contribute to a need for local grid reinforcements. This is however uncertain, and it is been assessed to only have a minor impact on the scenario results.

The impact of infrastructure costs are shown in Figure 10, where infrastructure costs are included under 'fuel – distribution cost'. The figure illustrates that the distribution costs of gas at the beginning of the period are significantly higher than those of gasoline and diesel. However, going forward towards 2030, as the network of gas stations is expanded, the distribution cost for gas actually becomes lower than for liquid fuels.

Externalities

Externality costs are indirect costs on the environment and/or people who are not directly participating in a market. Transport on the road network gives rise to a number of externality costs that must be priced in order to get an accurate picture of the total cost.

The main externalities here relate to congestion, accidents, CO_2, noise, air pollution and road wear. The cost of some of the most important externalities, such as accidents and congestion, greatly depend on where and when vehicles are on the road. Generally speaking, externality costs are higher in the city and when driving during rush hour, than driving in rural areas.

It should be noted that there is considerable uncertainty associated with quantifying the cost of externalities. Methodologically speaking, it is challenging, and the calculations depend on controversial factors such as the value of a human life. The externality costs used in this analysis are primarily based on calculations undertaken by the Economic Council (DØRS, 2013), as well as own assessments regarding various car segments' share of the overall maintenance cost of the road network.

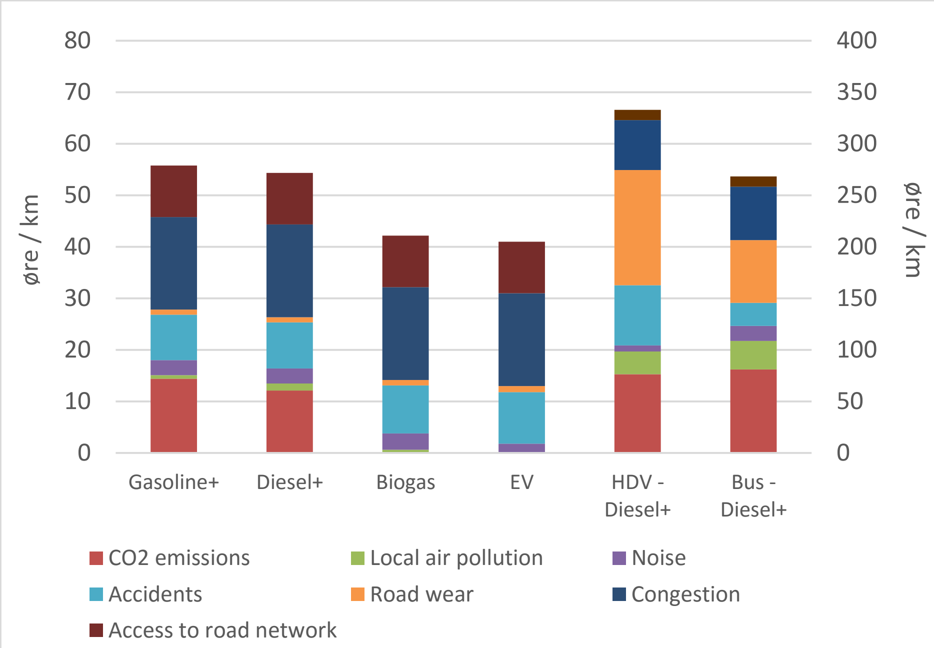

Figure 9: Externality cost for selected vehicles*. Calculated with a CO_2 cost of 1,000 DKK/ tonne. Gasoline+ and Diesel + are with today's biofuel blending %'s. NOTE: Trucks and buses are shown on the right y-axis.*

More recently (autumn 2015), there have been questions raised regarding the extent to which diesel vehicles are meeting the applicable standards, particularly with respect to NO_x emissions. These concerns have been backed by new analyses undertaken by, amongst others, the International Council on Clean Transportation (ICCT) and the General German Automobile club (ADAC). If this proves to be an ongoing challenge, externalities from diesel passenger cars in this report may be underestimated by 1 to 1.5 øre/km.

Total driving costs for passenger vehicles

For use in the scenarios, the total per km driving cost was calculated for each vehicle type and segment. These per km costs served as both inputs to an iterative process of scenario development, as well as inputs for the total annual transport costs of each scenario. Due to variations in development paths of the various automotive technologies, fuel prices, and infrastructure utilisation rates, the cost per kilometre evolves quite differently for the various vehicle models (see Figure 11). A more comprehensive description of the various vehicle's energy consumption and cost calculations is provided in a separate report (Ea Energianalyse, 2015b), while the externality cost calculations are described in another working paper (Ea Energianalyse, 2015c).

Total costs

The figure below compares the costs of various passenger vehicles in 2015. All vehicles in the figure correspond to a standard sized vehicle (though not the 'EV large'), with an annual driving demand of 18,000 km. The calculations assume a 15-year vehicle lifetime and utilise a discount rate of 4%.

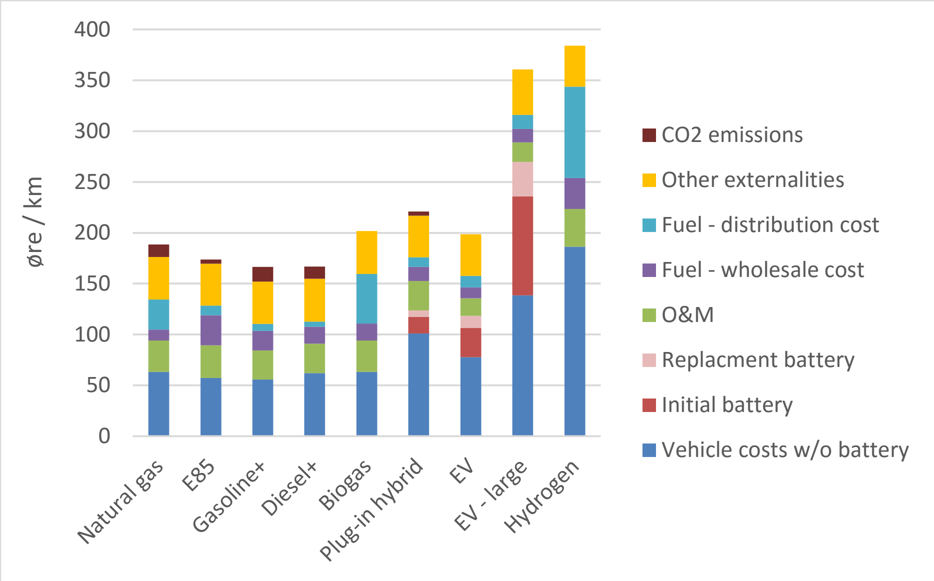

Figure 10: Total driving costs for passenger vehicles in 2015. *The calculations are based on 18,000 km/year. For Gasoline+ and Diesel+, the '+' indicates inclusion of biofuels. *The 'EV large' is not used in the scenarios, but included here to present a pure EV with a range that is comparable with other vehicles. It is a much larger car (i.e. Tesla S) than the others, all of which are roughly equivalent to a VW Golf. ** Unlike the other vehicles, hydrogen vehicles are not yet sold in significant quantities, and therefore there are few publicly available prices.*

The figure highlights the fact that the hydrogen vehicle (as well as the large EV), is significantly more expensive than the other technologies. As was noted previously, it also illustrates that the cost associated with gas distribution in 2015 (natural gas and biogas) is noticeably higher than that for liquid fuels and electricity. The total externality costs for EVs and biogas vehicles are slightly lower because their fuels are deemed to be CO_2 neutral.

While the figure above displayed the passenger vehicle costs in 2015 according to the various cost components, Figure 11 below displays the projected total passenger vehicle costs from 2015 to 2030. Please note that the y-axis does not start at 0.

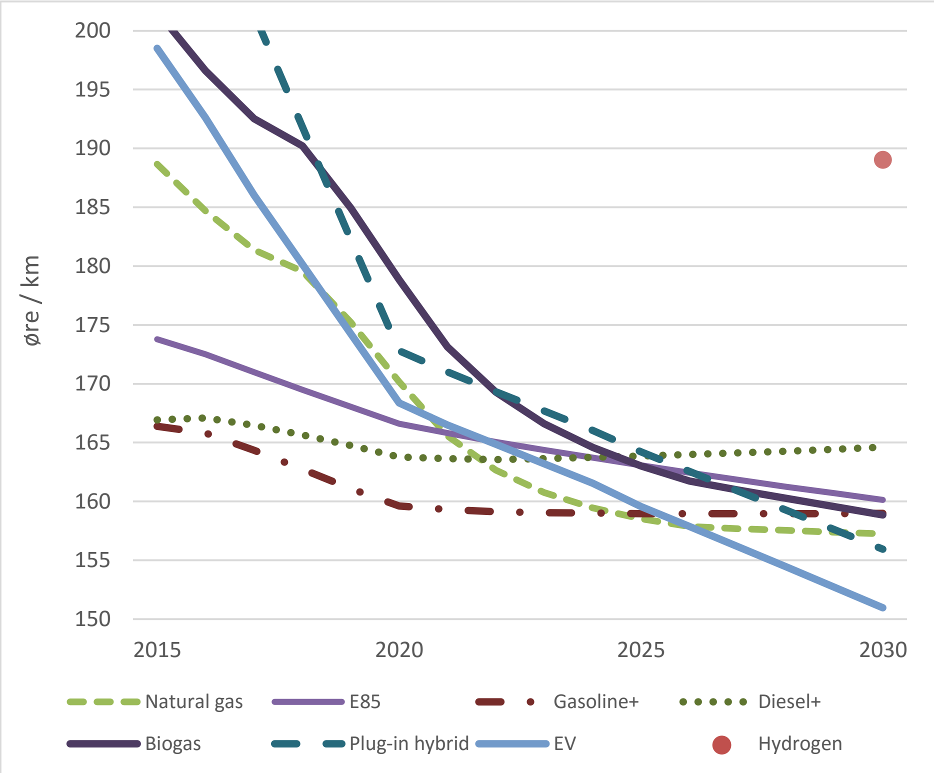

***Figure 11: Evolution in driving costs for passenger vehicles from 2015 to 2030**. The total socioeconomic cost of driving is based on 18,000 km/year. NOTE: Y-axis starts at 150 øre/km. *Unlike the other vehicles, hydrogen vehicles are not yet sold in significant quantities, and therefore the total costs are more uncertain, and only the point in 2030 is shown above*

The figure shows that electric and gas based vehicles (costs for hydrogen are only displayed for 2030) have significantly higher per km socioeconomic costs in the beginning of the period. According to the projection however, EVs become the cheapest alternative well before 2030, primarily due to assumptions regarding significant reductions in battery technology costs.

Natural gas vehicles briefly have the lowest socioeconomic cost prior to 2025, but shortly thereafter EVs become cheaper than both the natural gas and gasoline vehicles. That gasoline and diesel vehicles do not fall in price after 2020 is primarily due to the assumption of rising oil prices, which are largely offset by improvements in fuel efficiency (particularly for the gasoline vehicle up to 2020).

Lastly, the rapid decline in the per km cost of gas-powered cars during the first half of the period is primarily due to the assumption that the utilisation rate of gas fuelling infrastructure will improve over time.

5 Scenarios for a green transition

The scenario work employed the spreadsheet model PETRA, which based on a number of inputs and assumptions, projects the development path for road transport's energy consumption, CO_2 emissions and total costs. The overall method utilised in PETRA is illustrated in Figure 12.

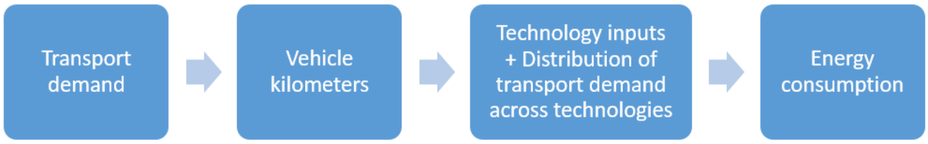

Figure 12: Overall methodology utilised in the PETRA model. *Please note that this is a simplification, as in practice a number of different inputs and assumptions feed into the model.*

The model includes passenger cars, vans, trucks, buses and motorcycles. The PETRA model and scenario assumptions are described in greater detail in a separate working paper (Ea Energianalyse, 2015d).

Main assumptions

- Vehicle lifetimes follow a 'lifetime curve', which describes what percentage of a model year is 'alive' after X number of years. For example, roughly 97% of passenger vehicles are alive after 5 years, and approximately 50% are still alive after 16 years.
- An age-dependent driving factor is implemented that factors into account that as vehicles age, they drive less km. I.e. after 5 yrs. a passenger vehicle drives 95% of the km it drove while new, and after 16 yrs. this falls to 68%.
- The model incorporates an efficiency factor that adjusts for the fact that a vehicle's energy consumption per kilometer driven increases with the age of the vehicle.
- Total traffic demand follows projections from the National Transport Model, which takes into account infrastructure expansions.
- It is assumed that in 2015, new diesel and gasoline vehicles drive roughly 20,000 and 16,000 km annually respectively. Transport demand per new vehicle is assumed to fall going forward, and in 2030, it is assumed that new diesel and gasoline vehicles drive approximately 18,000 and 15,000 km annually respectively.

5.1 35% Scenario

The main assumptions utilised in the 35% scenario are displayed in Table 3. With respect to biofuels, it is assumed that there will be an increased used of 2G biofuels, as it is assumed that 1G biofuels can contribute with a maximum of 7% of fuel demand.

S-curves

Within the scenarios, the phasing-in of new vehicle technologies, such as electric or gas vehicles for example, is assumed to take place in a smooth fashion according to so called 'S-curves' (logistic growth). This means that in the beginning of the period there is a specific growth rate applied to the number of new vehicles sold each year for a particular technology, with this growth rate fading off as the particular technology reaches a saturation point. The growth rates utilised were determined via iterative scenario calculations, which were adjusted in order to achieve the desired 2030 objectives.

As electric vehicles still have a modest market share, and/or a limited driving range, it is reasonable to assume that a large portion of private consumers may still be hesitant to purchase electric vehicles, even if they have a comparable total cost of ownership. It is difficult to predict various consumer segments preferences between EVs or PHEVs, but in the scenario calculations the number of the two electric vehicle options are split evenly.

For electric vehicles (EVs and PHEVs), the result of the iterative calculations were a growth rate of 30% per year during the beginning of the period (sales of new electric vehicles increased by 30% per year). As such, sales of electric vehicles (and gas vehicles) increase despite the fact that the socioeconomic costs of diesel and gasoline vehicles are lower during the beginning of the period.

Based on an initial growth rate of 30% in *new vehicle* sales, and a saturation point in 2050, in the 35% scenario, 12% of the passenger *vehicle stock* in 2030 is either an EV or PHEV, with this figure growing to almost 80% in 2050. This same S-curve methodology was applied to gas vehicles. The table below displays the distribution of *new vehicle* sales in 2030 for each of the various technologies according to transport segment.

New vehicle sales (2030)	Personal vehicles	Heavy-duty vehicles	Light-duty vehicles	Route buses (70%)	Tourist buses (30%)
Electric - EV	17%		10%	55%	
Electric - PHEV	17%		10%		
Flexi-fuel	0%	0%	0%	0%	0%
Gas (Biogas)	2%	15%	5%	25%	15%
Diesel	27%	85%	62%	20%	85%
Gasoline	37%		13%		

Table 3: Distribution of new vehicle sales in 2030 in the 35% scenario

Electrification

Heavy-duty vehicles (HDVs) are not anticipated to convert to electricity prior to 2030 due to battery cost and energy density considerations. In the short term, it is also anticipated that light-duty vehicles (LDVs) will be slower to convert to electricity, again because it is assumed that challenges associated with driving range will play a role. However, some segments of the LDV market are well suited to electrification (i.e. short fixed routes, city driving), and by 2020 it is assumed that roughly 20% of new LDVs will be electric.

Busses used in public transport and/or defined routes (within this report referred to as 'Route buses') are deemed to be the most suitable form of road transport to switch to electricity (or gas). Already today, there are number of electric buses in major cities, which have their own independent environmental and climate goals. In the 35% scenario, this development is expected to continue, and by 2030, it is assumed that 55% of new route buses will be electric.

Gas (Biogas)

Gas in the scenarios is deemed to be biogas. For the heavy transport sector, a switch from diesel to gas plays a crucial role because the potential for 2G biodiesel towards 2030 is limited. In 2030, the 35% scenario contained new gas vehicle sales of 15% for HDVs and tourist buses, and 25% for route busses. This trend is expected to continue towards 2050 as gas infrastructure is expanded, and the price difference between gas and diesel vehicles falls.

Biofuel blending

In the 35% scenario, it is assumed that Denmark will continue to blend biofuels in both diesel and gasoline. The 2030 blending assumptions utilised in the scenario are displayed in Table 4.

Biofuel	Blending options	Vehicle segment				Average %*
		Personal vehicles	HDVs	LDVs	Buses	
Biodiesel/ Drop-in syndiesel	B7/B30 (FAME)	B7	- 90% use B7 - 10% use B30	B7	- 90% use B7 - 10% use B30	**10.1%**
	Diesel drop-ins (HVO, F-T Syndiesel)	3.1%	3.1%	3.1%	3.1%	
Ethanol	E20/E10	- From 2020, all new gasoline cars are capable of using E20 - In 2030, this corresponds to 60% of the fleet using E20 - The remaining 40% run on E10.	N/A	- From 2020, all new gasoline LDVs are capable of using E20 - In 2030, this corresponds to 72% of the fleet using E20 - The remaining 28% run on E10.	N/A	**10.6%**
Biogas	Biogas	100% (energy)	100% (energy)	100% (energy)	100% (energy)	100%

Table 4: Biofuel blending in the 35% scenario in 2030. **Average percentage indicates the blending mixture on an energy basis.*

The blending assumptions utilised in the 35% scenario are based on E4techs's 2013 roadmap, *A harmonised Auto-Fuel biofuel roadmap for the EU to 2030* (E4tech, 2013). Towards 2030 it is assumed that Denmark will reply on the EU blending standards and not develop new national standards. However, it is assumed that the EU will develop a new standard prior to 2020, and this will be implemented in Denmark.

Biodiesel/Syndiesel

As indicated above, there are two main categories of diesel blends in the study. The first follows the EU standards B7 and B30, which involve blending diesel with Fatty Acid Methyl Ether (FAME) where the maximum FAME content (on a volume basis) of the blended fuel is 7% and 30% respectively. For some vehicle models, there are limits on how much FAME can be in the fuel blend without risking damage to engine components. The second type of diesel blends are 'drop-in' fuels, which are Hydro treated vegetable oil (HVO) or Fischer Tropsch produced syndiesel. These drop-in fuels don't have a 'blend wall' (i.e. there is no limit on the amount they can be blended) because the product is very similar to conventional diesel. The 35% scenario therefore makes a distinction between FAME, which is blended at levels according to applicable EU standards, and drop-in fuels, which are blended according to Danish political wishes, or EU requirements.

In the 35% scenario, the majority of the diesel blends will be 1G, as it is assumed that the resources for 2G biodiesel are limited. The combined potential of waste oils, fats and tall oil in Europe is estimated to be approximately 150 PJ, or approximately 2% of EU diesel consumption in 2012. (E4tech, 2013), (Eurostat, 2014). 2G resources can either be used to make FAME or HVO. In the scenario calculations, it is assumed that 2G resources are used to produce FAME, with Denmark having access to 2G resources corresponding to the EU average of 2% of diesel consumption. All drop-in fuels are therefore based on 1G HVO.

Today, all diesel vehicles in Denmark run on B7, and for passenger vehicles and LDVs, this is not anticipated to change towards 2030. The 35% scenario supplements this with 3.1% diesel drop-in fuels (on an energy basis), which is modelled as HVO.

The vast majority of the HDV fleet can run on B30 today, however new lorries that meet the Euro VI[11] standard for heavy transport may not be compatible

[11] Euro VI sets air quality standards related to exhaust emissions by establishing specific limits for CO_2 NO_x, So_x and particulate matter.

with B30. It will be possible for these new Euro VI compliant lorries to run on B30, but it will potentially increase vehicle costs and reduce fuel efficiency because they will require additional equipment. There is uncertainty regarding whether lorries will be required to run on B30 in the future, and it is therefore assumed that 10% of lorries in Denmark will run on B30 in 2030, with the remaining running on B7.

Bioethanol

Today, all gasoline vehicles run on E5. It is expected that meeting the EU's 2020 target of 10% renewable energy in the transport sector will primarily be done by ensuring that all new gasoline vehicles run on E10 by 2020. As such, it is assumed that a new E20 standard will be developed, and by 2020 all new gasoline vehicles are capable of using E20. By 2030, this will result in 60% of the gasoline vehicle fleet running on E20, with the remaining 40% running on E10. This assumption is based on E4tech's analysis, which stated that an EU standard typically takes 3 years to develop. In their analysis, E4tech assumed that this standard would be in place by 2018, but as this standard has not yet been agreed upon within the EU, the current analysis assumes a 2020 implementation year (E4tech, 2013). For the 35% scenario, this results in an average ethanol blend of 10.6% (measured on an energy basis) in 2030.

Biogas

In the scenario calculations, gas for transport purposes is assumed to be biogas. Projections indicate that by 2030 there will be a significant amount of biogas upgraded and fed into the Danish natural gas network. With a well-functioning certification system, it will be possible to ensure that the gas used in transport is certified as biogas. As a general rule, biogas qualifies as a 2G biofuel, and is therefore eligible for double counting when calculating Denmark's progress towards its 2020 RE transport target.

Results of the 35% scenario

Energy use

In the 35% scenario, energy consumption from road transport continues to decline. During the 2012-2030 period, energy consumption falls by 20%, from 156 PJ in 2012, to 124 PJ in 2030. This decline takes place despite a growing transportation demand, and is primarily due to enhanced fuel economy. This improved fuel economy is the result of fleet renewal and the continued increase in energy efficiency of new cars. In addition, electric vehicles contribute to increased energy efficiency in of themselves, as the efficiency of an electric motor is significantly higher than that of an internal combustion engine.

In 2030, when all biofuels and electricity are counted (excluding double counting), 15.7% of Danish road transport comes from renewable energy. The largest RE contributor in 2030 continues to be liquid biofuels (8 PJ), while electricity (3.7 PJ) and biogas (3.8 PJ) have similar lesser contributions.

During the scenario period, gasoline consumption falls considerably more than diesel consumption. This is largely because passenger vehicles and LDVs, many of which use gasoline today, convert to electricity, while only a small portion of the HDVs that currently use diesel convert to biogas. Furthermore, the blending ratio (on an energy basis) in 2030 is higher for bioethanol than for biodiesel.

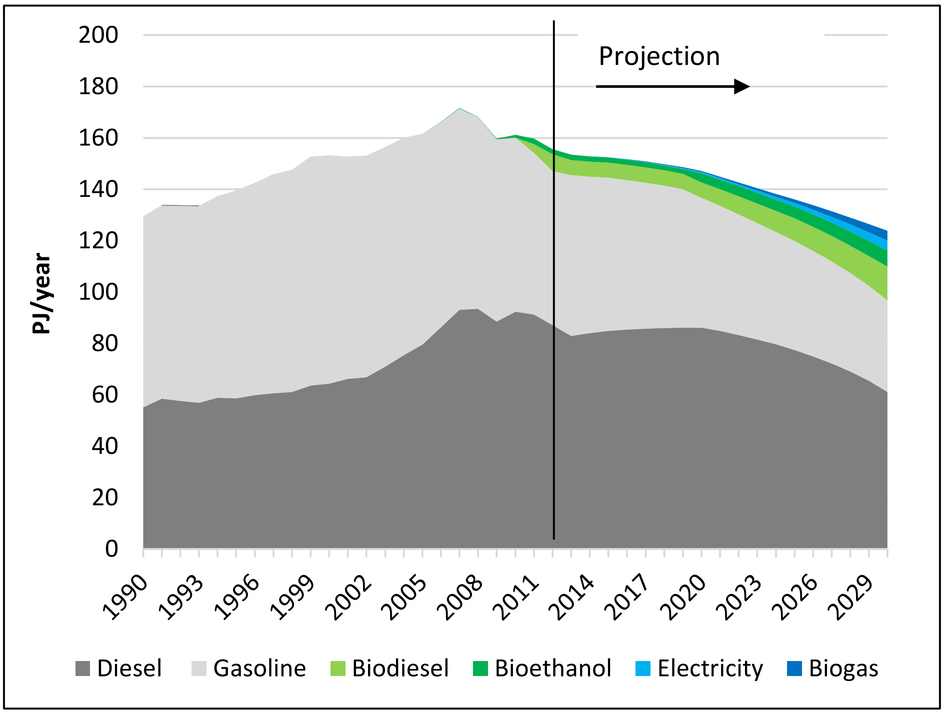

Figure 13: Energy consumption from Danish road transport 1990-2030 in the 35% scenario.

CO_2 emissions

CO_2 emissions from road transport decrease from 10.8 million tonnes in 2012, to 7.7 million tonnes in 2030, corresponding to a 29% reduction (see Figure 14 on the following page). When compared with 2005, which is the base year for the EU targets in the non-ETS sector, then the reduction in road transport emissions in 2030 would be 35%.

During the 2012-2030 period, CO_2 emissions from HDVs remain largely unchanged, despite a growing freight demand. This is due to assumed gains in energy efficiency, and the phasing in of biogas, which is deemed to be CO_2 neutral. The bulk of the CO_2 emissions reductions come from passenger vehicles and buses, as these two segments realise the greatest shift to RE, and where continued improvements in energy efficiency are expected.

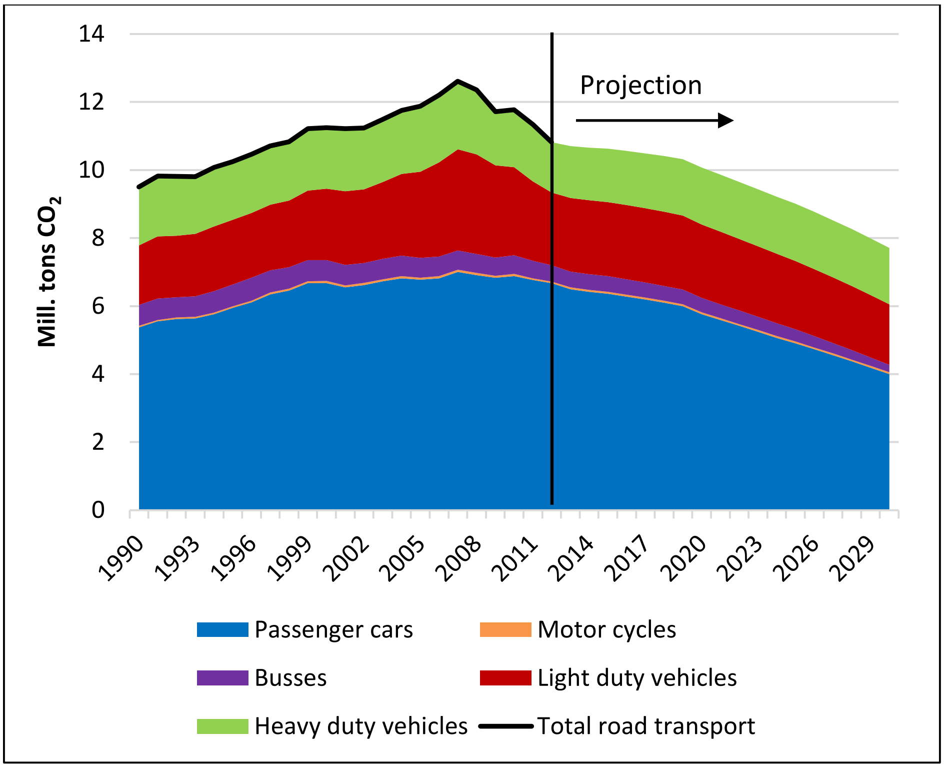

Figure 14: CO_2 emissions from Danish road transport 1990-2030 in the 35% scenario.

Figure 15 illustrates how the 35% CO_2 emissions reduction target is reached according to contributions from: energy efficiency improvements of new vehicles, biofuels, electrification, and conversion to biogas.

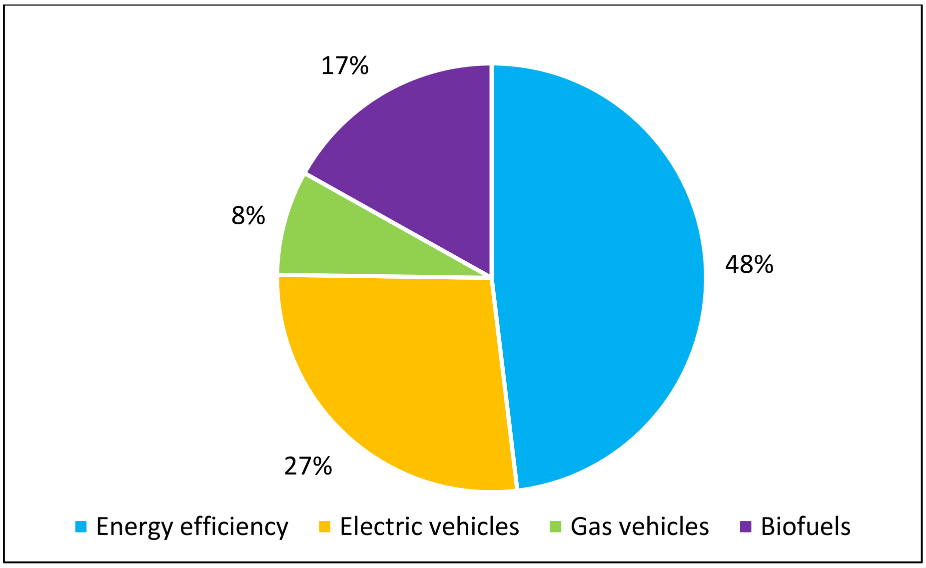

Figure 15: Contribution to CO_2 emission reductions in the 35% scenario.

5.2 Economic impact assessment[12]

The economic assessment of the 35% scenario is implemented by comparing it to the reference scenario. In the socioeconomic calculations presented below, the CO_2 cost is set to 0 DKK/tonne and all figures are in 2015 DKK. Figure 16 below displays the total annual economic impact of the 35% scenario relative to the reference scenario. Both total costs and total savings increase throughout the scenario period, which is primarily due to growing sales volumes of electric and gas vehicles.

The net additional costs increase up to 2028, when the annual net costs peak at 735 million DKK. In 2030, the net annual costs fall to roughly 664 million DKK. The figure illustrates that it is primarily the higher vehicle purchase cost (electric and gas), as well as additional distribution and infrastructure costs, that are responsible for the additional costs when compared to the reference scenario.

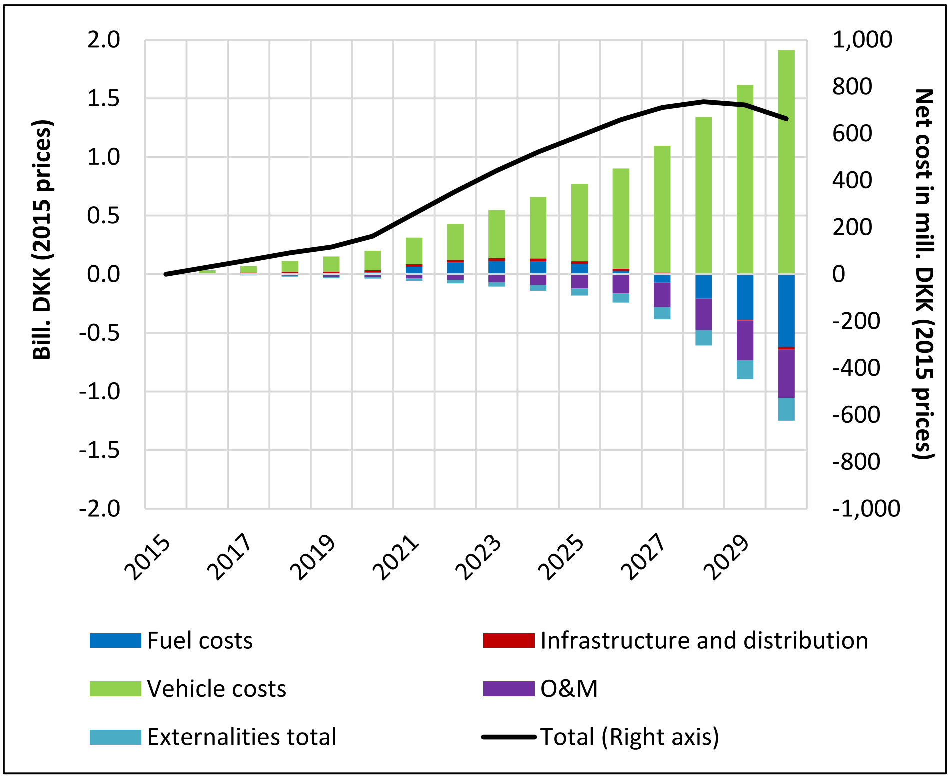

Figure 16: Total additional socioeconomic costs associated with the 35% scenario. *The additional costs are calculated by comparing the total costs from the reference scenario. The columns (annual costs/savings) are measured on the axis to the left, while the sold line (net annual cost) is measured on the right axis. All figures are in 2015 DKK. Externalities include all related costs such as noise, air pollution, congestion, etc. NOTE: Within this figure, the CO_2 externality cost is set to 0 DKK/tonne.*

[12] The economic impact assessments undertaken are described in detail in a separate working paper (in Danish), entitled "Notat om samfundsøkonomiske konsekvensberegninger" (Ea Energianalyse, 2015e).

On the other hand, the figure highlights the fact that the operation and maintenance (O&M), externality, and fuel costs all fall over the period. The externality costs savings are primarily the result of less noise and local air pollution as electric vehicles replace conventional vehicles.

Relative to the reference scenario, the upfront vehicle costs are higher throughout the entire period. This is primarily owing to the higher costs associated with electric vehicles (due to the battery cost) and, to a lesser extent, gas vehicles. From 2020 through 2026, the fuel costs are also higher in the 35% scenario, which is attributable to increased biofuel usage. However, by 2027, the high efficiency of EVs and the resulting fuel savings more than offset the additional biofuel costs. This trend quickly accelerates as EV sales increase during later years of the period.

O&M costs are lower throughout the entire scenario period, which is due to an assumption that O&M costs are lower for electric vehicles relative to their conventional counterparts. Lastly, the costs related to additional gas and electricity infrastructure play a rather minor role in the overall picture, which is partially due to the fact that a portion of this infrastructure development is also present in the reference scenario.

When the externality cost of CO_2 is set to zero, the accumulated additional socioeconomic costs in 2030 are roughly 4.0 billion DKK (in present value terms). This corresponds to an average additional cost of approximately 400 million DKK per year during the 2015-2030 period (not discounted). This results in an average CO_2 reduction cost of 1,003 DKK per tonne for the 35% scenario.[13]

5.3 Technology scenarios (40% scenarios)

In addition to the 35% scenario described above, three additional technology scenarios that each bring about a 40% CO_2 emissions reduction were also developed: an electricity scenario, a gas scenario, and a biofuel scenario.

Each of the technology scenarios take their point of departure in the 35% scenario, and only one aspect is changed, i.e. the degree of electrification, the number of vehicles running on gas, or the biofuel blending percentages (also the addition of a flexi fuel vehicle in the biofuel scenario). For each technology scenario, the changes are devised in order to bring about additional CO_2

[13] I.e. this is the CO_2 price that yields the 35% scenario a net present value of zero.

emissions savings of 600,000 tonnes in 2030, equivalent to moving from a 35% to 40% emissions reduction.

For each of the technology scenarios, the increased phasing in of RE comes at the expense of the conventional technologies (gasoline and diesel), while the relative distribution between diesel and gasoline vehicles remains the same as in the 35% scenario.

Electricity scenario

In the electricity scenario, the additional CO_2 reductions are brought about by increased electrification of the vehicle fleet. For passenger vehicles, electric drive vehicles represent 66% of new passenger vehicle sales in 2030 (up from 34% in the 35% scenario). New vehicle market share figures are also higher for route busses (80% vs. 55%), and for LDVS (36% vs. 20%) in 2030.

New vehicle sales (2030)	Personal vehicles	Heavy-duty vehicles	Light-duty vehicles	Route buses (70%)	Tourist buses (30%)
Electric - EV	31%		18%	80%	
Electric - PHEV	35%		18%		
Flexi-fuel	0%	0%	0%	0%	0%
Gas (Biogas)	2%	15%	5%	20%	15%
Diesel	13%	85%	49%	0%	85%
Gasoline	19%		10%		

Table 5: Distribution of new vehicle sales in 2030 in the electricity scenario. *The blue figures indicate which parameters differ significantly from the 35% scenario. Shares of gasoline and diesel also change, but the relative distribution between the two remains the same.*

Gas scenario

Within the gas scenario, each vehicle segment sees an increase in new gas vehicle sales. In 2030, 40% of new lorries and buses, and 32% of new LDVs run on gas. The expanded gas infrastructure is also assumed to affect the passenger car segment, where 15% of new vehicle sales are assumed to be gas powered.

New vehicle sales (2030)	Personal vehicles	Heavy-duty vehicles	Light-duty vehicles	Route buses (70%)	Tourist buses (30%)
Electric - EV	17%		10%	50%	
Electric - PHEV	17%		10%		
Flexi-fuel	0%	0%	0%	0%	0%
Gas (Biogas)	12%	40%	32%	50%	40%
Diesel	30%	60%	40%	0%	60%
Gasoline	24%		8%		

Table 6: Distribution of new vehicle sales in 2030 in the gas scenario. *The blue figures indicate which parameters differ significantly from the 35% scenario. Shares of gasoline and diesel also change, but the relative distribution between the two remains the same.*

A 40% CO_2 reduction in the gas scenario requires a significant increase in the number of new gas vehicles sold annually relative to the 35% scenario. This is not deemed to be feasible without the establishment of some form of incentive or support system. For lorries, it is also doubtful whether the 40% of new vehicle sales figure can be reached without involving lorries that transport goods internationally, a market segment that entails particular challenges with regards to private economy, international filling infrastructure, etc.

Biofuel scenario

The biofuel scenario involves increasing the number of buses and HDVs that can run on B30, additional diesel drop-ins, and the introduction of an E85 vehicle in the personal vehicle and LDV segments. The E85 vehicles run on the EU E85 standard, which on average contains 72% ethanol and 28% gasoline (on an energy basis). The blending limits for gasoline are not altered in the scenario, and it is assumed that the additional bioethanol use in the scenario (due to the introduction of E85 vehicles) is 2G bioethanol.

Biofuel	Blending options	Vehicle segment				Average %*
		Personal vehicles	HDVs	LDVs	Buses	
Biodiesel/ Drop-in syndiesel	B7/B30 (FAME)	B7	- 50% use B7 - 50% use B30	B7	- 50% use B7 - 50% use B30	**17.7%**
	Diesel drop-ins (HVO, F-T Syndiesel)	7.1% (energy)	7.1% (energy)	7.1% (energy)	7.1% (energy)	
Ethanol	E20/E10	- From 2020, all new gasoline cars are capable of using E20 - In 2030, this corresponds to 60% of the fleet using E20 - The remaining 40% run on E10.	N/A	- From 2020, all new gasoline LDVs are capable of using E20 - In 2030, this corresponds to 72% of the fleet using E20 - The remaining 28% run on E10.	N/A	**10.6%**
Biogas	Biogas	100% (energy)	100% (energy)	100% (energy)	100% (energy)	100%

***Table 7: Biofuel blending in the Biofuel scenario in 2030**. *Average percentage indicates the blending mixture on an energy basis.*

For all diesel vehicles, the blending % of drop-ins is increased to 7.1% (on an energy basis). As gasification technologies are not expected to realise a large-scale technological breakthrough prior to 2030, HVO is assumed to be the drop-in fuel. Encouraging a larger percentage of the heavy transport segment to run on B30 could for example be brought about by introducing a requirement that all lorries meeting the euro VI standard be capable of running on B30.[14] Given the above assumptions, the average biofuel blending for diesel in 2030 would be 17.7%. To put this into perspective, in its aforementioned report, E4tech estimates that the maximum EU biodiesel potential in 2030 is 10.1% of diesel demand (which is the biofuel blending percentage assumed in the 35% scenario).

Biodiesel consumption in the Biofuel scenario would result in the use of more than 7% 1G biofuel. If the other EU countries were to follow a similar development path, this would lead to a total EU consumption that exceeds the EU potential described in the E4tech report (E4tech, 2013).

New vehicle sales (2030)	Personal vehicles	Heavy-duty vehicles	Light-duty vehicles	Route buses (70%)	Tourist buses (30%)
Electric - EV	17%		10%	55%	
Electric - PHEV	17%		10%		
Flexi-fuel	20%	0%	20%	0%	0%
Gas (Biogas)	2%	15%	5%	25%	15%
Diesel	26%	85%	46%	20%	85%
Gasoline	18%		9%		

Table 8: Distribution of new vehicle sales in 2030 in the biofuel scenario. *The blue figures indicate which parameters differ significantly from the 35% scenario. Shares of gasoline and diesel also change, but the relative distribution between the two remains the same.*

Technology scenario results

The CO_2 emissions development path from Danish road transport in the 35% scenario, three technology scenarios, and the reference scenario, are displayed in Figure 17 on the following page.

Over the course of the entire scenario period, there is little difference in total CO_2 emissions between the three technology scenarios. In 2030, annual CO_2 emissions in the technology scenarios are roughly 600,000 tonnes less than in the 35% scenario, and the 35% scenario CO_2 emissions are approximately 1 million tonnes less than those in the reference scenario.

[14] E4tech estimates that there would potentially be 51% of all lories that could run on B30 if such a requirement was implemented (E4tech, 2013).

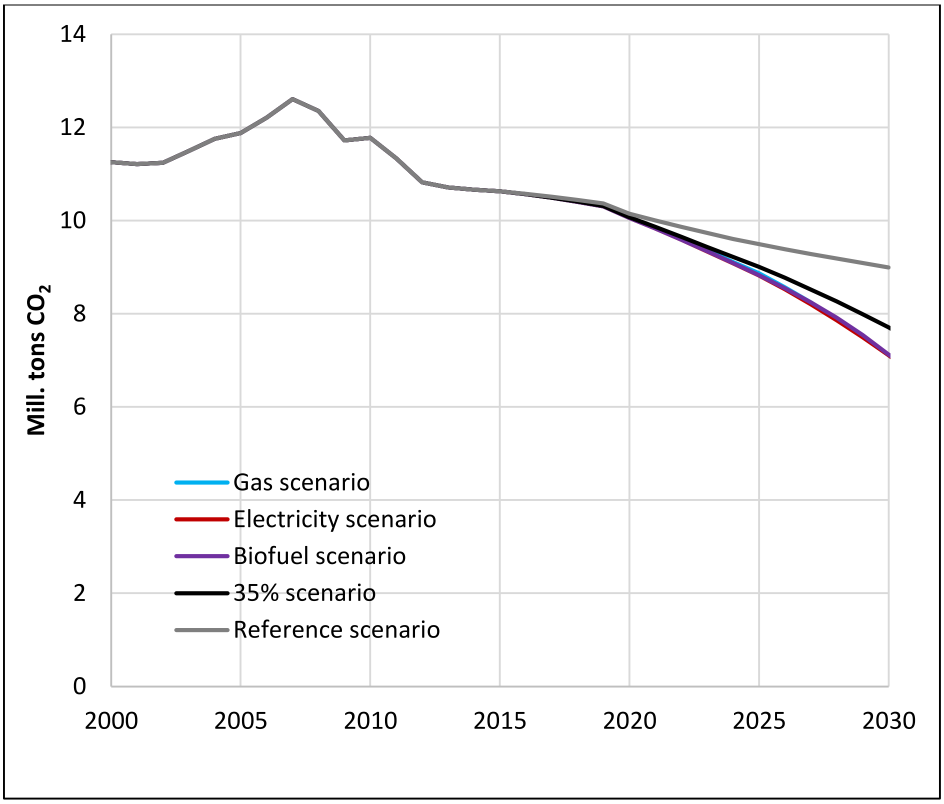

Figure 17: CO_2 emissions from Danish road transport 2000-2030 in the 35% scenario, three technology scenarios, and the reference scenario.

The socioeconomic costs associated with the above CO_2 emission reductions are displayed in Table 9.

Billions of DKK NPV 2015 -2030	*0 DKK/ tonne CO_2*	*EU ETS price/ tonne CO_2*	*1000 DKK/ tonne CO_2*
35% scenario	*4.1*	*3.4*	*0.0*
Technology scenarios - Additional cost (NPV) relative to 35% scenario:			
Electricity scenario	*+1.2*	*+1.0*	*-0.4*
Gas scenario	*+1.4*	*+1.2*	*-0.0*
Biofuel scenario	*+1.1*	*+0.8*	*-0.4*

Table 9: Costs for the 35% scenario and the three 40% technology scenarios*. Total NPV costs for the period 2015-2030 with a 4% discount rate, given three different CO_2 values. For the technology scenarios, the table displays the additional cost of extending from a 35% emissions reduction to a 40% emissions reduction.*

The table shows that the total discounted cost of implementing the 35% scenario is 4.1 billion DKK, which corresponds to an average cost of approximately 400 million DKK per year (not discounted). The bottom portion of the table displays the additional cost for each of the technology scenarios relative to the 35% scenario, i.e. the additional cost of going from a 35%

reduction to a 40% reduction. When no value is placed on the CO_2 savings, the total additional cost varies between 1.1 and 1.4 billion DKK.

However, since CO_2 emission reductions undertaken in the transport sector represent an alternative to reducing emissions in alternative non-ETS sectors, the cost of realising emissions savings in the transport sector should be compared with the cost of doing so in these alternative sectors. Optimally speaking, in a socioeconomic analysis it would be preferable to incorporate the benefit associated with reducing CO_2 emissions. However, as it is not possible to place a direct value on this benefit, the current analysis instead applies alternative values equal to the cost of reducing CO_2 emissions in other sectors. Table 9 displays this comparison given the EU ETS price, or a price of 1,000 DKK per tonne CO_2.

If it is assumed that the alterative cost of reducing CO_2 emissions is roughly 1,000 DKK per tonne, then the emission reduction costs associated with the 35% scenario would quite likely be lower than those from the majority of the remaining non ETS sectors. It is therefore socioeconomically desirable to reduce CO_2 emissions in the transport sector compared to other non-ETS sectors (agriculture, households, industry, etc.).

With a CO_2 emission savings value of 1000 DKK/tonne, the cost of the three technology scenarios (on a per tonne CO_2 saved basis) are on par, or cheaper than, the 35% scenario. This is because the additional CO_2 reductions undertaken in the electricity, gas and biofuel scenarios primarily take place near the end of the scenario period, when the CO_2 reduction costs are lowest.

CO_2 emissions towards 2050
The 35% scenario, and all three technology scenarios, can pave the way towards a CO_2 neutral transport sector in 2050. In order to achieve CO_2 neutrality by 2050, the remaining fossil fuels used in non-gas/electric-powered vehicles will have to be replaced with various forms of biofuels.

Cost projections carried out to 2050 point to the electricity scenario being the cheapest, however these projections are associated with a great deal of uncertainty, and rely heavily on forecasted prices for batteries, biofuels and oil.

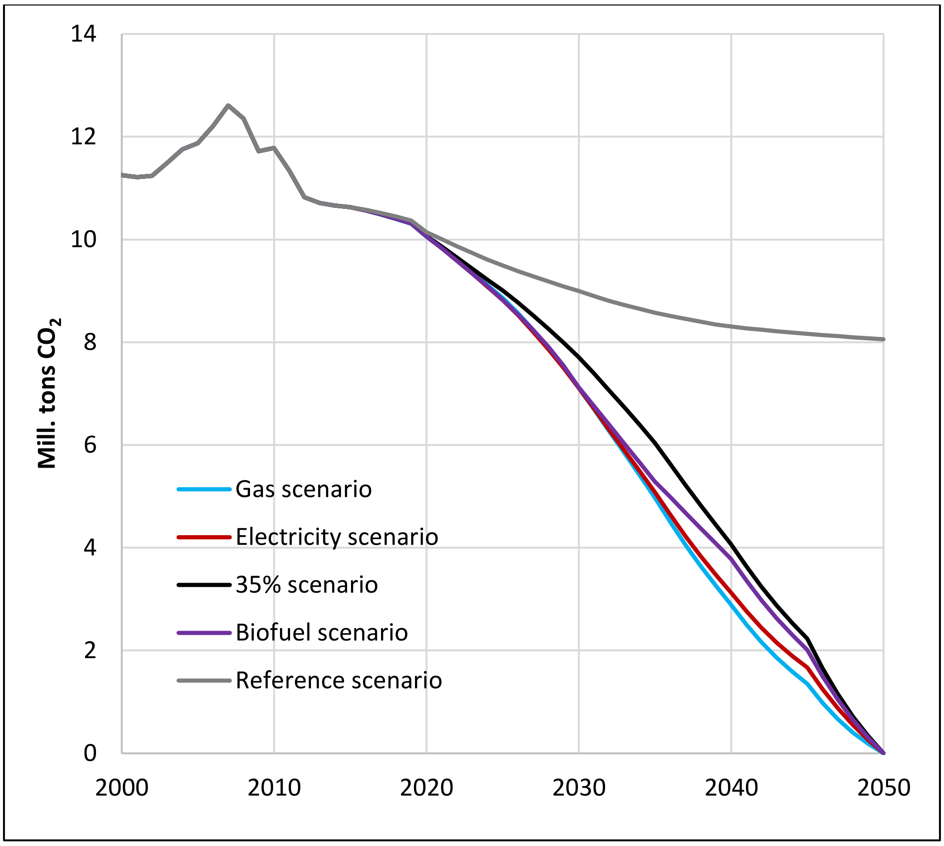

Figure 18: CO_2 emissions from Danish road transport for all 5 scenarios up to 2050.

5.4 Sensitivity analyses and discussion

Sensitivity analyses were undertaken for the 35% scenario and technology scenarios, regarding the price development for oil, batteries, biogas, and biofuels. The oil price sensitivities involved a situation where oil prices developed in such a fashion that they are 20% higher/lower in 2030 than otherwise forecast, and a situation where the oil price was maintained at the 2015 level. The results of the sensitivity analyses are displayed in Table 10.

Not surprisingly, the table shows that lower oil prices increase the socioeconomic cost of implementing CO_2 emission reduction efforts that phase out fossil fuels from the transport sector. For example, with an unchanging oil price through to 2030, the cost of implementing the 35% scenario increases to over 6 billion DKK. However, it is important to note that the calculations in the table do not include a valuation of the CO_2 savings (i.e. CO_2 price is 0).

Billion DKK NPV 2030	35% scenario	Electricity scenario	Gas scenario	Biofuel scenario
Main result	**4.1**	+1.2	+1.4	+1.1
Sensitivity analyses NPV 2015-2030				
Oil price				
+20%	**-1.1**	-0.5	-0.4	-0.4
-20%	**+0.9**	+0.4	+0.4	+0.4
2015 level	**+2.0**	+0.9	+0.8	+0.8
Biofuel price				
+10%	**+0.3**	0.0	0.0	+0.4
-10%	**-0.3**	0.0	0.0	-0.3
Biogas price				
+10%	**+0.2**	0.0	+0.3	0.0
-10%	**-0.1**	0.0	-0.3	0.0
Battery price				
+10%	**+0.4**	+0.3	0.0	0.0
-10%	**-0.3**	-0.3	0.0	0.0

Table 10: Socioeconomic costs of the 35% scenario and additional costs incurred in the three 40% technology scenarios*. The table shows the total socioeconomic costs of the 35% scenario compared to the reference scenario. The sensitivity analyses for the 35% scenario display the additional cost relative to the main result. Sensitivity analyses for the technology scenarios are relative to the corresponding sensitivity analysis for the 35% scenario (i.e. with a 20% higher oil price, the electricity scenario has a total cost that is 0.5 billion less than a 35% scenario with 20% higher oil prices).*

In addition to oil, the scenario analyses include price projections for a number of other parameters, the most important of which include biofuels, biogas and batteries for electric vehicles. Production costs for various liquid biofuels are highly dependent on the price development of input materials such as straw, wheat and rapeseed oil. For electric vehicle batteries, the price development his highly dependent on the technological development (often expressed via learning curves).

Catalogue of climate change mitigation measures & CO_2 reduction costs
As was discussed previously, EU countries have committed to reducing CO_2 emissions, also outside of the quota sector. If the trend from the recent Danish baseline projection is forecast to 2030, then Denmark will have a CO_2 emission reduction shortfall of 3-5 million tonnes in 2030.

In 2013, an inter-ministerial working group published a catalogue of Danish climate change mitigation measures as a basis for a climate plan (Inter-ministerial working group, 2013). The catalogue contains a range of initiatives in various sectors, including agriculture and transport. Based on this catalogue of measures, a CO_2 emissions reduction curve has been assembled, where only measures outside of the quota sector have been included. Some of the initiatives in the catalogue, for example, heat savings, have effects both inside and outside of the quota sector. For these measures, estimates have been made regarding the effect allocation.

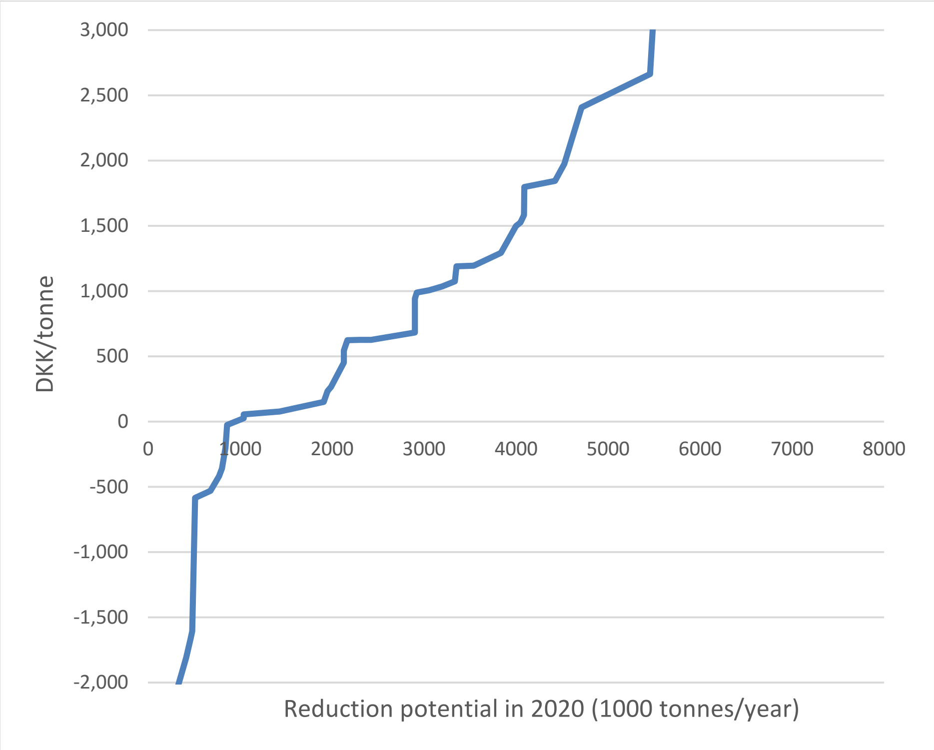

***Figure 19: Marginal CO_2 emission reduction costs in the non-ETS sector**. Source: Inter-ministerial working group (Inter-ministerial working group, 2013) and own calculations.*

Figure 19 illustrates that the climate catalogue found CO_2 emission reduction measures with a cost under 1,000 DKK/tonne totalling 3 million tonnes. If the target becomes a total reduction of 5 million tonnes, then the marginal CO_2 reduction cost increases to 2,500 DKK/tonne. The total non-ETS emission reductions potential via relevant measures was estimated to be over 7 million tonnes per year (Figure 19 displays only up to 5.5 million tonnes), with the most expensive reduction costs being over 10,000 DKK/tonne.

As a general rule, the catalogue stated that new policies and measures focused on the agriculture sector were on the cheap end of the mitigation instruments scale, while transport initiatives were to be found at the higher end. For example, when looking at measures with a cost of under 2,500 DKK/tonne, the agricultural sector could contribute with total emissions reductions of over 3.6 million tonnes, while the transport sector could only contribute with 0.5 million tonnes. (Inter-ministerial working group, 2013).

Transport related measures in the catalogue included raising fuel taxes, higher blending requirements for biofuels, promotion of gas in heavy transport, as well as a mileage-based road tax (commonly referred to as road pricing). As such, it is many of the same types of policies and measures that are investigated in the current analysis, but where this study finds significantly lower CO_2 emission reduction costs. The higher emission reduction costs found in the catalogue are partly due to the inclusion of distortionary losses, including for example the anticipated loss of state revenues due to increased cross-border trade.

6 Taxation and other instruments

The scenario work is undertaken without regard to the specific incentives that are required in practice to increase the use of biofuels, promote the phasing in of biogas, and to increase the share of electric vehicles in road transport. Improved fuel economy is assumed to be most affectively achieved through EU regulation.

However, taxation and incentive schemes were prominent subject areas at the two workshops held during the project. Preliminary analyses of the current taxation system in Denmark and other countries were discussed at the workshops, with a primary focus on passenger vehicle taxation.

The reduction of CO_2 emissions from the transport sector is a large and long-term task. It is therefore important that the tax structure and incentives utilised result in the lowest possible cost. Due in part to the discussions at the workshops, it was decided to take as a point of departure an 'ideal' taxation system, and thereby not be bound by restrictions found in the current taxation system.

6.1 Taxation of passenger vehicles

Brief analysis of the current tax system

The current passenger vehicle taxation system is comprised of a high value-based registration tax, an annual 'green owner' tax, and fuel and CO_2 taxes. On the other hand, passenger transport in general receives indirect support via a so-called 'transport deduction', which entitles commuters to a tax deduction.

All of the taxation elements depend on the vehicle's potential and/or actual fuel consumption. A deduction in the registration tax is given for vehicles that can travel many km/l, and the annual green owner tax is also based on how many km/l a vehicle operates. When fuel and CO_2 taxes are added, the cumulative financial incentive to reduce CO_2 emissions is in the range of 6,000 to 10,000 DKK/tonne.

The combination of high value-based taxation with significant CO_2 incentives, results in small energy efficient gasoline and diesel cars being very attractive for consumers.

It is apparent that the tax system was developed at a time when vehicles had significantly poorer fuel economy than today (fewer km/l). For example, the lowest rate of the green owner tax is already achieved when a gasoline vehicle can travel over 20 km/l.

Tax deductions for energy efficient vehicles are also calculated based on how many km the vehicles can drive per litre, rather than their fuel consumption per km. This noteworthy, because fuel savings (and thereby CO_2 savings) are considerably smaller with a change from, for example 30 km/l to 31 km/l (a 3% reduction), than with a change from 10 km/l to 11 km/l (a 9% reduction).

The value-based registration tax can result in the cost of CO_2 reduction elements that increase the vehicle's purchase price (for example, the batteries of an electric car) becoming 2.8 times more expensive (before deductions are made for high energy efficiency). EVs and hydrogen vehicles are completely exempt from registration taxes until the end of 2015. A political agreement from October 9th, 2015 between the government (Venstre), the Social Democrats, the Danish People's Party and the Danish Social-Liberal Party established a phase-in process into the existing tax system for electric vehicles, plug-in hybrid vehicles, and fuel cell vehicles. Electric and plug-in hybrid vehicles will be phased in over a 5-year period starting in 2016, resulting in full taxation in 2020. Fuel cell vehicles will meanwhile start a 5-year phase-in period in 2019. If the assumptions underlying the agreement change significantly during the phase-in period, the parties will revisit the phase-in period.

Principles behind an ideal tax system

An economically optimal tax system with low distortionary effects should, to the greatest extent possible, price the costs (externalities) that road transport imparts upon society. According to economic theory, the levies related to these externalities should, where possible, be placed where the costs arise. For example, CO_2 emissions should be administered via a tax on the fuel that gives rise to the CO_2 emissions, rather than an annual green ownership tax.

Similarly, a levy that is intended to address congestion, should vary depending on how much (and preferably also where and when) a car is driving. Based on previous analyses undertaken by the Ministry of Transport in 2010, the Economic Council in 2013, and Concito, externality costs for the various passenger vehicle types have been estimated. As was described in chapter 4, the calculations show that externalities constitute roughly 50 øre/km for passenger vehicles. The main costs relate to congestion, accidents and access

to the road network. Meanwhile, with a CO_2 value of 1,000 DKK tonne, the vehicle's climate impact during its use phase is 10-12 øre/km.
An electric vehicle has slightly lower externality costs due to lower costs associated with local air pollution, noise and CO_2 emissions. For a medium sized EV, and assuming that the electricity used is CO_2 neutral, the total externality costs are roughly 12 øre/km less than for a comparable ICE vehicle. If one compares the current taxation (and deductions) over the lifetime of the vehicle with the externality costs associated with the same vehicle, the calculations find that medium and large gasoline vehicles pay considerably more in tax than their externality costs justify. Conversely, small gasoline cars pay a good deal less, and electric cars significantly less (assuming EVs are exempt from registration tax).

(2015 DKK)	Small gasoline	Medium gasoline	Small EV (2015)	Medium EV (2015)
Current taxation	59,000	179,000	-4,000	-4,000
Externalities	89,000	98,000	80,000	73,000
Difference	-30,000	81,000	-84,000	-77,000

Table 11: Comparison of taxation and externalities. *Climate impact assuming a CO_2 value of 1,000 DKK/tonne.*

'Ideal' tax should be based on road pricing

An 'ideal' tax system would be based on a combination of various taxation elements, but where the largest share of tax revenues came from differentiated road pricing. This is because the majority of externality costs are those associated with congestion, accidents and the use of the road network, which all depend on how much, when and where a vehicle is used. In an ideal tax system, the vehicle's purchase price would have much less significance than it does under the current system.

However, there are currently a number of technical and economic challenges related to the introduction of differentiated road pricing. A compromise on this solution could be to base the vehicle mileage on measurements taken during the annual vehicle inspection, potentially differentiated according to vehicle owner residence and workplace information. If this too is not feasible in practice, then the annual green owner tax could be used as a (very rough) approximation. However, this tax is not dependent on how much the vehicle is driven, and is therefore a less effective instrument.

Electric vehicles require a phase-in period

Regardless of how a differentiated road pricing tax is implemented in practice, the analysis indicates that the 'ideal' tax system alone, would not result in in electric and other low emission vehicles being economically competitive with fossil fuel-based alternatives in the short term. In other words, even with a high cost placed on externalities, CO_2 emissions and local air pollution, consumers still lack sufficient incentive to purchase low emission vehicles.

In order to ensure the phasing-in of electric vehicles in the ideal tax system, it would therefore be necessary to supplement with a deduction for vehicles with the lowest CO_2 emissions. The deduction could, for example, be given to EVs, PHEVs and hydrogen vehicles, which under the EU standards, have CO_2 emissions under 50 g/km. This could be applied in a linear fashion, so that vehicles that emit 0 g CO_2/km receive a 100%, reduction, those that emit 25 g CO_2/km receive a 50% reduction, etc., and would thereby reward pure EVs more than PHEVs. The table displays an example of the 'ideal' tax system with the inclusion of a deduction for low emission vehicles.

(2015 DKK)	Small gasoline	Medium gasoline	Small EV (2015)	Medium EV (2015)
Import price	59,000	108,000	149,000	204,000
VAT	15,000	27,000	37,000	51,000
Sales price	**74,000**	**135,000**	**186,000**	**255,000**
Annual 'driving' taxes*	73,000	78,000	73,000	76,000
Fuel/CO_2 tax*	17,000	20,000		-
Fuel costs*	39,000	48,000	12,000	18,000
Fuel VAT + other fuel and CO_2 taxes*	28,000	32,000	12,000	13,000
Operations and maintenance*	58,000	58,000	35,000	35,000
Cost during vehicle lifetime	**289,000**	**371,000**	**318,000**	**397,000**
Deduction in 'driving' taxes*			-65,000	-65,000
Total cost during vehicle lifetime	**289,000**	**371,000**	**253,000**	**332,000**

Table 12: Comparison of vehicle lifetime costs*. Comparison of gasoline and electric vehicles under the 'ideal' tax system inclusive a temporary deduction to promote electric vehicles. Based on 2015 prices.*Indicates that the values are totals accumulated over the vehicle's lifetime.*

In the calculations in the table it is assumed that the EVs receive a registration fee deduction of roughly 15,000 DKK, and a 50,000 DKK discount on annual 'driving' taxes over the course of the vehicle's lifetime. This results in both the small and medium EVs becoming economically competitive with their gasoline counterparts.

Annual support pool

From the Danish state's point of view, it can be challenging to predict the appropriate level of deduction for low emission vehicles going forward. A potential solution could be to set aside an annual pool with a maximum of, for example, 200 million DKK for the promotion of EVs and other low emission vehicles up to 2025. Assuming that the required support is roughly 65,000 DKK per EV as in the example above, this would allow for support to roughly

3,000 EVs per year given today's prices. As the cost of low emission vehicles fall, this would allow for the individual deduction amount to be reduced, and thereby enable the annual pool to support a growing number of low emission vehicles. It will likely be necessary to adjust the individual deduction amount on an annual basis. If rates are set too low for one year, thereby resulting in the pool's funds not being fully utilised, these funds could be transferred to the following year, thus ensuring a steady increase in low emission vehicle sales until the annual deductions are phased out.

State revenue losses

It is difficult to forecast the 'ideal' tax system's fiscal effects, but a rough estimate points to a revenue loss for the Danish state in the range of 15-25%. Relative to today, the 'ideal' system would result in higher revenues from small vehicles, while larger and more expensive vehicles would generate less tax revenue.

In order to maintain State revenues at current levels, one could choose to impose a higher registration or annual owner tax on the most expensive vehicles. In order to avoid encompassing small electric vehicles within this tax (as they are significantly more expensive than their ICE counterparts due to battery costs), it would be necessary that such a registration tax would only be applicable to vehicles over a certain import price, for example 200,000 DKK, thus essentially being a targeted 'luxury tax'. If the level were set much lower than 200,000 DKK, then it would be necessary to give a larger deduction for low emission vehicles.

6.2 Taxation of lorries

Lorries pay the same fuel and CO_2 tax rates as passenger vehicles. In addition, lorries pay a road utilisation tax (vejbenyttelsesafgift) and weight tax. For a lorry that drives 50,000 km/year, total annual taxes are roughly 60,000 DKK.

(2015 DKK)	Annual costs based on 50,000 km/year
Fuel taxes[15]	39.325
CO_2 taxes[16]	6.270
'Road utilisation' tax	9.318
Weight taxes	3.500
Total	**58.413**

***Table 13: Taxation of lorries**. Annual costs based on 50,000 km per year.*

[15] A lorry uses roughly 11 MJ per km, corresponding to approximately 550 GJ per year. The energy tax on diesel is 71.5 DKK/GJ, resulting in an annual tax payment of 39,325 DKK.
[16] A lorry uses roughly 11 MJ per km, corresponding to approximately 550 GJ per year. The CO_2 tax is 11.4 DKK/GJ, corresponding to an annual tax payment of 6,270 DKK.

The main externality costs from lorries relate to wear on roads, CO_2 emissions, congestion and accidents. Other externality costs include local air pollution, noise and access to the road network (see Figure 20).

In total, the externality costs amount to roughly 3.3 DKK/km for diesel lorries (assuming a CO_2 price of 1,000 DKK/tonne). For a lorry running on biogas total externality coasts are roughly 2.6 DKK/km. For an average lorry traveling 50,000 km per year, annual externality costs therefore total roughly 180,000 DKK if running on diesel, and 140,000 DKK if running on biogas. As such, the externality costs associated with lorry transport are approximately three times higher than the taxes lorries pay.

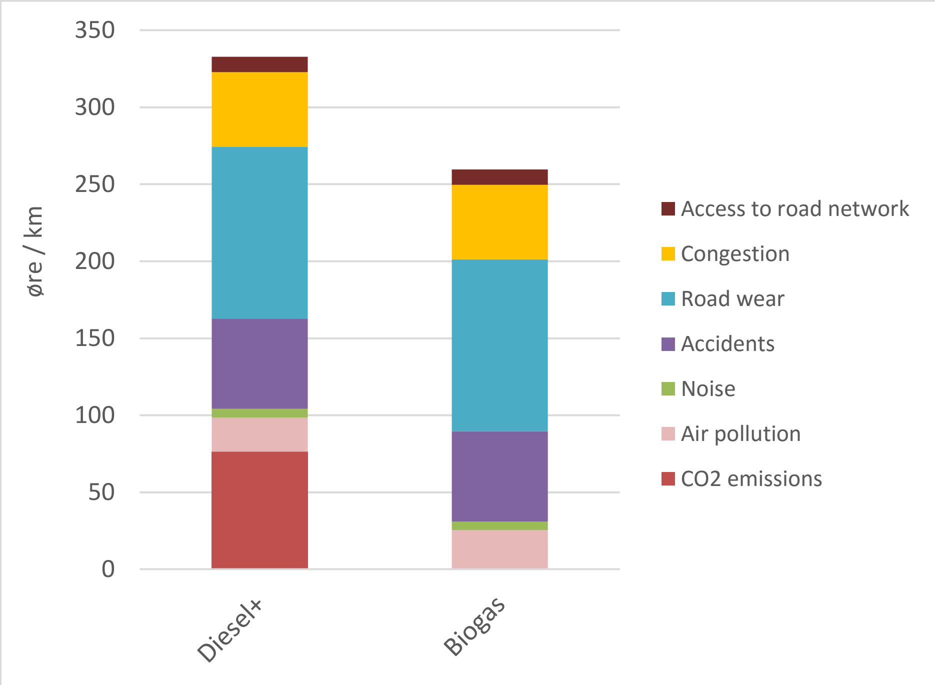

Figure 20: Externality costs for a lorries running on diesel and biogas in 2015.

The ’ideal’ lorry taxation system

For lorries, the ’ideal’ taxation system would be comprised of two main components:

- A fuel tax of roughly 74 DKK/GJ which reflects CO_2 emissions costs assuming a value of 1,000 DKK/tonne. This level corresponds to the current fuel tax.
- A differentiated road tax, averaging roughly 2.55 DKK/km, which covers the remaining externality costs.

Previously there were plans to introduce km-based road pricing for lorries in Denmark, but the plans were abandoned in 2013. According to the government at the time, this was due to the high costs associated with the establishment and operation of the toll system. If there is a desire to have lorry freight transport cover their externality costs, this could be achieved with less targeted measures than differentiated road pricing. More simple solutions could for example include a kilometre-based charge, based on odometer measurements or a higher road utilisation tax.

The above discussion has not assessed the negative commercial effects of restructuring the freight taxation system in a manner that requires the road freight sector to cover their externality costs. It should also be noted that the externality-based taxation of road freight is not a prerequisite for achieving the CO_2 reductions realised in the scenarios.

6.3 Measures to promote green gas and liquid biofuels

The 35% scenario includes an increased phasing-in of both liquid biofuels and green gas in road transport.

Promotion of liquid biofuels

It is assumed that liquid biofuels will continue to be blended with gasoline and diesel. In 2020 or thereabouts, it is assumed that the current E5 and B7 standards will be supplemented by E10, E20 and B30. By 2030, it is assumed that the E5 standard can be completely phased out.

By 2020, it is assumed that all new cars can run on E20, and a portion of the heavy duty vehicle fleet will use B30. Today, most lorries are capable of running on B30, but new diesel vehicles that meet the Euro VI standard will require additional modifications before they can use B30. There is uncertainty regarding the extent to which the EU is willing to impose such a requirement.

Biofuel blending requirements are assumed to continue to be the main instruments that ensure the phasing in of biofuels. Where there are different standards available, the oil companies can be responsible for ensuring that the total blending requirements (on an energy basis) are obtained. Biofuel blending requirements are assumed to continue to be EU driven, and it is assumed that the EU will place a requirement on automobile manufacturers ensuring that that all new passenger vehicles can run on E20 by 2020. Blending of more expensive drop-in diesel does not require a blending standard. Requirements for the addition of drop-in fuels is an important tool for oil companies to ensure that the total blending % target for biofuels is reached. These can be adjusted annually depending on how much of the fuel purchased is E20 or B30. Relative to today, where there is only one diesel standard (B7) and one gasoline standard (E5), the task of ensuring the sale of the relevant quantities of biofuels will become more challenging for the oil companies.

Promotion of green gases
Biogas is supported in Denmark today by, amongst other measures, a subsidy when it is added to the natural gas network. Thereafter, biogas can in principle be sold to customers at the same price as natural gas.

The task of ensuring a phasing in of green gas in the transport sector requires different measures than the phasing in of liquid biofuels. The use of natural gas (and green gas) in transport is currently very limited, so it is not sufficient to only require the blending of green gas into the natural gas network.

The phasing-in of green gas for use in transportation is conditional on the establishment of a gas filling infrastructure, and that relevant stakeholders in the transport sector (initially, owners of vehicle fleets within heavy transport in particular) invest in gas-powered vehicles. A number of studies have examined the possibilities for promoting gas in the transport sector, the most recent of which being a report by the Danish Energy Agency and COWI, "Framework conditions for gas in heavy road transport" from 2014. (COWI, 2014). The main findings included:

- That from a private sector perspective, it is not economically viable to operate with natural gas in buses or trucks.
- That there is uncertainty regarding the overall economics for fleet owners, particularly regarding the resale value of vehicles, and in relation to contract lengths that can safely be entered into (for example municipal bus services).

The report also suggests that either the purchase price of gas vehicles to be dropped by 40,000 to 75,000 DKK, the gas engine energy consumption must be reduced by about 5-10%, or the gas price lowered by between 0.4 and 0.9 DKK per m^3 (excl. VAT), in order for gas vehicles to be competitive. The energy tax on biogas and natural gas for transport are currently 2.87 DKK/m^3, which is at the same level as diesel.

Experience from abroad has revealed that it is difficult to promote gas in the transport sector, even when the framework conditions are relatively favourable, as is the case in Germany, the Netherlands and Sweden. The report points out that although gas vehicles are exempt from taxes in Germany until 2018, the gas vehicles sales trend has stagnated.

Possible measures

If the Danish state is interested in promoting the use of gas in the transport sector, this can be done via several different types of instruments, including, for example:

- Infrastructure grants
- Subsidies for vehicles (or tax deductions)
- Lower taxes on gas for transportation

In addition, local authorities and transport companies have the opportunity to promote the use of gas through the tendering of bus services, etc.

The most targeted measure to ensure the phasing-in of gas is deemed to be a lower tax on gas for use in transportation, as the desired outcome is the increased use of gas at the expense of diesel (and gasoline). This measure can then provide motivation for relevant stakeholders to invest in gas infrastructure and vehicles.

However, as was stated above, the evidence from abroad indicates that stakeholders in the transport sector will not necessarily invest in gas-powered vehicles, even if it appears to be commercially attractive. One possibility could therefore be to supplement this lowered tax on gas for use in transport with a partnership approach with relevant stakeholders, including for example:

Stakeholder	Role
Gas companies	Establish and connect filling stations
Municipalities / Transport companies	Tendering of bus and waste collection vehicles, & placement of filling stations
Fleet vehicle owners	Investment in gas-powered vehicles
Service stations	Placement of filling stations in connection with existing tank systems

Compared to many other countries, Denmark has a strong history of cooperation between public and private actors, which can be vital in the promotion of gas-powered vehicles. The Danish Energy Agency already supports a number of regional partnerships. There is therefore an effort underway that may be possible to build further upon.

Measures to promote green gas

The question then becomes, how to ensure the phasing-in of green gases at the expense of natural gas? It is our assessment that it is unlikely to require additional measures to do so. This is because the majority of Danish biogas can be expected to be produced from waste products, for example from livestock manure, industrial waste, municipal waste and straw. The majority of biogas can therefore be regarded as a 2G biofuel, and is thus eligible for double counting when calculating Denmark's progress towards its 2020 RE transport target. Oil and gas companies will therefore have an economic interest in ensuring that the gas sold in the transport sector is a green gas.

The above of course assumes that enough biogas can be produced in Denmark. The 35% scenario requires 2 PJ of green gas in 2030 (rising to 15 PJ in 2050). To put this into perspective, the Danish Energy Agency's biogas task force anticipates that biogas production, due to the existing production side subsidies, will increase from approximately 4 PJ in 2012, to 14 PJ in 2020, and 18 PJ in 2025. That is to say, an increase of approximately 14 PJ from 2012 to 2025. The vast majority of this new biogas production is anticipated to be upgraded to natural gas quality, and thereby could be used in the transportation sector.

7 Glossary

- **1G biofuel:** Biofuels based on corn and other edible crops
- **2G biofuel:** Biofuels based on residues from agriculture, forestry, industry or households
- **Advanced biofuels**: 2G biofuels with the exception of biofuels produced from used cooking oil or animal fat.
- **Biofuel standards (B7, B30, E10, and E20):** Biofuels standards are a mixture of diesel or petrol with biofuels. B standards indicate blends of diesel with biodiesel, and E standards specific mixtures of gasoline and ethanol. The number indicates the percentage by volume.
- **Blend wall:** A cap on the proportion of biofuel that can be added to fuel without damaging the engine.
- **Distortionary effects/losses:** Occur when market actors change their behaviour due to a tax, charge, subsidy, etc.
- **Drop-in fuel:** A biofuel product that can be directly blended with conventional fuels (diesel and gasoline) in any ratio. The analysis refers primarily to drop-ins for diesel.
- **EJ:** Exajoule - One billion (10^9) Gigajoules (GJ)
- **Energy efficiency:** in this report, energy use per km driven. Energy efficiency is presented according to EU regulation, and also in g CO_2 /km.
- **Externality costs:** Externality costs are secondary costs, in this case related to transport and include noise, road wear, congestion, air pollution, CO_2 and access to the road network.
- **FAME:** Fatty Acid Methyl Ether – a biodiesel product that can be blended with diesel. FAME does not have the same chemical properties as diesel, and therefore there are restrictions on the proportion different diesel engines can tolerate.
- **Fischer Tropsch:** Catalytic processes that converts a mixture of hydrogen and carbon monoxide to liquid fuels.
- **Flexi-fuel:** Vehicles that can run on several different types of fuels, including high blending % biofuels
- **Fuel directive:** EU Directive that stipulates that suppliers of road transport fuels must reduce greenhouse gas emissions from transport fuels by 6% by 2020, measured on a well-to-wheel basis.
- **GJ**: Gigajoule - One billion (10^9) joules
- **Heavy transport:** Transport with lorries and busses
- **HVO:** Hydro treated vegetable oil – a drop-in fuel for diesel

- **Methanisation:** Synthesis of CO_2 and H_2 to methane (CH_4) and water (H_2O)
- **NPV:** Net Present Value (sum of all discounted costs)
- **Non-ETS sector** - The EU distinguishes between the ETS sector and the non-ETS-sector, with varying CO_2 emission reduction targets. The quota sector comprises the majority of electricity and heat production in the EU, and quotas can be traded within the ETS sector. The non-ETS sectors include agriculture and transport.
- **O&M:** Operation and maintenance
- **PJ**: Tera joule – one million (10^6) Gigajoule (GJ)
- **Plug-in hybrid**: Essentially an electric car with a small internal combustion engine that is used to produce electricity and thus acts as a 'range extender'
- **RES Directive:** EU Directive, which establishes a target of 10% renewable energy (RE) in transport fuel by 2020 for Member States.
- **Road transport:** Road transport includes cars, vans, lorries, buses and motorcycles. (Trains, ships and aircraft are thus not included).
- **Socioeconomic costs**: Cost without taxes and subsidies. The current analysis does not include distortionary losses/gains of the existing tax system, but does include related costs (externalities) from noise, road wear, congestion, air pollution, CO_2 and access to the road network.
- **Sunk cost:** Costs that cannot be changed by new decisions.
- **TJ**: Tera joule – one thousand (10^3) Gigajoule (GJ).

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