ANNEX TO RESEARCH REPORT VTT-R-00741-17

EXTENDED ABSTRACT IN ENGLISH

How to Reach 40% Reduction in Carbon Dioxide Emissions from Road Transport by 2030: 2017 Update

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Confidentiality: Public

The key conclusions in the Road Transport 2030 update report

- The question to be answered in this report regards the alternatives enabling a 40 percent reduction in greenhouse gas emissions by 2030 (and up to 2050). The level of the base year 2005 is approximately 11.7 Mt CO_2. In the basic scenario of this update, the 2030 carbon emissions are approximately 9.2 Mt, i.e. approximately 21 percent below the base year. **Emissions should therefore be reduced a further 2.2 Mt, i.e. approximately 19 percent.** In the basic scenario, the actual share of biofuels (excluding the double counting required by the present distribution obligation) is approximately 14 percent, and the share of electricity is very limited.
- **The updated version examines five different scenarios.** It also introduces two novel scenarios: an optimistic 'electricity max' scenario with 400,000 battery electric vehicles and 200,000 plug-in hybrid vehicles, and a 'natural gas max' scenario with 200,000 natural gas passenger vehicles, 50,000 vans and a 10 percent biogas share in the mileage of heavy duty vehicles. In order to reduce carbon emissions by 40 percent, both scenarios require liquid drop-in biofuels that can be used in high blends. **In all scenarios, including 'electric max' with its emphasis on electric cars, the demand for biofuels is bigger than present usage and present production capacity in Finland.** In addition to changes in the vehicle fleet, 'electricity max' and 'natural gas max' scenarios would imply major changes in the distribution infrastructure for alternative power sources, for which there will be costs.
- **Published in November 2016, the government's energy and climate strategy set the target for 50 percent reduction in transport emissions by 2030.** Also, the share of biofuels should be at 30 percent (actual energy share); the target for electric vehicles was 250,000 and for natural gas vehicles 50,000.
- Compared to the 21 percent reduction of the basic scenario of this survey, 250,000 electric passenger cars would reduce emissions by an additional nearly 5 percent. Similarly, increasing the share of biofuels from the present 13 percent to 30 percent would reduce CO_2 emissions by approximately 12 percent. In this respect, it can be argued that **both advanced biofuels and carbon-free electric vehicles will definitely be necessary for achieving 40 or 50 percent reduction in greenhouse gas emissions.**
- **The relative cost impacts of different decisions mainly depend on external factors, such as prices of crude oil and electric vehicles.** Also, carbon emission pricing and the measures for 2030 implemented in the EU's climate policy have an influence in the situation. National level measures can also be implemented with regard to the price development of domestic biofuel production. When moving towards low-carbon and smart transport, the importance of tax decisions is significant. **The estimated price for domestic biofuels is approximately 1,000 to 1,200 €/toe** (pre-tax price 0.82 to 0.98 €/litre, whereas the price of fossil diesel fuel is 0.47 €/l).
- **The cost impacts have been assessed from the viewpoint of distribution prices of fuels as well as annual costs per vehicle category** (passenger car and transit bus). As regards passenger cars, all powertrain and fuel alternatives were assessed in the light of present taxation. A petrol car was used as a reference point. The price of avoided CO_2 tonne with present prices and taxes was 50 to 300 €/tCO_2 for biofuels (liquid and gas), 800 to 2,500 €/tCO_2 for plug-in hybrids, and 200 to 1,400 €/tCO_2 battery electric vehicles. As regards other fuels than biofuels, annual mileages of 17,000 or 30,000 km had a huge impact on the results. The price of avoided CO_2 ranged from -200 to +1,800 €/tCO_2 for fossil diesel fuel, and from -100 to +180 €/tCO_2 for natural gas. The carbon reduction potential was, however, limited for both of them. As regards diesel vehicles, air quality impacts in urban areas will also have to be taken into account. If the purchase price (with taxes) of electric vehicles would drop to the level of petrol vehicles, the electric vehicle would be very cost-efficient due to lower costs of use. **Electric buses are already quite competitive due to their high utilisation rate**.
- **The general equilibrium model was used for calculating and assessing the national economic impacts**. There were two versions made of the 'electricity max' scenario, differing in regard to price development: a) 'electricity max' basic version in which electric cars are still more expensive than combustion engine vehicles in 2030; and 'electricity max 2' in which the price of electric cars drops to the same level with combustion engine vehicles already in 2025. The first version is the most expensive as regards the impact on GDP, whereas the second version is the least expensive. **In regard to the differences in the scenarios, the price development of new electric vehicles is essential** even if the required investments in the infrastructure affected results slightly. The calculations show that the possible large-scale promotion of electric vehicles should only be started when the prices have dropped and the vehicle's (battery) performance has improved. **The total impact of different scenarios' on GDP ranged from -2.7 to +0.1.**

0. Extended Abstract

Background

VTT Technical Research Centre of Finland Ltd and VATT Institute for Economic Research conducted a joint survey in2013 to 2015 regarding the measures and costs of achieving the target of 30 to 40 percent reduction in carbon dioxide (CO_2) emissions of road transport by 2030, compared with emissions of 2005. The survey was funded mainly by the Ministry of Economic Affairs and Employment (MEAE). The final report of the survey was published as VTT's research report (VTT-R-00752-15) in June 2015.

Most of the calculations of the survey were carried out in 2014. Since then, a number of changes have occurred in the operational environment, making it necessary to update the report. The original survey was part of the TransSmart research programme coordinated by VTT. In spring 2016, the external steering group of the TransSmart programme made a recommendation regarding the report update. The update task was partly funded by TransSmart programme's coordination project in 2016, and partly by the Ministry of Transport and Communication (MINTC).

The issues that have surfaced in the operational environment since 2014 include:

- increase in electric vehicle supply
- the strategic programme of Prime Minister Juha Sipilä's government, May 2015
- the emission scandal of diesel passenger vehicles in autumn 2015, and its escalation in 2016
- restrictions to diesel car use in certain cities due to air quality problems, and initiatives to ban new combustion engine cars, especially in large cities, by 2030
- COP 21 and the Paris Agreement in late 2015
- discussions about building bio-refineries and sufficiency of wood supply in Finland
- the working group established by Ministry of Economy and Employment (MEAE) focusing on changes to national legislation required by the ILUC Directive and promotion of biofuels after 2020
- the European Commission's 'Summer Package' for 2016: a suggestion for burden-sharing in the non-emissions trading sector; land use, land use-change and forestry (LULUCF) proposal for a Regulation as well as Communication from the Commission on low-carbon transport
- Directive on the deployment of alternative fuels infrastructure (2014/94/EU) and its national implementation: the national working group's final report with recommendations was published on 11 November 2016
- preparation and publishing of the national energy and climate strategy on 24 November 2016
- the European Commission's 'winter package' was published on 30 November 2016, including the proposal for the Renewable Energy Directive (REDII).

New objectives for transport sector

The Strategic Programme of Prime Minister Juha Sipilä's Government from spring 2015 sets the goal of increasing the share of renewable transport fuels to 40% by 2030 (taking into account the double counting). The so-called summer package of the Commission in July 2016 proposes 39% reduction of non-emissions trading sector's carbon dioxide emissions by 2030. The national energy and climate strategy, adopted by the government in November 2016, sets clear numerical targets for the transport sector:

- Transport emissions will be reduced to approximately 50% by 2030 compared to the situation in 2005; the emission reduction measures will be targeted especially to road transport in which the emission reduction potential is the largest.
- With regard to all fuels sold to land transport, the physical share of energy content in transport's biofuels will be raised to 30% by 2030.
- An additional goal is to have at least 250,000 electric vehicles (battery electric vehicles, hydrogen vehicles and plug-in hybrid vehicles) and at least 50,000 natural gas vehicles.

The starting point for the original report from 2015, as well as for this update, was to examine the emissions reduction target of 40% from the viewpoint of vehicle and fuel technology, because the emissions reduction target set in the national energy and climate strategy is 50%. Other means of reducing emissions from transport include improving energy efficiency at a system level as well as promoting travel and transport modes that reduce, for example, passenger car transport.

Implementation of the update and specifications during the process

The update was conducted by VTT Technical Research Centre of Finland Ltd. In order to provide a basis for the update, VTT organised a workshop for the operators in the energy and transport sector on 25 August 2016. The workshop was attended by approximately 30 people. Some stakeholders provided written comments on the update while others commented on the survey and the update only orally during the workshop. In addition, during the update process, VTT communicated with various stakeholders and companies.

For example, the following changes were made in the calculations and estimates during the update process:

- mileages were revised from the original survey: the growth in passenger car mileage by 2030 was decreased by 8 percent and the growth in heavy goods vehicle traffic mileage by 2030 was increased by 9 percent
    - the mileages now correspond to the mileage values used in the calculations for the national energy and transport strategy
- the energy efficiency projections of the vehicle fleet were revised especially with regard to heavy goods vehicles
- based on the above-mentioned factors, as well as on the vehicle and energy quantities, a new, so-called baseline scenario was calculated for 2030, in which carbon dioxide emissions, however, remain on the same level as in previous estimates (passenger car emissions decrease while heavy goods vehicle traffic emissions increase)
- in the so-called 'development' scenario based on biofuels, the number of electric vehicles was slightly increased
- two optimistic vehicle fleet scenarios were created
    - in the 'electric max' scenario, there are 600,000 plug-in vehicles in 2030
    - in the 'natural gas max' scenario, there are 200,000 natural gas passenger cars in 2030, and also 10 percent of the heavy goods vehicle traffic's energy demand is supplied by natural gas
- the WAM figures ('With Additional Measures') for vehicle and fuel amounts from the research project 'Sustainable Energy and Climate Policy and the Role of Renewables in Finland (KEIJU)' have also been taken into account; these figures are nearly same as the figures in the new energy and climate strategy
- the estimates about the renewable fuel production potential were revised

- the estimates about the development of electric vehicle prices were revised
- the calculations about the ‘development’ scenario’s impact on national economy were redone; also, the ‘electric max’ and ‘natural gas max’ scenarios were calculated as new cases.

New fleet calculations (vehicle and fuel figures)

As in the original study, ALIISA model developed by VTT for examining the impacts of changes in the car fleet, was used in the fleet’s development and fuel calculations; As mentioned above, compared to the 2015 report, mileages and the development of energy efficiency in different vehicle categories have been changed, but these changes rule each other out almost completely regarding total CO_2-emissions..

Based on the revised projections of energy efficiency, mileages and vehicle sales, new calculations were made to find out which vehicle and fuel technology combinations would enable achieving the 40% reduction in carbon dioxide emissions. However, changes in travel and transport mode choices and various steering measures were excluded from the examination.

The following alternatives were assessed:

- Baseline scenario
  - the number of vehicles designed for alternative fuels (ethanol, gas, electricity) is too small (35,000) to have practical significance
- ‘Development’ scenario
  - passenger vehicle fleet includes 100,000 battery electric vehicles, 50,000 plug-in hybrid vehicles and approximately 50,000 natural gas passenger cars; alternative technologies are used to some extent in other vehicle categories as well
- ‘Electric max’ (new)
  - passenger vehicle fleet includes 400,000 battery electric vehicles and 200,000 plug-in hybrid vehicles, some electric vehicles also in other vehicle categories
- ‘Natural gas max’ (new)
  - 200,000 natural gas passenger vehicles, 50,000 natural gas powered vans, and natural gas also has a 10% share of the mileage in heavy goods vehicle traffic
- WAM (“With Additional Measures”)
  - passenger vehicle fleet includes 200,000 battery electric vehicle and 50,000 plug-in hybrid vehicles, some alternatives in other vehicle categories
  - corresponds to a large extent with the energy and climate strategy of November 2016

For each scenario, a “+drop-in” scenario was also calculated in which the necessary 40% reduction in emissions is ultimately achieved with compatible biofuels.

It is necessary point out that **the vehicle volumes presented here are scenarios, not predictions or forecasts**. This report does not take any position on how or what instruments and measures are necessary to accomplish these vehicle volumes.

In the final report of the distribution infrastructure group, the goal set for vehicle fleet is that all new passenger cars and vans could use alternative propulsion by 2030.

Review of vehicle technology

Supply of electric vehicles (private cars and buses) has increased substantially. Many major car manufacturers, including BMW, Mercedes-Benz and Volkswagen, have made announcements of massive investments in developing electric vehicles. For example, Volkswagen announced in June 2016 that the company would introduce more than thirty battery electric vehicle models by 2025. The company's objective is to sell two to three million battery electric vehicles annually at prices that are not significantly higher than of those cars with other means of propulsion. Volkswagen's goal is that, by 2030, one third of the cars sold would be equipped with an electric drive. Volkswagen makes approximately 10 million passenger cars annually. The goal is somewhat ambitious because the market share of electric vehicles was only 1% of new registrations in the EU in 2015.

Consultancy companies Roland Berger and Bloomberg have recently published estimations about the price trends of vehicles and electric cars in particular. Roland Berger estimates that the extra price for electric passenger cars is at 5,000 to 10,000 euros, whereas Bloomberg estimates that short range electric vehicles may at the same price level with combustion engine cars as early as 2022.

Flex-fuel vehicles running on high blend ethanol fuel have nearly disappeared from the market almost completely. Natural gas passenger cars, vans and buses are still available. At present, there are only spark-ignition natural gas engines available for lorries, but their energy consumption, power level and reliability do not meet the demands of long-distance lorry transport. In order to increase the use of natural gas in heavy lorries significantly, new heavy-duty gas engines with high efficiency and low emissions are required.

Assessments of production capacity of advanced biofuels and other renewable transport fuels

Despite the focus of this update report not being in the production potential of advanced biofuels and other renewable transport fuels, the subject was nevertheless assessed.

New investments in the industry and development of production technologies have been postponed by uncertainties regarding the instruments directed at transport between 2020 and 2030. Another reason for the delay is the absence of final decisions at the EU level and national level. Issues lacking final decisions are, for example, the target for greenhouse gas emission's reduction level until 2030, the minimum levels required for renewable sources of energy, part of the sustainability criteria for biofuels (e.g. LULUCF, REDII and connection to ILUC Directive) and different instruments used to achieve the goals, such as taxation.

Depending on the scenario, the demand for renewable transport fuels in 2030 would be approximately 840,000 to 1,300,000 toe/a (tonnes of oil equivalent per annum). Consequently, compared to the present production capacity in Finland, the additional demand is 300,000 to 580,000 toe/a, assuming that the entire production would remain in the Finnish markets. The present capacity of renewable diesel and petrol component production in Finland at the HVO plants in the Sköldvik and Lappeenranta refineries is approximately 510,000 toe/a. The combined ethanol production at five different plants is approximately 15,000 m^3/a, or 7,700 toe/a. The biogas use in transport in 2015 was approximately 23 GWh/a, or 2,000 toe/a.

The most viable means of increasing Finnish transport fuel production is found from refining various community and industrial wastes and side-streams into transport fuels. A cost-efficient way to increase biogas production is to utilize waste streams that are subject to waste disposal charges. In the 'natural gas max' scenario, however, the demand for biogas is so large that other sources of raw material are also needed, such as synthetic natural gas (SNG) production from bark and other forest residues. Electrically assisted methane productions (P2G, power to gas) may become competitive in case there is very cheap renewable electricity available. Ethanol is also being produced from waste streams of food industry, straws and sawdust. A sawdust-based bioethanol plant of 10,000 m^3/a capacity is under construction in Kajaani, and there are also plans for a straw-ethanol plant in Myllykoski, for example.

The largest single investment plan is a bio-refinery in Kemi, which, if realised, would produce more than 200,000 toe/a components for diesel and petrol from various wood residues, side-streams, and perhaps partly from stemwood material. The report includes updates regarding the development situation of wood-based thermal refining of fuels in Finland and in view of projects funded by the EU's NER300 programme. In order to reduce capital and production costs, the development projects in Finland are aimed at integrating new units and feedstocks to existing oil refineries, bio-refineries and power plants. The development scenario estimate is that, by 2030, it may be possible to invest in as much as 850,000 to 1,100,000 toe/a, equalling investments of 2,000 million euros.

The prospective addition to production capacity of these investment opportunities could be, for example, approximately 100,000 to 150,000 toe/a for the existing HVO plants; approximately 200,000 to 300,000 toe/a for increasing bio raw material use in existing oil refineries; approximately 50,000 toe/a for new sawdust and straw-ethanol plants; approximately 50,000 to 100,000 toe/a for new biogas plants; approximately 150,000 toe/a for plants that refining diesel, petrol and biogas from bark and other forest residues; and approximately 50,000 to 100,000 toe/a for electrically assisted P2G/L fuels. In addition, there is the possible decision to invest in the bio-refinery in Kemi.

The production cost estimate for renewable diesel fuel is approximately 1,000 to 1,200 €/toe (0,82 to 0,98 €/litre) depending on the raw material. As the number of plants increases, the costs lower according to a learning curve. New technologies of producing advanced biofuels have been commercialised slowly in the EU and the rest of the world. The implementation of the development scenario calls for rapid decisions regarding the 2030 policy framework and instruments. In addition, a rise in risk finance is necessary for the development of and investments in innovative and advanced renewable transport fuels as well as electric vehicles and charging infrastructure.

Finland's wood and other biomass resources allow for the realisation of the 'development' scenario. However, competition between refining locations as well as between electricity and heat production has intensified to the extent that at least regional conflicts may arise. More detailed reports about the subject can be found in the publications of the Prime Minister's Office.

Furthermore, advanced biofuels or their raw materials can be imported which is setting a competition limit for additional production in Finland. Also, different modes of promoting low carbon mobility compete and complete with each other in the national 2030 policy measures.

The price effects of alternative technologies

There are considerable uncertainties affecting the costs of transport in 2030. A substantial part of these are beyond our influence. The most important uncertainties are:

- crude oil price, which also affects the tax-free market prices of fossil fuels
- price development of biofuel raw materials and production, affecting the tax-free production costs of these fuels
- price development of vehicles, especially electric cars
- development of energy consumption of vehicles
- carbon pricing and taxation in general

The tax decisions regarding transport in Finland have a significant impact on the proliferation of alternative propulsion options towards 2030. In accordance with the original report, this update does not take a position regarding the instruments and measures needed for reaching the targeted levels of alternative vehicles.

Cost effects were assessed by analysing fuel prices and examining the overall costs of alternative technologies. Cost calculations were executed for passenger vehicles (all propulsion alternatives) and buses (diesel and gas fuels).

Figure 0.1 presents the end-user price structure for fuels in 2017. According to the current Distribution Obligation Law, the distributors are obliged to deliver a certain quantity of biofuels to the markets. It is up to operators to decide, for example, how the obligation is divided between different fuels and distribution points. For this reason, it is not possible to draw direct correlations between the pump prices and the real prices of biofuels. The cost of the biocomponent may be divided to a largest quantity of fuel, and, for example, the current 0.15 €/litre higher pump price of 100% renewable diesel now on the market probably mainly indicates the extra cost from special logistics needed for an additional grade of fuel.

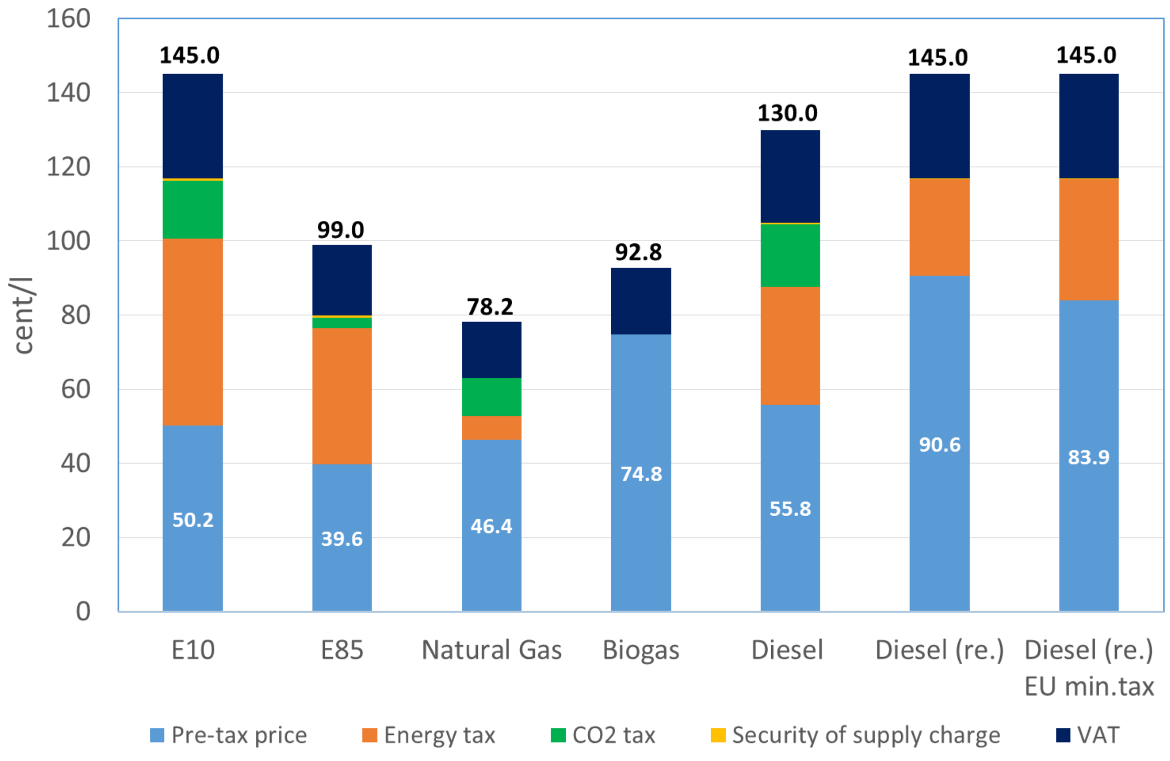

Figure 0.1:. Break-down of pump price in January 2017. The price of 0.99 €/litre for E85 fuel equals approximately 1.40 €/litre as petrol equivalent. Natural gas and biogas prices are presented as petrol equivalents. Diesel (re.) stands for renewable diesel.

Figure 0.2 shows what the pump prices of January 2017 would mean translated into tax-free energy prices.

When used as a component, the taxation of renewable double-counted paraffinic diesel fuel corresponds to approximately half the tax rate fossil diesel (0.26 €/litre and 0.53 €/litre, respectively). However, EU's minimum tax for diesel fuels (0.33 €/litre) has to be imposed even on 100% pure renewable diesel. Present taxation in Finland is less stringent for natural gas, biogas (no energy tax at all) and electricity than other fuels. With regard to passenger cars, the situation is partly levelled by tax on driving power, but this is not applicable to heavy goods vehicle traffic.

It is possible to estimate the actual costs of biofuels on the basis of production costs, on the one hand, and quoted prices of bio-components, on the other. Production costs of biofuels have estimated at approximately 1000 to 1200 €/toe; the prices derived from product prices and quoted prices support this estimation.

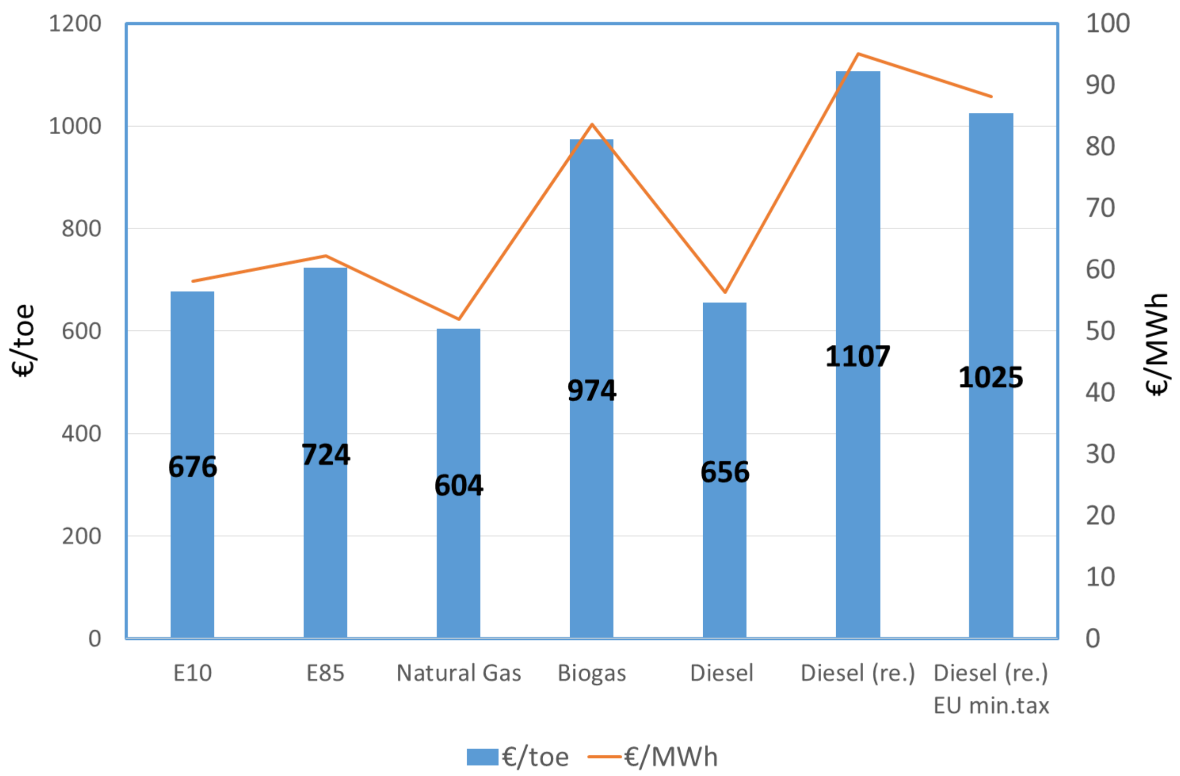

Figure 0.2: Tax-free pump prices of different fuels in proportion to energy content. Diesel (re.) stands for 100% renewable diesel. Compression to distribution pressure (200 bar) is included in gas prices.

Table 0.1 presents a calculation of pump prices at different levels of carbon taxation and different price levels of renewable diesel. Case A has been calculated using present taxation (carbon tax 62 €/tonne) of diesel fuel with no bio-components. Cases B and C do not include bio-components either. Cases D and E include prices of different bio-components and present tax level. In Cases B and C, the carbon tax has been adjusted so that B and D as well as C and E arrive at the same pump price in pairs.

By comparing the pump price in Figure 0.1 (1.30 €/litre) and Case A in Table 0.1, it seems that 15% share of bio-component in diesel raises the price by approximately 5 cents/litre compared to fossil diesel.

According to Table 0.1, depending on the bio-component, the pump price for 100% renewable diesel at present tax rates is 11 to 31 cents/litre more expensive than fossil diesel. If the carbon price was raised to a level from 88 to 139 €/tonne, the pump prices would become even.

The implementation of emissions reduction objectives requires that, by 2030, the diesel pool includes approximately 40% share of bio-component, because presently the petrol pool is not able receive large quantities of bio-components that contain oxygen (ethanol, ethers). Based on Table 0.1, diesel fuel that contains 40% of bio-components should cost 1.36 €/litre, with the tax-free price of the bio-component at 1,200 €/toe (1,260 €/tonne). At present, in early

February 2017, the pump price for diesel fuel with bio-components is at approximately 1.30 €/litre.

According to VTT's LIISA calculation system (a system for calculating exhaust emissions from road transport in Finland), the fuel consumption of lorries in Finland in 2015 was approximately 1.1 Mt, or about 1.3 Mm^3. Heavy goods vehicle transport is altogether commercial transport. Assuming that the bio share of diesel fuels was increased from the present 15% to 40%, the pump price would rise 0.10 €/litre (from 1.30 €/litre to 1.40 €/litre). This would incur no more than an approximated 130 million euros additional costs to the heavy goods vehicle transport annually. This is what happens if the taxation remains at present level. However, the trend is probably that the carbon tax on fossil fuels or prices of emission allowances will rise in order to reduce emissions, which will reduce the cost gap.

Table 0.1: Pump prices for diesel and renewable diesel; the variables are the price of the bio-component and the CO_2 tax. Columns A, D and E have been calculated with present taxes.

	Fossil diesel			Renewable diesel	
	A	B	C	D	E
CO2 price €/t	**62**	**88**	**139**		
Pre-tax price €/t	560	560	560	**1050**	**1260**
Pre-tax price €/l	0,466	0,466	0,466	0,819	0,983
Energy tax €/l	0,3277	0,3277	0,3277	0,2595	0,2595
CO2 tax €/l	0,1990	0,282	0,446		
Supply security charge €/l	0,0035	0,0035	0,0035	0,0035	0,0035
Taxes combined €/l	0,5302	0,614	0,777	0,263	0,263
Price excluding VAT €/l	0,996	1,080	1,243	1,082	1,246
VAT €/l	0,239	0,259	0,298	0,260	0,299
Pump price incl. taxes €/l	1,24	1,34	1,54	1,34	1,54
Extra price A compared				0,11	0,31
Extra price B compared				0,00	0,21
Extra price C compared				-0,20	0,00

In the 2015 report, a well-to-wheel (WTW) review was undertaken regarding carbon dioxide emissions of different propulsion alternatives. Volkswagen Golf was used as a case study (Figure 5 in the original report), because of its wide range of propulsion alternatives. For the update, the alternatives for cost comparison were picked from the catalogue published in September 2016, with a view on getting as close comparability as possible. The 85 kW petrol engine, with a price tag of €24,975 (including tax), was selected as the benchmark. The most expensive alternative was a plug-in hybrid costing €41,991.

The estimated annual costs for each propulsion alternative were based on the sales catalogue. Calculations were made for a five-year period and two different annual mileages (17,000 km per year and 30,000 km per year). In addition, the review was made either with a fixed residual value percentage (40%) or a fixed residual value (€10,000). Applying a fixed sum aims at taking into account that battery life is limited, after all. Presently, the guarantee for batteries is usually up to eight years, and it is likely that the batteries need to be replaced once in the vehicle's lifetime. There may also emerge different battery pricing models for different consumer groups (e.g. leasing). In fact, Renault already provides such service for customers in France. Pump prices in Figure 0.1 have been used as fuel prices in the calculations.

With energy tax, vehicle tax, driving power tax, and car (registration) tax taken into account, the present taxation model favours gas and electric cars. In the case study, the car tax applied for the petrol car (€4,200) is more than double compared to the battery electric alternative (€1,700).

Figure 0.3 presents the annual costs for mileage of 17,000 km per year and fixed residual value, which is the most unfavourable situation for the battery electric car. In Figure 0.4, the annual cost is calculated for mileage of 30,000 km per year and fixed residual value percentage (40%), which is the most favourable case for battery electric cars.

Plug-in hybrid vehicles are the most expensive (8,100 to 10,300 €/a) alternative regardless of the situation, with the battery electric vehicles being the second most expensive (7,400 to 9,000 €/a). For these alternatives, the residual value type accounted for 1,200 to 1,300 €/a. Increasing the mileage from 17,000 to 30,000 km has only limited impact on the annual costs, approximately 300 to 900 €/a.

With an annual mileage of 17,000 km, the petrol car is the cheapest alternative (5,900 €/a). The range of costs for combustion engine vehicles is 5,900 to 6,400 €/a.

With an annual mileage of 30,000 km and fixed residual value percentage, natural gas is marginally the least expensive option, costing 7,100 €/a. The cost range for combustion engine cars is 7,100 to 7,800 regardless of the residual value. An increase in mileage increases the costs by 1,200 to 1,400 €/a.

With a mileage of 30,000 km/a, the gap between the battery electric car and the most expensive combustion engine vehicle (flex-fuel) is just 200 to 1,300 €/a depending on the residual value.

A very optimistic review was also made in which the price of battery electric cars was assumed very similar to petrol vehicles (approx. 25,000 €) and the residual value in euros was the same as that of petrol vehicles (10,000 €). In this calculation, with the mileage 17,000 €/a, the battery electric vehicle is the cheapest option, costing 4,900 €/a as opposed to 5,900 €/a cost of the petrol vehicle. If the purchase price and the resale value of battery electric vehicles are equal to petrol vehicles and the taxation of electric cars remains at a lower rate than combustion engine vehicles' taxation, battery electric vehicle would be by far the least expensive alternative for consumers.

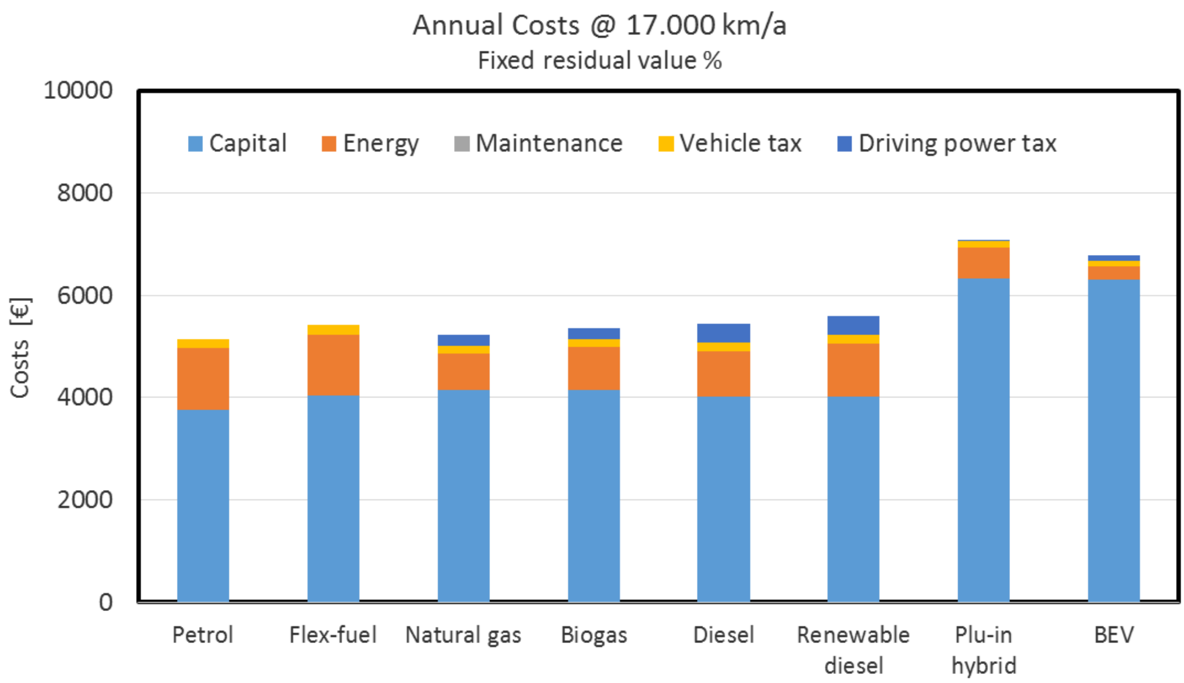

Figure 0.3: Annual cost with a fixed residual value and 17,000 km/a mileage.

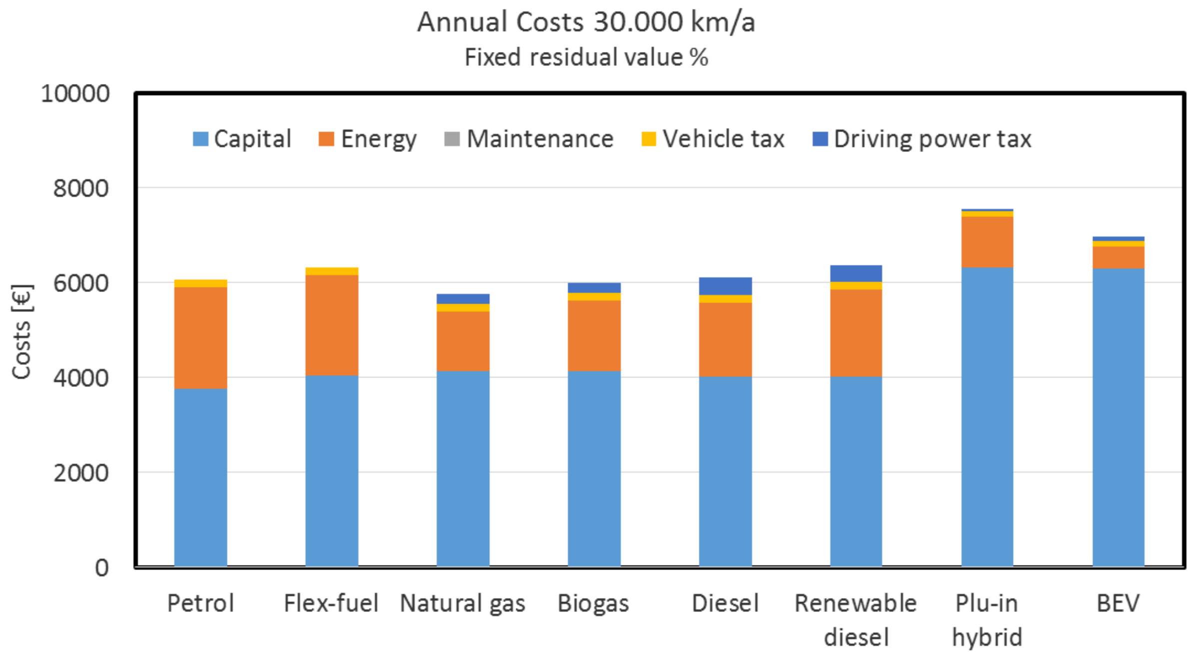

Figure 0.4: Annual cost with a fixed residual value percentage and 30,000 mileage.

Figure 0.5 shows the price of avoided CO_2 tonne with different residual values and mileages. A fossil fuel-based petrol vehicle was used as a point of reference.

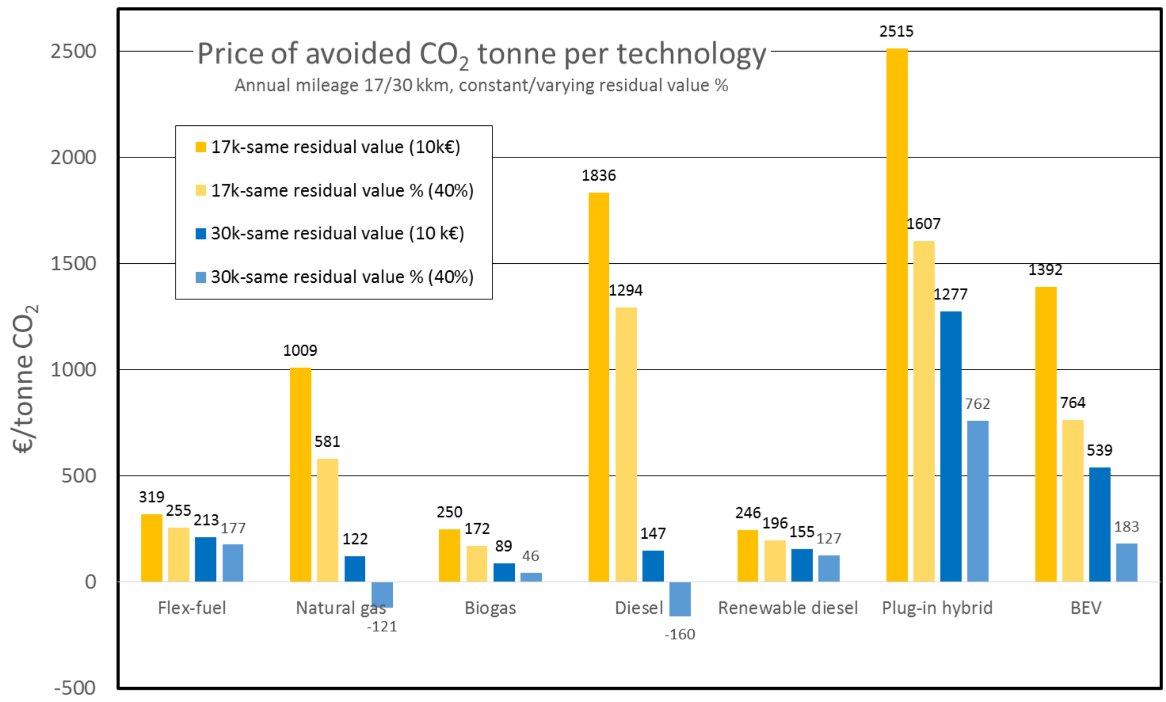

Figure 0.5: Cost of avoided CO_2 tonne with different residual values and mileages. A fossil fuel-based petrol vehicle was used as a point of reference.

According to this survey, the price of CO_2 tonne which has been avoided with biofuels is in the range of 50 to 300 €. The plug-in hybrid vehicle is the least cost-efficient alternative in all situations, with a price tag of 800 to 2,500 € per avoided CO_2 tonne. With the cost range at 200 to 1,400 € per CO_2 tonne, the battery electric vehicle performs much better. The cost efficiencies of natural gas and diesel are highly affected by the annual mileage, with price range of -100 to +1,800 € and -200 to +1,800 € per avoided CO_2 tonne, respectively. As regards diesel cars, the air quality impacts must also be taken into account.

With petrol vehicle as the reference point, it needs to be taken into account that switching to fossil diesel or natural gas will not enable significant reduction of carbon emissions, because, being based on improvement of energy efficiency alone, the potential is not sufficient.

As regards heavy goods vehicle traffic, urban buses were under examination. The examined alternatives were diesel, renewable diesel, natural gas and biogas. VTT has a lot of measured data on buses which could be used in the calculations. The calculations require performance data proportionate to mileage, such as fuel consumption in litres per 100 km and emissions data as grams per kilometre. Vehicle manufacturers do not usually publish performance data in these formats.

VTT has also assessed the costs of electric buses. There are, however, uncertainties related to electric buses and electric bus systems, such as battery life or vehicle and charging infrastructure prices, which resulted in not including buses in this review. However, according to an assessment by Pihlatie et al., electric buses (city buses) may already be competitive compared to diesel buses even without any incentives or other special support measures. The on-going field trials will confirm the accuracy of the assessments in the next few years.

The diesel and gas bus calculations were conducted using mileages of 40,000 and 80,000 km/a. The result for 80,000 km/a mileage in Figure 0.6 is interesting. The applied calculation parameters give nearly identical kilometre costs for diesel and natural gas; similarly, renewable diesel and biogas also give nearly identical costs. When reviewing the results, it must be taken into account that taxation of natural gas is lower compared to diesel and that there is no energy tax for biogas. Lower mileage (40,000 km/a) weakens the competitiveness of gas vehicles.

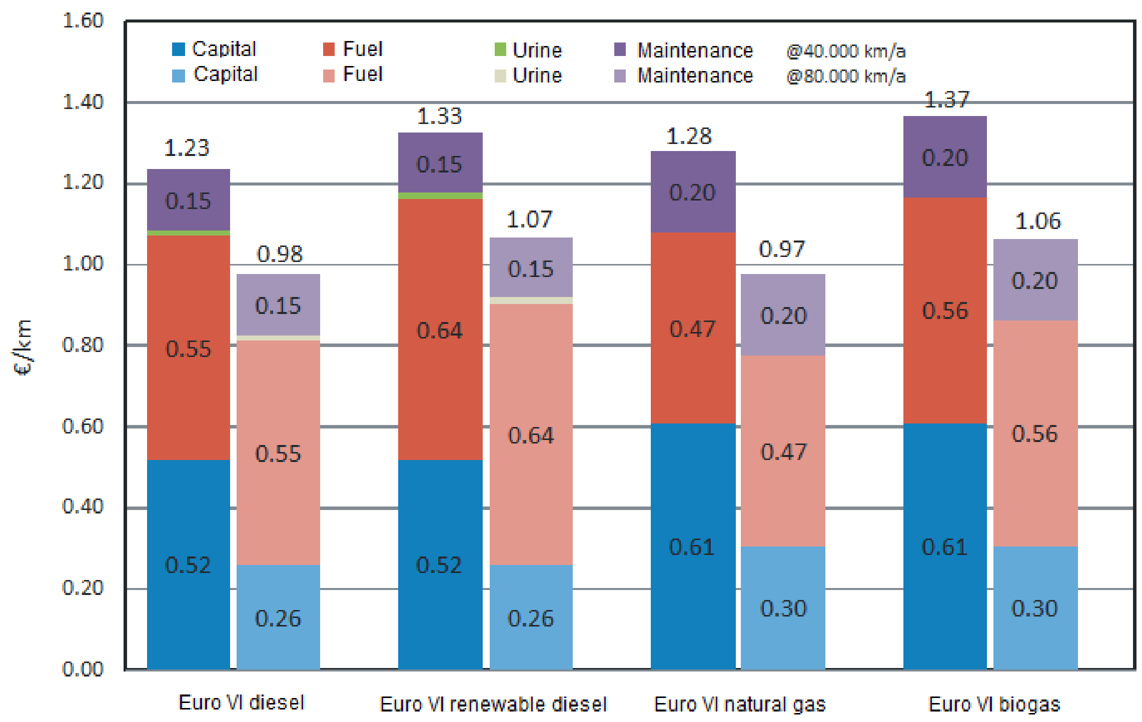

Figure 0.6: Costs per kilometre for buses, with different fuel alternatives. Mileages 40,000 or 80,000 km/a.

Figure 0.7 shows the price of avoided CO_2 tonne per mileages of 80,000 km/a, or 40,000 km/a. The price of avoided CO_2 tonne with biofuels is approximately 100 €, with the impact of mileage on the price being minimal. For natural gas, the impact of mileage on the price of avoided CO_2 is critical. The CO_2 emissions measured from the tailpipe are marginally smaller for natural gas (-5%) than for diesel; with the mileage of 80,000 km/a, the natural gas vehicle is 0.01 €/km cheaper than diesel, resulting in the price of carbon reduction becoming negative. With an annual mileage of 40,000 km, the kilometre cost of natural gas is 0.05 €/km higher than diesel due to the more expensive car; the price of avoided CO_2 tonne is approximately 900 euros.

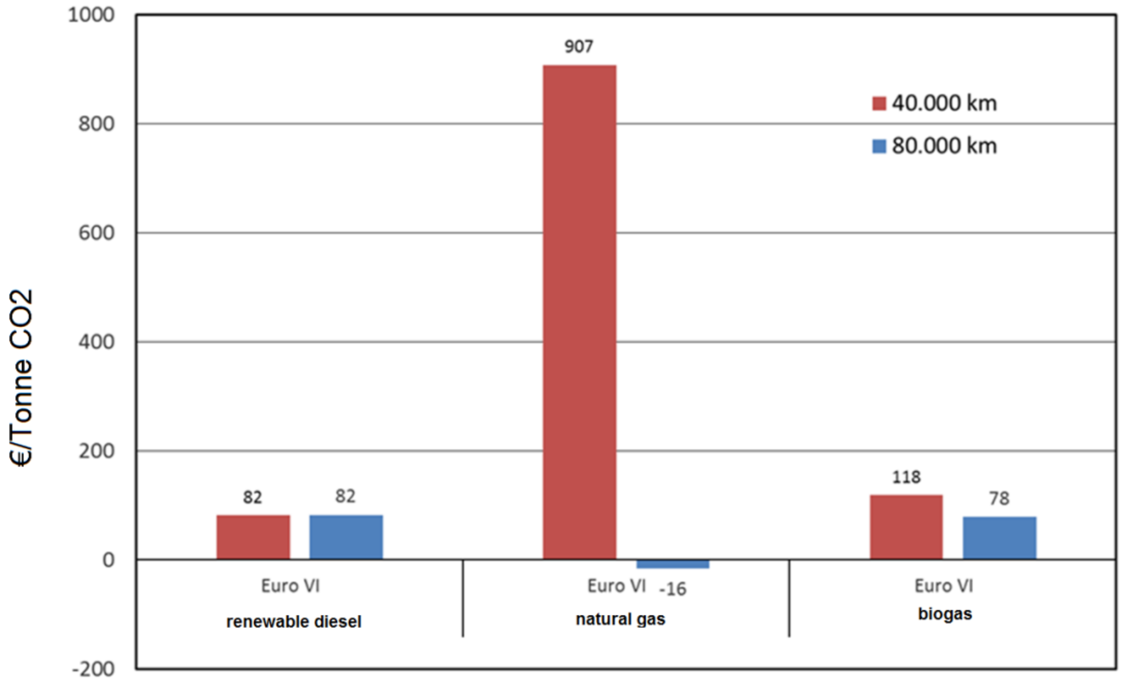

Figure 0.7. The cost of avoided CO_2 tonne for a bus with a typical annual mileage of 80,000 km as well as with an alternative mileage of 40,000 km/a.

Impacts on the economy

The impacts on national economies were assessed and calculated using the general equilibrium model as in the original report in 2015. In order to retain comparability, the basis for this assessment, i.e. the national economy projections, were not altered. Instead, the update concentrates on assessing the transport emissions reduction criteria.

In different transport scenarios, changes in vehicle fleet, consumption of fuels and electricity, and production of indigenous fuels are carried out in relation to the economic baseline. In the national economy assessment, these changes were taken as a given, and focus was directed on multiplier effects resulting from the changes.

The possible changes required in vehicle taxation and user charges resulting from changes in vehicle fleet were not evaluated separately. Instead, it was assumed that the changes take place as proposed in the scenarios in question. The amount of public support which biorefineries may require was not evaluated here either. Moreover, the review assumes that the impact of changes in fuel and vehicle tax revenues on the economy will be compensated with higher commodity taxes aimed at overall consumption. In practice, this would mean increase in value added tax, for example. As a consequence, changes in vehicle fleet and driving power products would not alter the overall tax revenue. It is assumed in all scenarios that other economic drivers will remain the same.

Figure 0.8 examines the differences in scenarios from the viewpoint of growth contribution of demand components in the national economy. In all reviewed scenarios, liquid biofuels (in addition to other technologies) are used in order to achieve the 40 percent emissions reduction. Also, in all scenarios, the use of biofuels will increase from the 2020 level. Increasing the number of electric vehicles reduces the demand of biofuels.

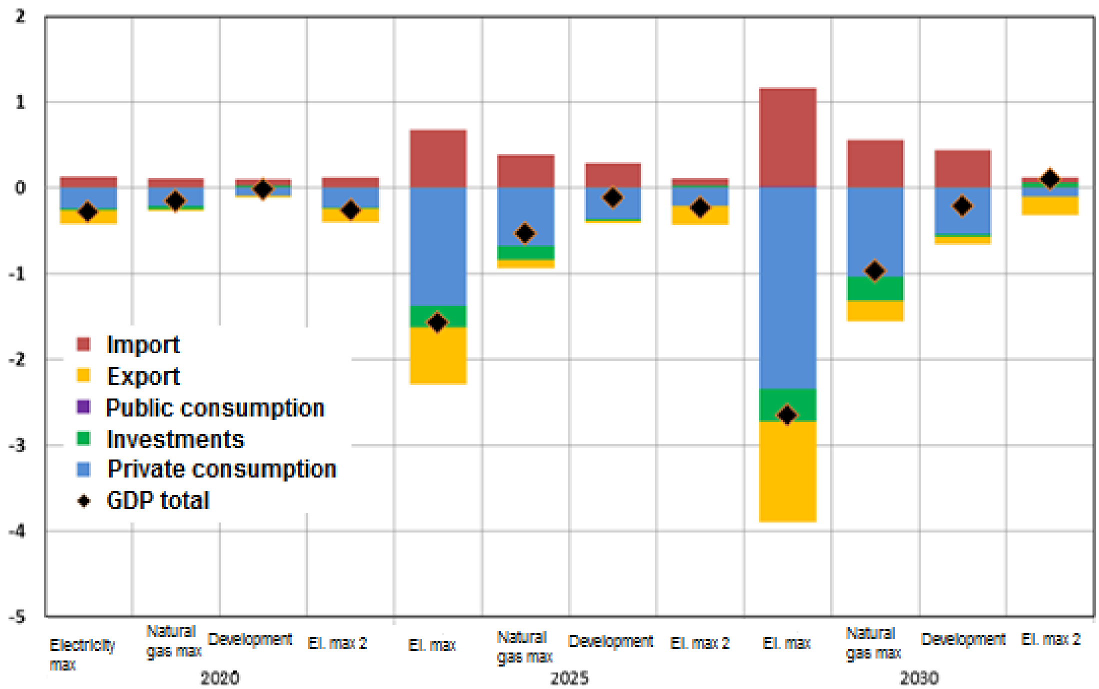

Figure 0.8. The impact of different scenarios on demand components of economy and the overall change in GDP.

There were two versions made of ‘electricity max’ scenario, differing in regard to price developments of electric vehicles. The basic version of ‘electricity max’ scenario predicts that, in 2030, electric vehicles are still more expensive than combustion engine vehicles. In the ‘electricity max 2’ version, the price of electric cars is at the same level with combustion engine cars as early as 2025.

As regard the differences in the scenarios, price developments of new cars are relevant, even if investments in the infrastructure will alter the differences to some extent.

In both the ‘natural gas max’ and the basic version of ‘electricity max’, the additional cost will first and foremost reduce consumer demand, which explains half of the reduction in GDP compared to the baseline. The reduction of imports is partly explained by reduction in consumption; it is also partly affected by a decrease in exports (which results in a decrease in the imports of intermediate products as well). The reduction in consumption is mainly caused by the increasing prices of fuels and cars, which weakens the purchase power of the consumers. In the ‘development’ scenario, the weakening of purchase power is affected by fuel prices rather than car prices. The ‘electricity max 2’ scenario presumes that the price gap disappears altogether, resulting in minimal impacts on consumer demand.

In the ‘natural gas max’ scenario, the additional cost for a singular vehicle is smaller than in the basic version of the ‘electric max’ scenario, but the estimated cost of Finnish biogas production has been revised compared to the earlier version. The assumption here is that the production costs of biogas will rise, when, due to increasing production, more expensive production processes and feedstocks have to be adopted. In practice, this will take place when the gas-fuelled fleet will exceed 50,000 vehicles.

The Finns cannot have much influence on the price development of electric passenger cars. Finnish companies and Finnish research are, however, at the forefront of development in biofuels, and choices made in Finland can influence the development. With regard to electric vehicles, the calculations indicate that it would be feasible to commence possible measures for promoting electric vehicles only after the prices have gone down and the performance of the vehicle batteries has improved (the situation stated in the ‘electricity max 2’ scenario).

As regards the intermediate consumption of the whole economy, the share of road haulage (both marginal and intermediate consumption) is less than one percent, and a half percent of the overall costs. There are big differences between different sectors: the share of many labour-intensive public services of intermediate consumption is three to four percent, whereas the share of almost all industrial sectors is smaller. The share of road haulage rises to between one and four percent of the intermediate consumption mainly in mining and excavation industry, forest industry, chemical industries, and in some parts of processing of metals; and it is related to the value chains of these sectors in which the domestic haulage of raw materials is necessary. Many sectors use transport fuels as an intermediate products, but their share has not been taken into account here.

Estimate of the situation in 2050

Even if the main purpose of this report is to compare different alternatives regarding the situation in 2030 and to aim at achieving the goals set for the reduction of greenhouse gas emissions by that time, the review, with regard to ‘electricity max’ scenario, has been extended until 2050. This was done in order to investigate the possibilities of achieving the 80 to 90% reductions of greenhouse gas emissions in road transport by 2050, as a continuum to the range of measures of 2030.

The assumption in extending the ‘electricity max’ scenario until 2050 was that, from 2030 on, all new passenger vehicles and vans would be electric; in other words, combustion engines would either be completely ‘banned’ in these vehicle types or they would be too expensive to be purchased. Moreover, the use of electricity in heavy goods vehicles would increase gradually by 2050 so that two thirds (67%) of smaller lorries without trailers would be electric and the rest equipped with a combustion engine; and the share of electric versions in heavier semi-trailer tractors would be 50% and the rest would run on combustion engines.

Even if this was not considered a very realistic future, the calculation was aimed to define the quantity of vehicles requiring liquid fuels left in 2050. Because the plants manufacturing bio and renewable fuels are big investments with an average operational life of 20 to 30 years, it was necessary to assess the level of domestic demand in 2050 for the products they manufacture.

On such assumptions, regardless of the electrification of passenger cars and vans being fairly far advanced by 2050, there are nevertheless nearly half a million petrol or diesel passenger vehicles and vans left in 2050. This somewhat surprising result derives from the vehicles’ long lifetime and high scrapping age which are typical of Finland; with present taxation, the scrapping age of passenger cars is almost 20 years and the lifetime of heavy goods vehicles is typically also over 20 years. This is, however, strongly affected by vehicle taxation model: if vehicle taxation was shifted from acquisition to usage, the time for taking old cars off the roads would certainly be shorter. Moreover, by 2050, the whole passenger vehicle and van fleet could be electric.

In addition to the above-mentioned, the fleet would include less than 100,000 heavy-duty diesel vehicles, as it could not be assumed that it is possible to electrify all heavy duty vehicles already by 2030. By 2050, however, the share of electricity could be significant for different technologies, such as fuel cells platforms that use hydrogen or electricity derived from an overhead wire as with trolley buses, at least on main road sections.

Table 0.2 summarises the overall fuel demand in the ‘electric max’ scenario for 2030 and 2050. It indicates that over 1 million toe/a of diesel fuels are still needed in 2050. Similarly, the same amount of renewable diesel that is estimated to equal the demand of drop-in diesel when aiming for the 40% carbon reduction by 2030 would enable to reduce emissions to the level of more than 80%.

Table 0.2. Fuel demand in 2030 and 2050 according to the ‘electricity max’ scenario. In order to achieve a more substantial carbon reduction, the amount of biofuels has been raised in the columns marked with a plus sign (+.)

Total	**2030**	**2050**
	ELECTRICITY MAX+	**ELECTRICITY MAX+**
Fossil petrol toe/a	**674 779**	**86 902**
Fossil diesel toe/a	**1 603 463**	**536 187**
Renewable diesel toe/a	**718 101**	**718 101**
Ethanol toe/a	**49 721**	**14 343**
Biogas toe/a	**41 537**	**219 105**
Electricity toe/a	**204 637**	**900 175**
Hydrogen toe/a	**0**	**0**
Renewables total	**1 014 073**	**1 851 723**
Share of renewables (%)	**30.8 %**	**74.8 %**
Energy total toe/a	**3 392 315**	**2 474 812**
Energy total; relative to BASIC 2030 (%)	95 %	71 %
CO_2 emissions (tonnes/a)	**7 036 101**	**1 928 896**
CO_2 emissions reduction (%) cf. year 2005	-40 %	-84 %
Bio share in diesel (vol-%)	32.0 %	57.3 %
Ethanol in petrol (vol-%)	10.0 %	20.0 %
Biokaasun osuus metaanista (%)	100 %	100 %
Biogas GWh/a (1 toe=11,63 MWh)	**483**	**2548**
Diesel fuel demand total, toe/a	**2 321 394**	**1 254 288**

It is therefore very likely that there would be demand for the 2030 renewal diesel production capacity for a further 20 years, and, if the bio-share was gradually increased, the 90% reduction of greenhouse gas emissions could be achieved. Moreover, the consumption of air transport would probably even increase the demand and production requirements.