The economic impact of low-carbon vehicles in the Netherlands

Final report for the
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Executive Summary

- The analysis presented in this report has two focuses: 1) the economic impact of a current policy initiatives scenario, under which the Netherlands is expected to surpass EU vehicle emissions targets for 2020 2) the economic impact of two more ambitious targets for decarbonisation of vehicles in the Netherlands in the period up to 2050.
- We use E3ME, an econometric model of the energy system, environment and economy, to model the macro-economic impacts if there is a transition to a higher share of low-carbon vehicles in the fleet. It is important to note that we do not model the policies or drivers that bring about this change.
- In each case, we compare the macroeconomic impacts against a reference scenario in which there is no improvement in the efficiency of new vehicles after 2015.
- Under current policy initiatives, the Netherlands is on course to exceed the EU-wide targets and achieve a new car emissions level of 84g CO_2/km by 2020. If this happens, our analysis shows that by 2030, GDP will be 0.2% higher and there will be a net total of 6,000 more jobs compared to the reference scenario.
- Of the two possible targets for further decarbonisation that we examine, the more ambitious target is similar to one already proposed by the Dutch government, namely that there should be more than one million advanced electric vehicles in the national vehicle stock by 2025. Under this more ambitious target, the analysis presented in this report shows that GDP will be 0.4% higher in 2030 compared to the reference scenario and that there will be a net increase of nearly 25,000 more jobs by 2030 than in the reference scenario.
- The more ambitious target also involves further decarbonisation of the Netherlands vehicle fleet between 2030 and 2050, so that the share of advanced EVs reaches 100% of sales and 97% of the vehicle stock by 2050. If these goals are attained, we project that GDP will be 0.7% higher in 2050 compared to the reference scenario and that there will be a net total of 32,800 more jobs by 2050 than in the reference scenario.
- A further benefit of achieving the more ambitious target is that consumers are better off overall because, over the lifetime of the vehicles, the fuel savings due to improved efficiency outweigh the additional costs of the vehicle technology, and so consumers have more money to spend on other goods and services. This effect, combined with an economic stimulus that boosts levels of employment, leads to a 0.8% increase in real incomes by 2030 and 1.5% increase in real incomes by 2050, compared to in the reference scenario. Consequently, the level of household consumption is 0.8% higher in 2030 and 1.5% higher in 2050 compared to the reference scenario.
- Both scenarios for further decarbonisation suggest economic improvements for two main reasons. First, the demand for new vehicle technologies in the Netherlands and the rest of the EU generates growth in the motor vehicle supply chain, leading to an increase in output and employment. Second, and more important, there is a reduction in demand for oil and consumers will reallocate

their spending to other goods and services, which tend to have a higher domestic content and a higher labour-intensity.

- In the high ambition scenario, there is also €1.2bn annual investment in charging infrastructure by 2050, which boosts demand in the economy and leads to a further increase in output and jobs.
- The cost of the charging infrastructure is ultimately paid for by vehicle owners. Infrastructure in households and workplaces is assumed to be paid for upfront when purchasing a new EV, whilst the public charging infrastructure is paid for by the higher electricity prices charged to EV users.
- Another consequence of improving the fuel-efficiency of the vehicle stock is that total demand for petrol and diesel will fall. However, around 65% of all petroleum refined in the Netherlands is currently exported to Belgium and Germany. Consequently, the impact on the petroleum refining industry will depend mainly on what happens in these external markets.
- Improvements in vehicle efficiency would also bring environmental benefits. Total cumulated CO_2 emissions in the Netherlands could be up to 258 $MtCO_2$ lower over the period 2020-2050 than they would be in the reference scenario.

1 Overview

After lengthy political negotiations, the European Parliament and the Council of the European Union reached agreement in November 2013 to introduce a Europe-wide passenger car emissions target of 95 gCO_2/km by the end of 2020 and to impose penalties on car manufacturers who are not able to satisfy the required restrictions on emissions. This regulation has now been formally accepted as European law[1] and builds on targets already in place which specify that vehicle emissions, as averages across vehicle fleets, should not exceed 130 gCO_2/km by 2015.

In July 2013, Cambridge Econometrics, in collaboration with Ricardo AEA, published the report 'Fuelling Europe's Future'[2], which presented evidence on the effects on the European economy of meeting the European vehicle emissions targets and the economic effects of decarbonising Europe's vehicle fleet further in the period up to 2050. The study, which was informed by stakeholders in the transport sector and experts in the motor vehicles industry, found that decarbonising the vehicle fleet in Europe could have positive consequences for the European economy.

The purpose of the present report is to build on the analysis carried out at the European level in the 'Fuelling Europe's Future' study and to focus specifically on the expected economic impact of low-carbon vehicles in the Netherlands. This report presents modelling results of the macroeconomic effects of meeting, and surpassing, the vehicle emissions targets in the Netherlands by 2020, and the macroeconomic effects of achieving further targets for decarbonisation in the period up to 2050.

The structure of this report is as follows: the remainder of this chapter summarizes progress in vehicle efficiency and the levels of passenger car sales in the Netherlands since 2001. Chapter 2 describes the modelling approach used in this analysis and Chapter 3 provides a detailed description of the scenarios modelled. The following three chapters present the implications of the scenarios for technology costs (Chapter 4), infrastructure costs (Chapter 5) and fuel costs (Chapter 6). In Chapter 7, the macroeconomic results for each scenario are presented and explained, and the expected impact on the petroleum-refining sector in the Netherlands is examined in detail. The final two chapters consider the limitations of our analysis (Chapter 8) and summarise the conclusions that can be drawn from our analysis (Chapter 9). There are also three appendices, which provide more details of the E3ME model, the technology cost assumptions and details of the calculation for the total cost of ownership in each scenario.

Progress in vehicle efficiency in the Netherlands

Compared to other EU member states, the Netherlands has made significant progress since 2007 in decarbonising the domestic vehicle fleet of cars. By 2011, the Netherlands had already surpassed the 2015 target of an average of 130 gCO_2/km of emissions for new vehicles and, by 2012, average new vehicle emissions on the NEDC test cycle basis had fallen to 120 gCO_2/km. This rapid improvement in carbon efficiency was primarily a result of tax incentives to promote the purchase of low-carbon vehicles. For example,

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[1] Regulation (EU) No 333/2014 of the European Parliament. Available online at: http://eur-lex.europa.eu/legal-content/EN/NOT/?uri=uriserv:OJ.L_.2014.103.01.0015.01.ENG

[2] Cambridge Econometrics and Ricardo AEA (2013), 'Fuelling Europe's Future'. Available online at: http://www.camecon.com/EnergyEnvironment/EnergyEnvironmentEurope/FuellingEuropesFuture.aspx

Vehicle Registration Tax in the Netherlands is now based completely on vehicle CO_2 intensity, and petrol vehicles that emit less than 111 gCO_2/km and diesel vehicles that emit less than 96 gCO_2/km[3] are exempt from both Vehicle Registration Tax and Annual Motor Tax. Tax incentives for fuel-efficient vehicles have also led to reductions is the average engine size and weight of new vehicles sold in the Netherlands. With an engine size of 1,438 ccm and a gross weight of 1,714 kg[4], the average new vehicle sold in the Netherlands is among the smallest and lightest in the EU.

Tax incentives also partly explain why the Netherlands is now at the forefront of the transition to more efficient powertrain technologies. This leading position is seen in the fact that Hybrid Electric Vehicles (HEVs) and Battery/Fuel-cell Electric Vehicles (BEVs/FCEVs) accounted for 3.6% and 0.8%[5] respectively of new vehicle sales in 2012, compared to Europe-wide averages of 0.9% and 0.2%. The transition to the use of low-carbon electric vehicles in the Netherlands has also been helped by large investments in EV charging infrastructure. By the end of 2013, over 3,500 public charging points had been installed[6] in the Netherlands and the first hydrogen station had been built[7].

Figure 1 shows historical average new vehicle emissions (based on the NEDC test-cycle) in the Netherlands and a number of comparator countries. The new vehicle fleet in the Netherlands has been decarbonised more rapidly than in any other EU member state and, although new vehicle emissions in the Netherlands were among the highest in the EU in 2001, they are now among the lowest.

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[3] Kok, R. (2011), ‘The effects of CO2-differentiated vehicle tax systems on car choice, CO_2 emissions and tax revenues’. Available online: www.abstracts.aetransport.org/paper/download/id/3686

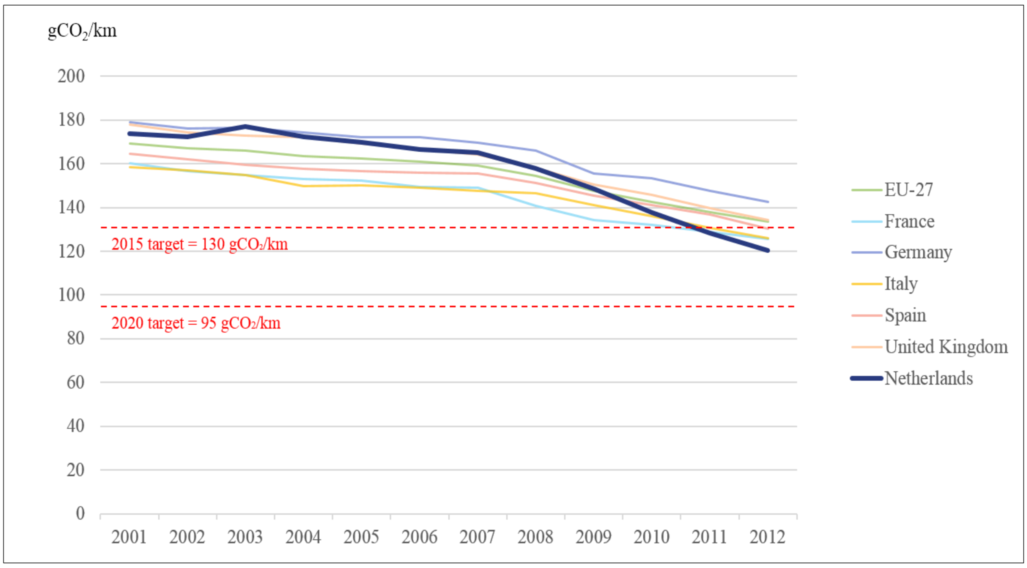
[4] The International Council on Clean Transportation (2012 data)

[5] The International Council on Clean Transportation (2012 data)

[6] ‘Rijksdienst voor Ondernemend Nederland’ (2013). See: http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/energie-en-milieu-innovaties/elektrisch-rijden/stand-van-zaken/cijfers

[7] http://www.ngvjournal.com/en/stations/item/14448-new-hydrogen-fueling-station-and-bus-concept-launched-in-the-netherlands?utm_source=emBlue%20Email%20Marketing%20emBlue_Newsjournal10-01-2014&utm_medium=Email&utm_campaign=emBlue%20emBlue_Newsjournal10-01-2014%20-%20Oferta:2272173

Figure 1: Average new passenger car emissions in the Netherlands and comparator countries (NEDC test-cycle basis)



Source: The International Council on Clean Transportation (2014).

The reduction in new vehicle emissions in the Netherlands could become even faster in the period to 2030, if the ambitious national targets set by the Dutch government were to be achieved. The government's target is to have 200,000 Electric Vehicles (EVs) in the stock by 2020, and 1,000,000 by 2025. Since the Netherlands already has one of the highest densities of charging points per electric vehicle in the EU, and the government is committed to a rapid increase in the number of public charging posts, the Netherlands is becoming an attractive environment for EV ownership.

Vehicle sales and industry output

In 2012, sales of vehicles in the Netherlands accounted for approximately 5%[8] of total vehicle sales in the EU-27. Partly because of the recession, there was a sharp fall in vehicle sales in the Netherlands in 2009. However, since 2009, growth has picked up, as shown in Figure 2. This trend in domestic vehicle sales is also largely reflected in gross output in the car manufacturing industry in the Netherlands.

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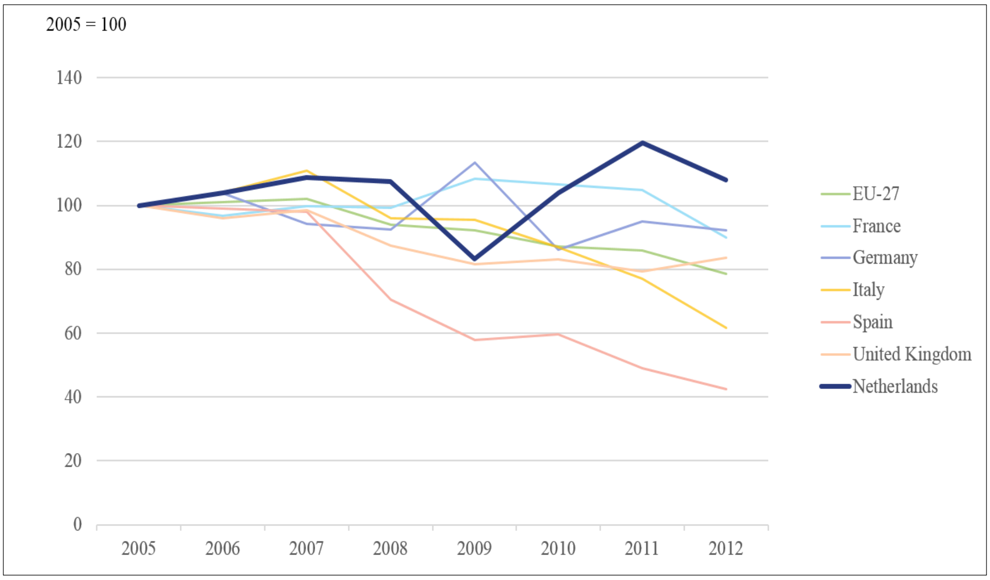
[8] The International Council on Clean Transportation (2014)

Figure 2: Growth in passenger car sales in the Netherlands and comparator countries



Source: The International Council on Clean Transportation (2014).

Reporting conventions

All euro figures presented in tables, charts and text in this report have been converted to the 2010 price base.

Key abbreviations used in this report include:

- ICE – Internal Combustion Engine
- HEV – Hybrid Electric Vehicle
- PHEV – Plug-in Hybrid Electric Vehicle
- BEV – Battery Electric Vehicle
- FCEV – Fuel-cell Electric Vehicle
- EV – Electric Vehicle (i.e. includes PHEVs, BEVs and FCEVs)
- GDP – Gross Domestic Product
- GVA – Gross Value Added

2 Approach

This study compares the macroeconomic impacts of three different scenarios with different levels of light-duty vehicle decarbonisation to the macroeconomic impacts of a reference scenario. In the reference scenario, there is no reduction in new vehicle emissions after 2015 and the 2020 Europe-wide emission targets, which have now been formally accepted into European law, are not met. The reference scenario is therefore, to some extent, unrealistic and implausible as a future outcome. It is representative of a state in which no progress is made to improve future vehicle fuel efficiency. The reference scenario was defined in this way in order to assess the economic impact of the recently legislated vehicle emission targets for 2020, as well as higher ambition targets. The three comparison scenarios all meet the proposed Europe-wide emissions targets[9] for new vehicles, but there is a considerable difference in the levels of reduction of vehicle emissions achieved in each scenario over the period 2020-2050.

The emissions reduction in each of the three comparison scenarios is achieved through a combination of more fuel-efficient technologies and more efficient types of powertrain. Examples of more fuel-efficient technologies include start-stop technology, low rolling resistance tyres, aerodynamic improvements and light-weighting. The more efficient types of power train are primarily Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEV), Battery Electric Vehicles (BEV) and Fuel-cell Electric Vehicles (FCEV). The scenarios are described in more detail in Chapter 3.

Our analytical approach combines a bottom-up model of the vehicle stock in the Netherlands and a top-down econometric modelling approach to estimate the macroeconomic impacts of the mix of vehicle technologies defined in each of the scenarios.

The bottom-up vehicle stock model

Cambridge Econometrics' vehicle stock model for the Netherlands uses historical data for vehicle sales by powertrain type in order to model the characteristics of the current and future vehicle stock in the Netherlands. Data for average new vehicle efficiency and new vehicle costs are used to calibrate the model. In order to model the evolution of the stock over time, there are additional assumptions about the lifetime of vehicles and the average number of kilometres driven per year. We also make assumptions about the fuel-efficient technologies that will be integrated into new vehicles, the cost of these technologies and the associated impact these technologies will have on fuel demand.[10] The vehicle stock model is used for analysis of changes in the cost and fuel consumption of passenger cars. Efficiency improvements in vans are based on European averages from the 'Fuelling Europe's Future' report[11], and we do not model any improvements to the fuel-efficiency of buses, HGVs, or other modes of transport. The main assumptions, inputs and outputs of the vehicle stock model are shown in Table 1.

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[9] In line with current trends, the European target is surpassed in the Netherlands, where average new vehicle emissions reach 84g CO2/km in each of these scenarios in 2020.

[10] The improvements in fuel-efficient technology that were used in this study were taken from 'Fuelling Europe's Future' (CE, 2013).

[11] Cambridge Econometrics and Ricardo AEA (2013), 'Fuelling Europe's Future'. Available online at: http://www.camecon.com/EnergyEnvironment/EnergyEnvironmentEurope/FuellingEuropesFuture.aspx

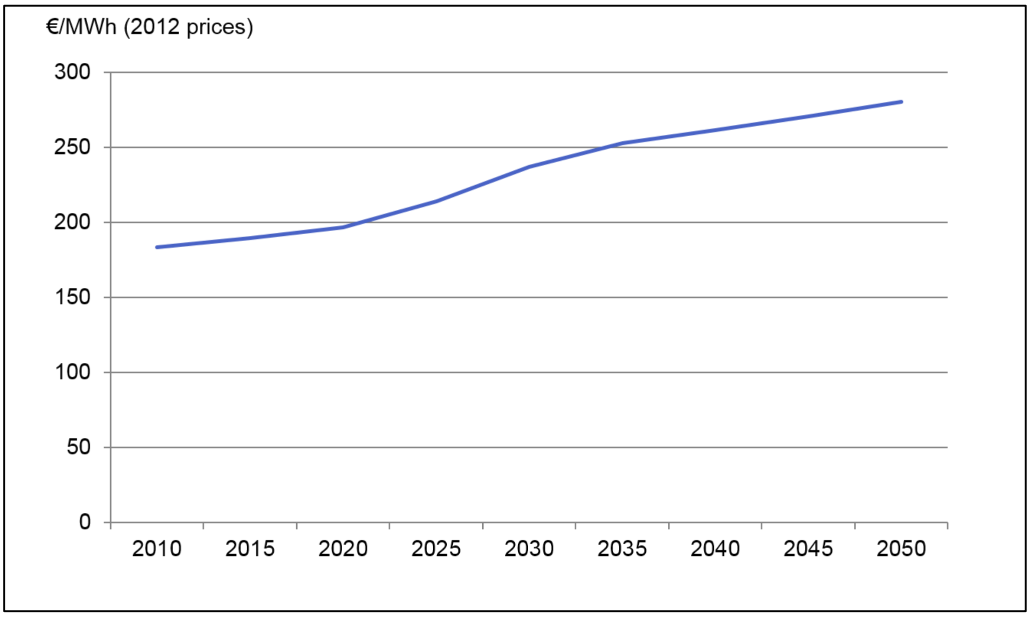
Table 1 Key assumptions, inputs and outputs from the vehicle stock model

Key assumptions	**Value/comments**
Average distance travelled per year	Based on data from BOVAG (2013), we assume 13,317 km travelled per year, on average over the projection period. This assumption does not vary across powertrain type.
Average vehicle lifetime	We assume an average lifetime of 16.5 years (with a standard deviation of 4 years) in the projection period for all powertrain types. This assumption is based on data from BOVAG (2013).
Annual vehicle sales	We assume that total vehicle sales in the Netherlands remain constant at 491,450 per annum over the projection period. This assumption is the same in all scenarios.
Characteristics of the current vehicle stock	Based on sales data for 1980- 2012 sourced from the ICCT (2013) and BOVAG (2013).
Electricity price	The electricity price is taken from Scenario 4 in the EC's Energy Roadmap, in which 80% of power generation is from renewable sources by 2050. It is assumed that EV users will be charged the same price for electricity as households. Refer to Figure 3.
Oil price	Oil prices are based on central projections from IEA (2013). Refer to Figure 4.
Average vehicle emissions in the rest of the EU	For each scenario, we assume that vehicle emissions in the rest of the EU follow a similar path to average vehicle emissions in the Netherlands, but, consistent with current trends, EU average new vehicle emissions are always assumed to be slightly higher than in the Netherlands.
Technology costs	Refer to Chapter 4 and Appendix B.
Inputs	
New vehicle sales mix by powertrain type	Scenario specific (refer to Chapter 3). Based on the scenarios used in the 'Fuelling Europe's Future' report.
The uptake of fuel-efficient technologies in new vehicle sales	Scenario specific (refer to Chapter 3). The uptake of various fuel-efficient technologies is based on uptakes in the equivalent scenarios from the 'Fuelling Europe's Future' report.
Outputs	
Average cost of new vehicles	Determined by: • the share of various powertrains in the sales mix and stock • the quantity of efficient technologies installed in conventional ICEs in the vehicle sales mix and stock
Fuel consumption of the vehicle stock, by fuel type	

Energy price assumptions

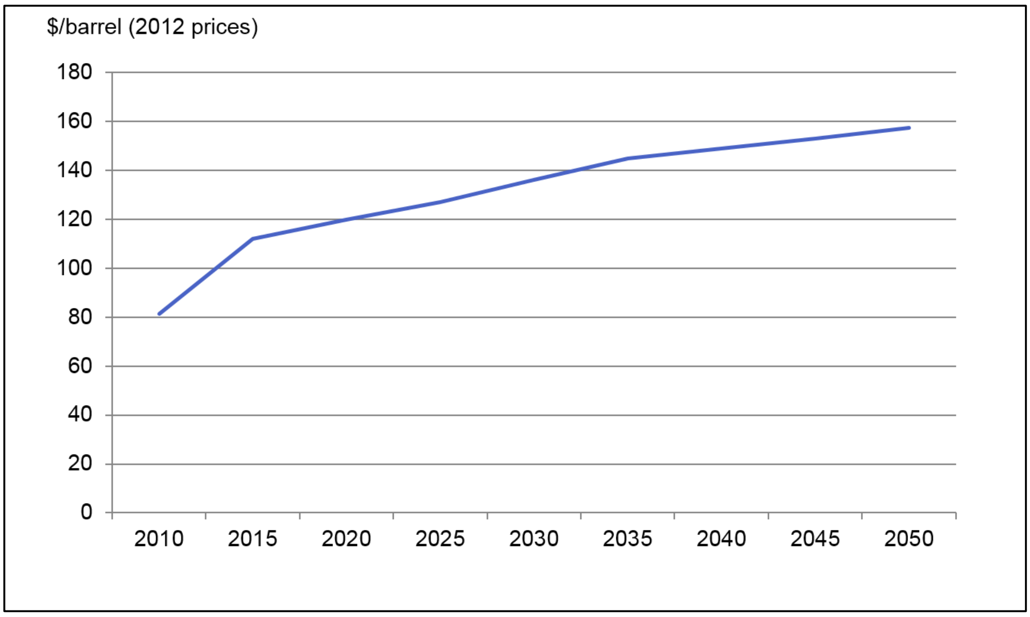
Electricity price and oil price assumptions are shown in Figure 3 and Figure 4, respectively. Electricity prices are consistent with the European Commissions' Energy Roadmap 2050, where the renewable content of electricity reaches 80% by 2050. Oil price assumptions are taken from IEA (2013) for the period to 2035, and then extrapolated to 2050.

Figure 3 EV user electricity price assumption



Source: European Commission 'Energy Roadmap 2050' and own calculations.

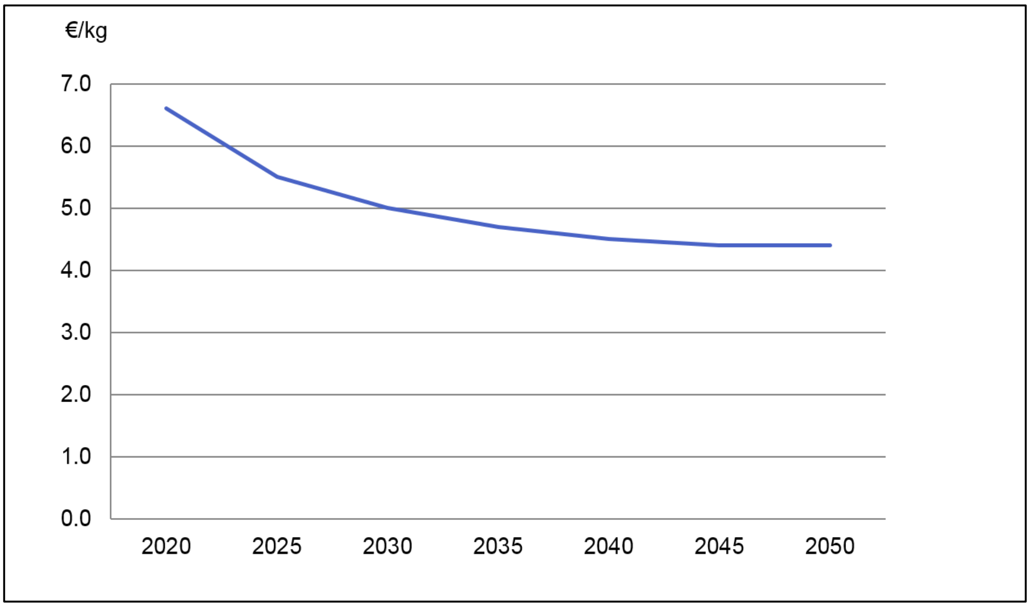
Figure 4 Oil price assumption



Source: IEA (2013) and own calculations.

Hydrogen price assumptions are based on a report by McKinsey (2010), which shows that, in a scenario in which all hydrogen is produced by electrolysis, and with an electricity grid that has 80% renewable content by 2050, the production cost falls over the period to 2050 due to learning effects and economies of scale.

Figure 5 Hydrogen production cost assumption



Source: McKinsey & Company (2010), 'A portfolio of power-trains for Europe: a fact-based analysis'. Hydrogen production scenario with 100% electrolysis and 80% renewable content of electricity by 2050.

The E3ME model

The results from the vehicle stock model are used as exogenous inputs to the E3ME model, to assess the impact of low-carbon vehicles on the Netherlands economy. E3ME[12] is a macroeconometric input-output model that uses historical data to estimate economy-energy-environment interactions within Europe. Because the model is defined at the level of EU member states, the economic baseline and the estimated parameters in the model reflect the specific characteristics of the Netherlands economy. The model provides economic results for the Netherlands specifically, as well as for other EU countries and the EU as a whole. The accounting identities and empirically-estimated economic relationships in the model predict the likely outcomes of the transition to a low-carbon vehicle fleet in the Netherlands. The main drivers of the macroeconomic results are a change in vehicle fuel demand and costs; an expansion of the motor vehicles supply chain; and an increase in technology costs and infrastructure investment. More details on E3ME, its assumptions and limitations are available in Appendix A.

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[12] See www.e3me.com and Appendix A for further information.

3 Scenarios

Four scenarios were modelled in order to estimate the macroeconomic impact of low-carbon vehicles in the Netherlands:

- Reference (REF)
- Current Policy Initiatives (CPI)
- Medium Ambition (MED)[13]
- High Ambition (HIGH)[14]

In each scenario, we assume that the rest of Europe achieves a similar level of vehicle efficiency as that achieved in the Netherlands.

Reference scenario (REF)

The REF scenario is the baseline against which all other scenarios are compared. Although this scenario includes some ICE efficiency improvements in the years up to 2015, we assume that the sales mix does not change after 2015 and, consequently, that the 2020 new vehicle emissions targets, which are now part of EU law, are not met. This scenario is not considered to be a business-as-usual baseline, but it is used as a reference case to assess the macro-economic impact of all future efficiency improvements (inclusive of those that have already been set as law). New vehicle emissions in the Netherlands reach 106 gCO_2/km in 2015 (on the NEDC test cycle basis) and remain at this level for the period up to 2050. Total CO_2 emissions from the vehicle stock continue to fall in the period up to 2035, as the relatively efficient new vehicles begin to replace more carbon-intensive vehicles that are withdrawn from the stock. Hybrids and EVs contribute 6% and 1% of the sales mix, respectively, for the period 2015-2050. In the reference scenario, it is also assumed that the rest of Europe will not meet the 2020 emissions targets, with the result that average emissions from new vehicles for Europe as a whole are 130 gCO_2/km (on the NEDC test cycle basis) over the period 2015-2050.

Current Policy Initiatives scenario (CPI)

In the CPI scenario, it is assumed that the 2020 target of 95 gCO_2/km is met in Europe, while, as a result of current trends, this target is surpassed in the Netherlands, where average emissions from new vehicles are assumed to reach 84 gCO_2/km (on the NEDC test cycle basis) by 2020. However, the CPI scenario assumes no further improvement in the fuel efficiency of new vehicles after 2020. It is assumed that in the period 2020-2050 hybrids account for 9% of the sales of new vehicles and EVs account for 2%. Alongside the small increase in the proportion of hybrid and electric vehicles in the period to 2020, there are technical improvements in the efficiency of the internal combustion engine (ICE), and these account for most of the reduction in emissions from new vehicles.

Medium Ambition scenario (MED)

The MED scenario represents a future in which current policy targets are met and there is some further decarbonisation of new vehicles in the period to 2050. The efficiency improvements, however, are limited to the conventional ICE and hybrid vehicles. In this scenario, hybrid-electric vehicles account for 69% of the sales of new vehicle in 2030 and 88% in 2050, but plug-in hybrids and electric vehicles do not increase their market shares. This scenario is broadly consistent with Europe meeting the indicative

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[13] Consistent with the TECH 1 scenario from ‘Fuelling Europe’s Future’

[14] Consistent with the TECH 3 scenario from ‘Fuelling Europe’s Future’

target[15] of 68-78gCO_2/km in 2025 that the European Commission is currently considering. In the Netherlands, average emissions from new vehicles fall to 60 gCO_2/km by 2025, and then to 28 gCO_2/km by 2050 (on a tank-to-wheel basis).

High Ambition scenario (HIGH)

The HIGH scenario represents a future in which there is rapid decarbonisation of the vehicle fleet in Europe. For the Netherlands this scenario is broadly consistent with current Dutch government targets,[16] of 230,000 advanced electric vehicles in the stock by 2020, and just over one million advanced electric vehicles by 2025 (of which around 65% are plug-in hybrids, 25% battery electric and 10% fuel cell electric vehicles).

In this scenario, advanced electric vehicles and hybrids account for 80% and 15% respectively of sales of new vehicles by 2030, with the result that average emissions from new vehicles fall to 15.5 gCO_2/km in 2030 (on a tank-to-wheel basis). By 2050 it is assumed that 100% of new vehicles sold are electric and therefore average emissions from new vehicles fall to 0 gCO_2/km. This scenario is comparable to the TECH 3 scenario in ‘Fuelling Europe’s Future’ and similar to the EV breakthrough scenario in CE Delft (2011).[17]

Features of the scenarios

All the scenarios that we have modelled have some important features. These features are explained and discussed in the remainder of this chapter, and the features specific to each scenario are described in detail in Chapter 3.

Europe-wide vehicle emissions reduction

One important feature of all the scenarios is that we assume that the average level of emissions reductions in new vehicles across Europe will be similar to that achieved in the Netherlands[18]. For example, in the REF scenario it is assumed that the Netherlands, and the EU as a whole, do not meet the proposed European emissions targets. The reason for making this assumption is that, to date, vehicle emissions regulation has mostly been set at the European level. Therefore it seems likely that the whole of the EU will follow a similar trend in future emissions reduction, even if some countries, such as the Netherlands, remain ahead of the EU-average, while other countries lag behind.

This assumption affects the inputs to the modelling, as the technology cost reductions would not be realised if the Netherlands were the only country to decarbonise their vehicle fleet. Furthermore, it affects the model results, as some of the demand in the low-carbon vehicles supply chain in the Netherlands comes from car manufacturers in the rest of Europe, and the reduction in petroleum demand in the Netherlands is partially a result of reductions in demand in Belgium and Germany, which are two of the largest importers of petroleum from the Netherlands.

The power sector

In all scenarios modelled, we assume that the power sector will have a high renewable content: that by 2030, 60% of electricity will be generated from renewable sources and that this share will rise to 80% by 2050. There are two reasons for this assumption. First, Europe, and specifically the Netherlands, is committed to delivering a highly decarbonised power sector and further decarbonisation will be required to meet the EU’s 2050 emissions targets. Secondly, this assumption enables us to model the economic

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[15] See: http://www.transportpolicy.net/index.php?title=EU:_Light-duty:_GHG

[16] http://www.nederlandelektrisch.nl/english/

[17] CE Delft (2011), “Impacts of electric vehicles”, available online: http://www.cedelft.eu/publicatie/impact_of_electric_vehicles/1153

[18] Following recent trends, in all cases we assume that new vehicles in the Netherlands remain slightly more carbon-efficient than the EU average

impact of an almost completely decarbonised vehicle stock in the most ambitious scenario. In this scenario we assume that advanced electric vehicles account for 100% of new vehicle sales and around 75% of the vehicle stock in the Netherlands by 2050.

There are two main implications of assuming these level of renewable content in power generation by 2030 and 2050. Due to the relatively high cost of renewable technologies, electricity prices in our scenarios are higher[19] than if the generation mix contained a higher proportion of gas-fired power generation in place of renewable electricity. However, this assumption also creates the potential for energy synergies where hourly electricity supply and demand profiles can be more closely balanced. Such synergies[20] could be created if most EV charging were to take place at times when the underlying electricity demand is low, e.g. over-night. The electricity price charged to Electric Vehicle users is assumed to be the same as that charged to households, and the margins are sufficient to pay for the required public chagrining infrastructure.

Tax revenue neutrality

As described above, we assume that EV users will pay the same price for electricity as households (in the case of both public and private charging), and that they do not pay any additional levies. The basis for this assumption is principally due to the difficulty that electricity companies would have in imposing price-differentials for the various end-users of electricity in private dwellings i.e. separating electricity consumed for heating/appliances and electricity used for EV charging.

However, the tax rate on petrol and diesel consumption is relatively high (€0.759/litre for unleaded petrol in 2014)[21] and therefore, reduced consumption of petrol and diesel in the CPI, MED and HIGH scenarios leads to lower tax revenues, despite the increase in expenditure on other goods and services in these scenarios. If taxes are lower, the economy does better by definition, as there is a transfer from government balances to real economic flows. However, if the loss of government revenue is not paid for, this would introduce a bias in the economic results. To correct for this bias, we ensure government revenue neutrality by assuming that any loss of fuel duty revenues, due to lower expenditure on petrol and diesel in the CPI, MED and HIGH scenarios, is directly compensated by an equivalent increase in VAT revenues, through an assumed increase in the VAT rate in these scenarios. Increasing the VAT rate to compensate for a loss of fuel duty revenue is used for illustrative purposes only. This is not a policy recommendation, but this assumption is necessary in order to present a neutral viewpoint in which government fiscal balances do not differ between scenarios. The feedback from higher VAT rates to the rest of the economy is modelled, and, when considered in isolation, leads to a reduction in real disposable income and consumption. As VAT is a tax on consumption, it is a similar form of taxation as fuel duty, and will have a similar impact on consumer welfare at the aggregate level.

Drivers of efficiency improvements

The improvements in vehicle efficiency in the CPI, MED and HIGH scenarios are achieved through a combination of:

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[19] Our electricity price assumptions are taken from Scenario 4 in the European Commissions' 'Energy Roadmap 2050'. In this scenario, the renewable content of power generation reaches 83% by 2050, and the resulting electricity prices are 32% higher than the reference scenario, that has 40% renewable content by 2050.

[20] We do not explicitly model potential energy synergies in this analysis, but they were modelled at the European level in the 'Fuelling Europe's Future' report.

[21] European Comission, Taxes in Europe database see: http://ec.europa.eu/taxation_customs/tedb/taxSearch.html

- improved efficiency of internal combustion engines (and vehicle platforms generally)
- an increased proportion of more carbon-efficient powertrains in the sales mix (i.e. the deployment of hybrid vehicles in the CPI and MED scenarios, and plug-in hybrids and battery electric vehicles in the HIGH scenario)

Most of the efficiency improvements in the HIGH scenario are assumed to come from the increased share of electric vehicles in the sales mix. In the CPI scenario, however, most of the reduction in fuel consumption in the period to 2020 is assumed to be due to improved efficiency of the internal combustion engine. It is assumed that this improved efficiency will be achieved because many technologies that are starting to be introduced in some cars will become mainstream by 2020. These technologies include:

- low friction design and materials
- gas-wall heat transfer reduction
- direct injection (homogeneous)
- cam-phasing
- combustion improvements
- mild downsizing (15% reduction of cylinder content)
- medium downsizing (30% reduction of cylinder content)
- reduced driveline friction
- optimising gearbox ratios / downspeeding
- start-stop hybridisation
- aerodynamics improvement
- low rolling resistance tyres
- weight reductions
- improvement in the efficiency of auxiliary systems
- thermal management

The introduction of these technologies brings about considerable improvements in the fuel efficiency of traditional ICEs with the result that, over time, the efficiency of diesel and petrol ICEs converges. By 2020 the efficiency of petrol ICEs in the CPI scenario is improved by around 37% compared to a 2010 vehicle. Around 9% of this improvement has already occurred by 2013. Further details of the cost and fuel savings associated with each technology are available in Appendix B[22].

Emissions in the vehicle stock

Turnover of the vehicle stock is quite a slow process. The average lifetime of a vehicle in the Netherlands is around 16 years. As a result, the effects of efficiency improvements in new vehicle sales in the three decarbonisation scenarios (CPI, MED and HIGH) in the period 2015-2020 are not fully realised until around 2030. Equally, the effect of investment in fuel-saving technology in the period 2040-2050 is not fully reflected in the timeframe assessed in this report.

Figures 6 and 7 show the assumed levels of tank-to-wheel emissions of the vehicle stock in the Netherlands between 2010 and 2050 in each of the four scenarios. For each scenario, Figure 8 shows the shares in sales of new vehicles in the Netherlands in 2030 and 2050, while Figure 9 shows the shares of each type of vehicle in the total vehicle stock of the Netherlands in those two years.

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[22] For a fuller understanding of the implementation of these technologies see Cambridge Econometrics et al (2013) ‘Fuelling Europe’s Future’.

Figure 6 Average tank-to-wheel emissions from new vehicles in the Netherlands (NEDC test cycle basis)

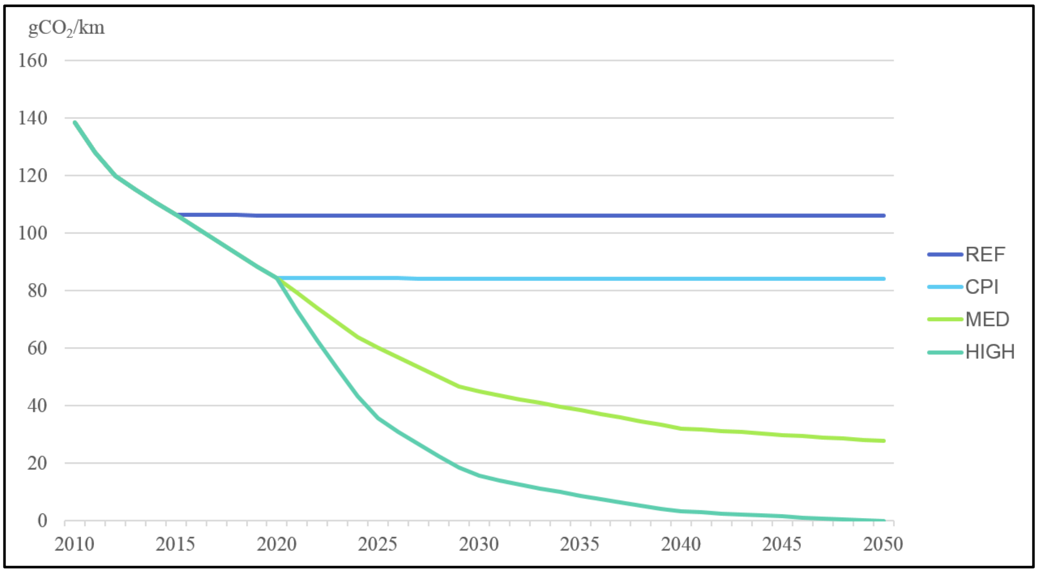


Figure 7 Average tank-to-wheel emissions of the vehicle stock in the Netherlands (Real world basis)

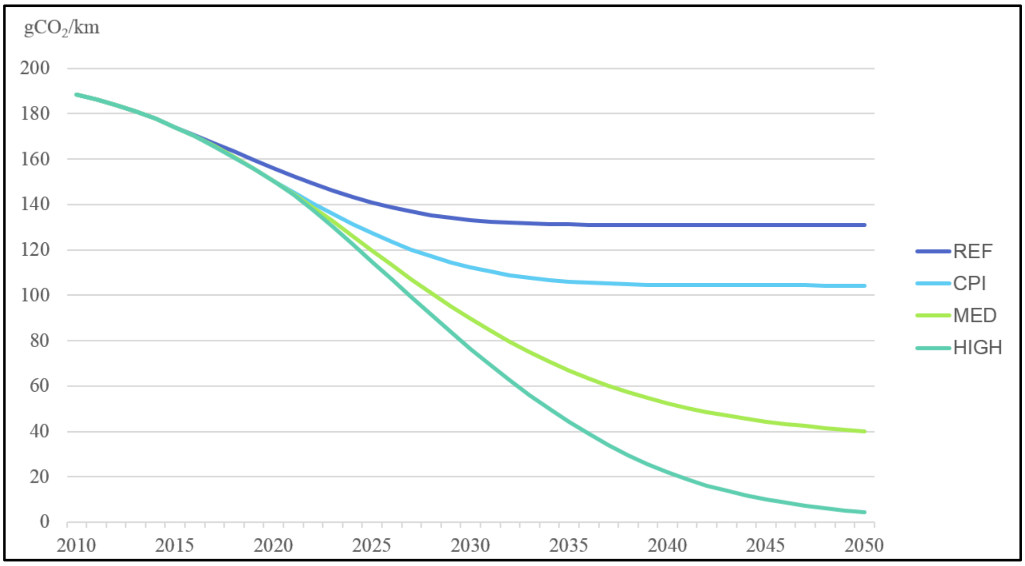


Figure 8: Vehicle sales mix in the Netherlands, 2030 and 2050

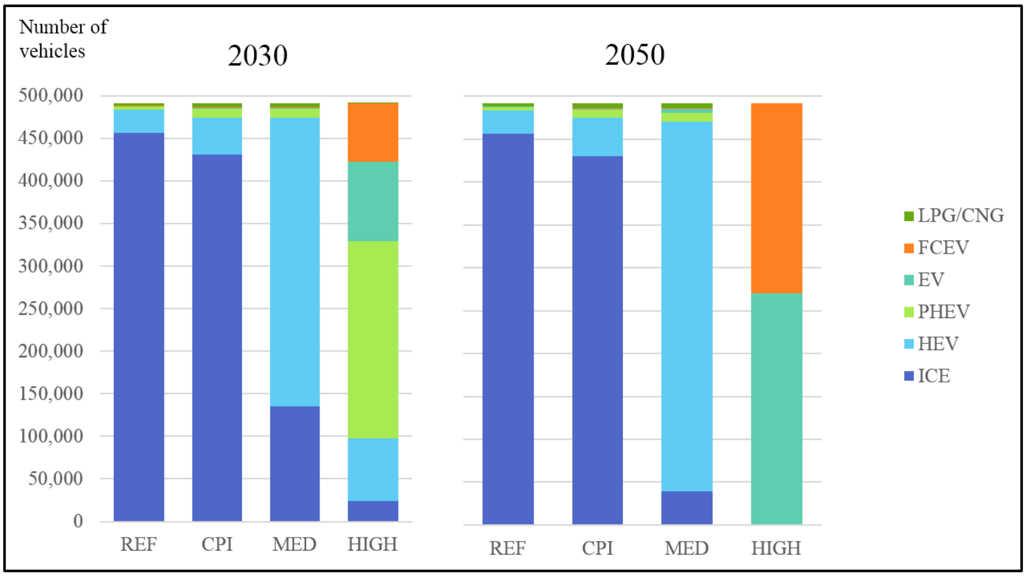
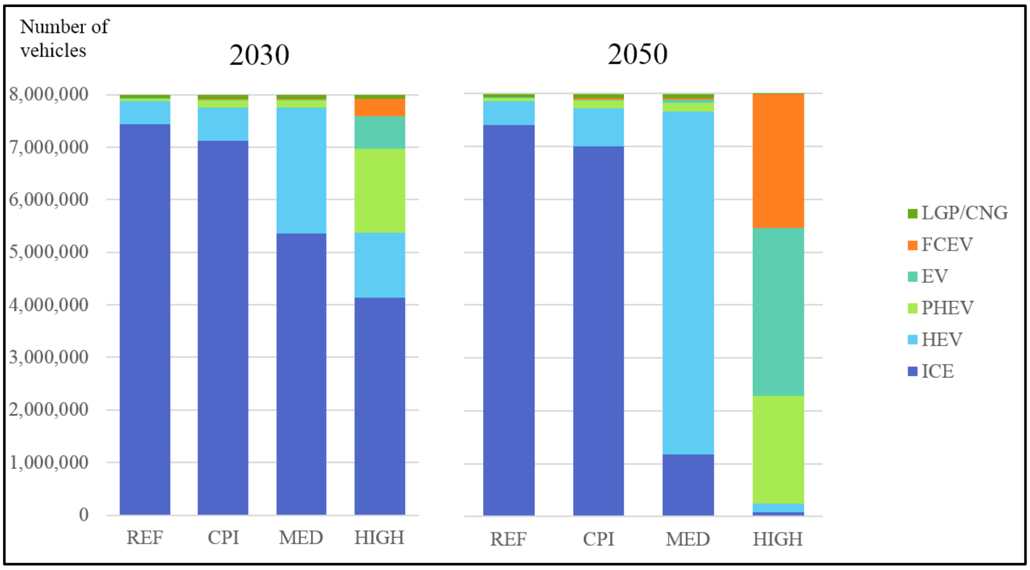


Figure 9: Vehicle stock in the Netherlands, 2030 and 2050



4 Technology Costs

Reducing emissions from new vehicles will depend on increasing the amount of efficient technology in new vehicles, and also on the increased use of more efficient powertrains. On its own, the required increase in fuel-efficient technology in the CPI, MED and HIGH scenarios has two key macroeconomic consequences:

- The motor vehicles supply chain will expand to include producers of fuel-efficient technologies, thereby bringing about increased economic output and jobs.
- Consumers and businesses will face higher vehicle costs, with the result that real incomes and consumption will be reduced while price inflation rises.

This chapter discusses the technology cost assumptions that were used in the scenarios and the implications for the price of new vehicles.

Cost assumptions

The differences in the cost of the average new vehicle between each of the scenarios depends on 1) the cost and quantity of fuel-efficient technologies installed in new vehicles and 2) the composition of various powertrains in the sales mix.

The assumptions used for technology costs are based on data provided by the European car manufacturers association ACEA to the European Commission's Impact Assessment on the 95g/km target (TNO et al 2012). The costs have been verified by industry experts and also by CLEPA, an organisation that represents companies that manufacture low-carbon vehicle technologies. The costs are consistent with the assumptions used in the 'Fuelling Europe's Future' report[23]. For each technology, we assume a learning rate of 10% for every cumulative doubling of European sales.

By 2020, fuel-efficient technology improvements to the conventional ICE add €450 to the cost of the average ICE vehicle in the CPI, MED and HIGH scenarios, when compared to the REF scenario, in which the improvements to the fuel-efficiency of new vehicles are limited. In all three decarbonisation scenarios, the cost of efficient technologies falls over time because of economies of scale and learning effects. Figure 10 shows the reductions in costs due to learning effects for an illustrative subset of fuel-efficiency technologies.

However, despite learning effects, the increase in the amount of technology required in order to achieve a lower level of emissions leads by 2030 to an increase in the cost of the average car of ICE-type in the MED and HIGH scenarios of around €1,500 compared to cars in the REF scenario.

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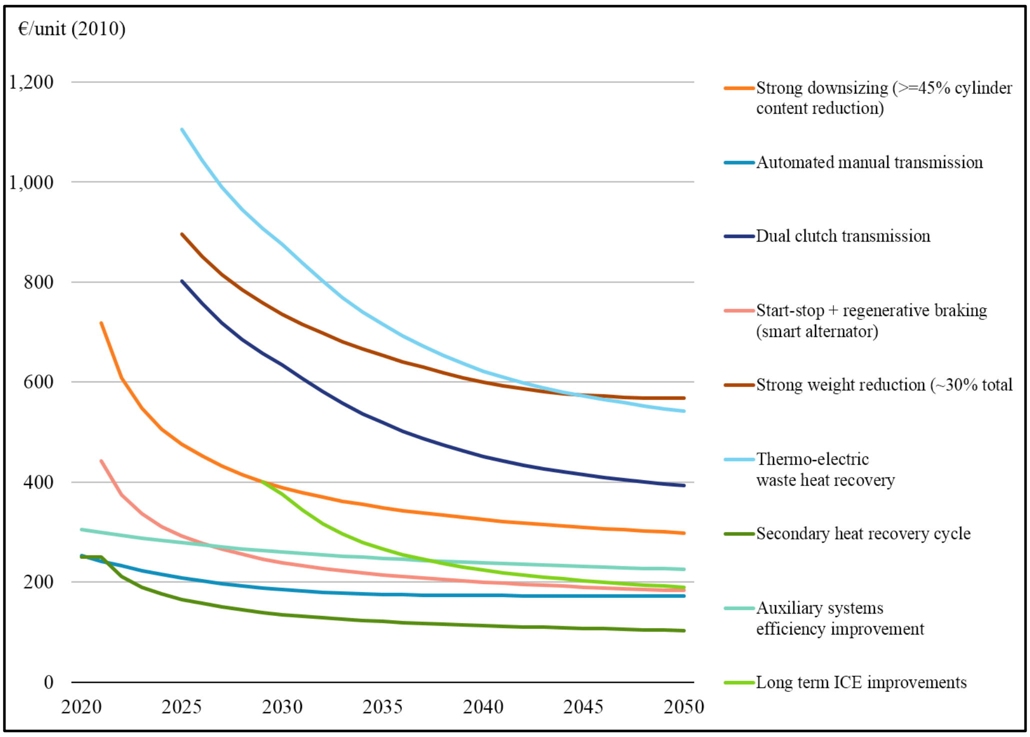
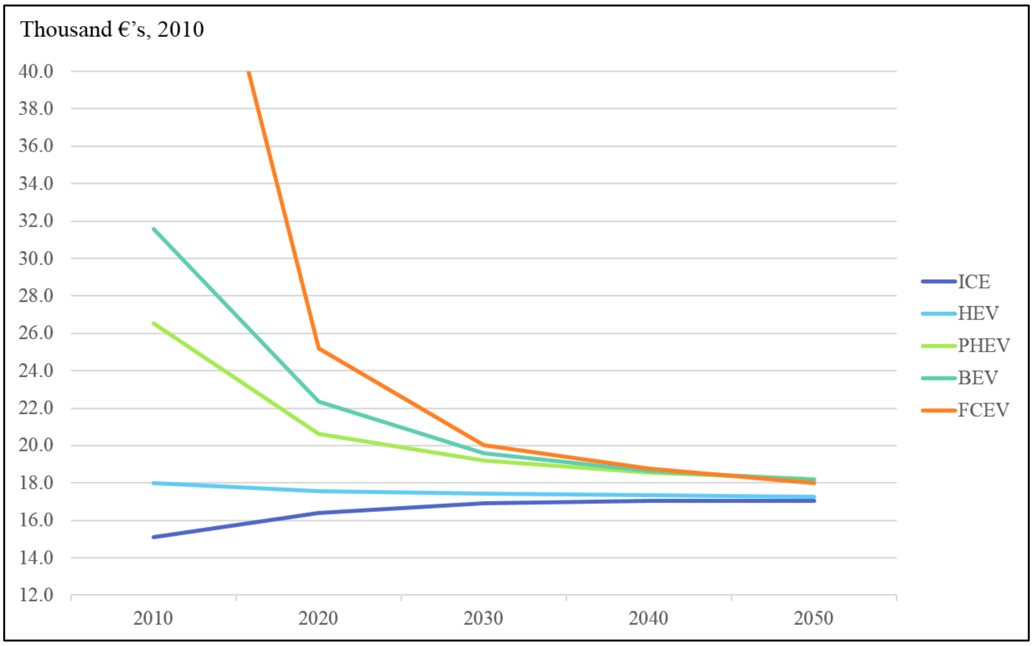
[23] In the 'Fuelling Europe's Future' report, these assumptions were also tested against industry feedback from Nissan, automotive suppliers group CLEPA, battery makers association Eurobat and the European Aluminium Association.

Figure 10: Technology cost reductions (HIGH scenario)



In addition to a higher technology content, in the HIGH scenario there is also a shift in sales by powertrain type, away from conventional ICEs towards more expensive electric motors. The assumptions about cost reductions for the various types of vehicle based on the shares of each type in new vehicle sales in the HIGH scenario are shown in Figure 11.

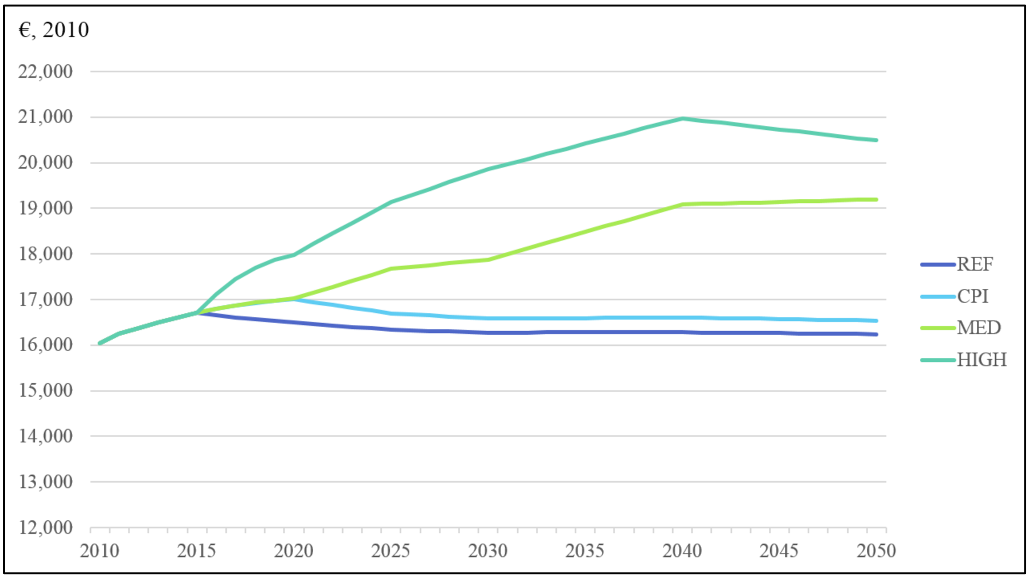
Figure 11: Cost assumptions by vehicle type excl. tax and margins (HIGH scenario)



The average price of vehicles increases slightly in all scenarios in the period up to 2015, as a result of expected technology improvements. However, vehicle prices start to diverge after 2015 in the different scenarios. In the MED scenario there is a steady increase in vehicle prices, from €17,000 in 2020 to €19,000 by 2040, due to an increase in the proportion of more expensive hybrid vehicles in the sales mix[24]. In the 2040-2050 period, the average price of vehicles in this scenario remains at around €19,000, because the share of hybrids in the sales mix remains fairly steady in this decade, and any learning and scale effects in hybrid technologies have already been fully realized before 2040.

In the HIGH scenario, a more ambitious decarbonisation pathway with a higher share of advanced EVs causes the average price of new vehicles to rise more steeply, reaching €21,000 by 2040. In the period to 2050, however, prices begin to fall slightly due to learning effects in electric vehicle technologies and scale effects caused by the mass manufacturing of advanced EVs.

Figure 12: Average vehicle price (incl. tax and margins)



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[24] All cost figures are reported in 2010 prices.

5 Infrastructure Costs

In the HIGH scenario, it is assumed that the number of advanced electric vehicles[25] in the Netherlands grows to more than one million by 2030 and increases further to reach 5.7 million by 2050. Investment in EV charging infrastructure and hydrogen power stations would be essential in order to support the expanding fleet of battery electric and fuel-cell electric vehicles in this scenario. In the REF and CPI scenarios, it is assumed that the number of advanced EVs will not increase beyond current levels and, consequently, it is assumed that there is no new investment in EV charging infrastructure. Similarly, technological improvements in the MED scenario are limited to improvements to the efficiency of the ICE and increases in the number of conventional hybrid vehicles, therefore, we also do not assume any additional investment in EV infrastructure in this scenario.

Financing the increase in infrastructure investment

The cost of the required hydrogen fuelling stations and EV charging infrastructure is around €1bn per annum by 2030. In any one year, the cost is assumed to fluctuate within the range €600m to €1.2bn. The total cost of infrastructure will depend on the total number of EV charging points and hydrogen fuelling stations required. This will include new infrastructure, and towards the end of the period, replacement infrastructure. We have modelled this as a function of the number of EVs/FCEVs, and an estimate of the required density (charging points per EV and re-fuelling stations per FCEV). These assumptions were verified against experts in the motor vehicles and electricity supply industries as part of the ‘Fuelling Europe’s Future’ report. Total investment spending in the Netherlands is projected to be around €185bn in 2030, and so the additional investment required for supporting infrastructure is around 0.55% of total economy-wide investment.

We have made certain assumptions about the financing of this investment in infrastructure. We assume that EV users will pay for the cost of charging units at home and at work as a one-off payment in addition to the cost of the vehicle itself. The cost of the public infrastructure is assumed to be paid for by additional margins on sales of electricity used in these charging units. Similarly, the cost of the hydrogen infrastructure is assumed to be paid for through the retail price of hydrogen fuel sold to FCEV users. Therefore, although the investment in infrastructure does lead to an increase in demand and economic activity, it does also displace spending on other goods and services, as EV users ultimately end up paying for the infrastructure investment, either in as an upfront cost (in the case of private EV charging infrastructure) or by higher electricity prices (in the case of public infrastructure).

EV charging infrastructure costs

For this study, we assume that EV users regularly top-up their vehicles as and when they need to, and therefore a fairly high density of charging infrastructure is required to meet their needs. Over the period 2030-2050, we assume a density of 0.8 home-charging units, 0.2 workplace units and 0.4 public slow-charging posts for each electric vehicle in use. We assume that the density of public fast-charging posts falls from 0.05 posts per EV in 2020, to 0.004 posts per EV in 2050. These assumptions are based on Infrastructure Scenario 2 from the ‘Fuelling Europe’s Future’ report, which were used for the central model runs in that analysis. It is assumed that EV users are ‘grazing’,

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[25] Advanced electric vehicles include plug-in hybrid vehicles, battery electric vehicles and fuel-cell electric vehicles.

topping up their vehicles frequently for short distance journeys. There is a lot of initial investment in fast-charging until a critical mass is reached, at which point the geographical coverage of charging infrastructure is sufficient to support a larger electric vehicle fleet.

The assumptions for the cost of the charging infrastructure are those used in the 'Fuelling Europe's Future' report. The initial costs are summarized in Table 2 below.

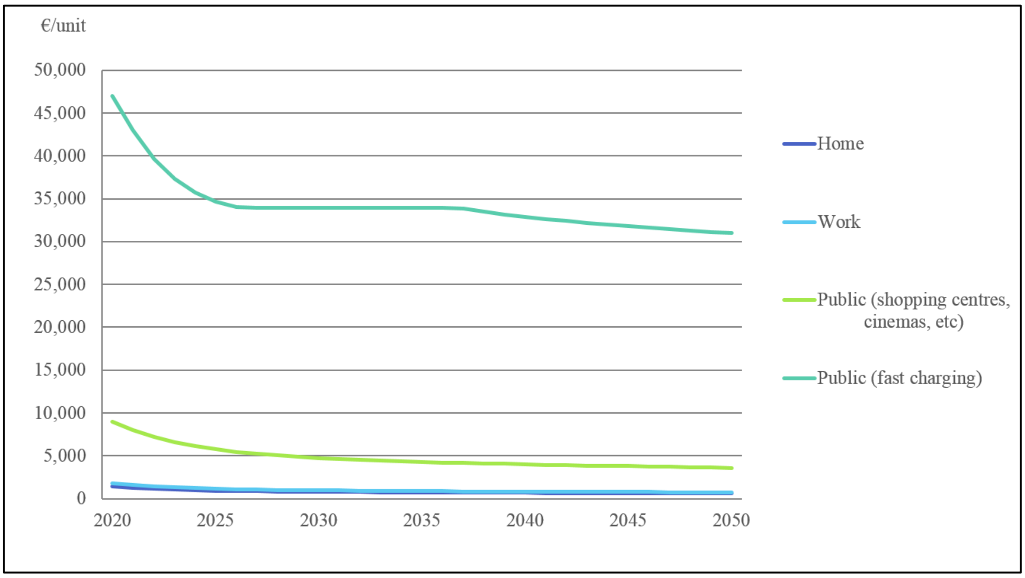
Table 2: Cost of EV charging infrastructure

	Cost of unit production, FOAK (€)	Cost of installation per unit, FOAK (€)
Home charging	400	1,000
Work charging	800	1,000
Public (shopping centres, cinemas, etc)	6,000	3,000
Public (fast charging)	22,000	25,000

Source: Cambridge Econometrics et al (2013), 'Fuelling Europe's Future'.

The cost of fast-charging infrastructure points are assumed to fall quite quickly in the HIGH scenario because of learning effects and economies of scale resulting from the fairly rapid take-up of advanced vehicles in the 2020s. Modest reductions in charging units at home and work are also assumed, so that by 2030 the cost of a home charging unit falls from an average of €1,400 (including installation costs) to around €970 (including installation costs). Further cost reductions continue through to 2050, but these reductions are fairly modest as most of the learning-effects are assumed to be realized in the first 10-20 years of large-scale production.

Figure 13: EV infrastructure costs (2020-2050)



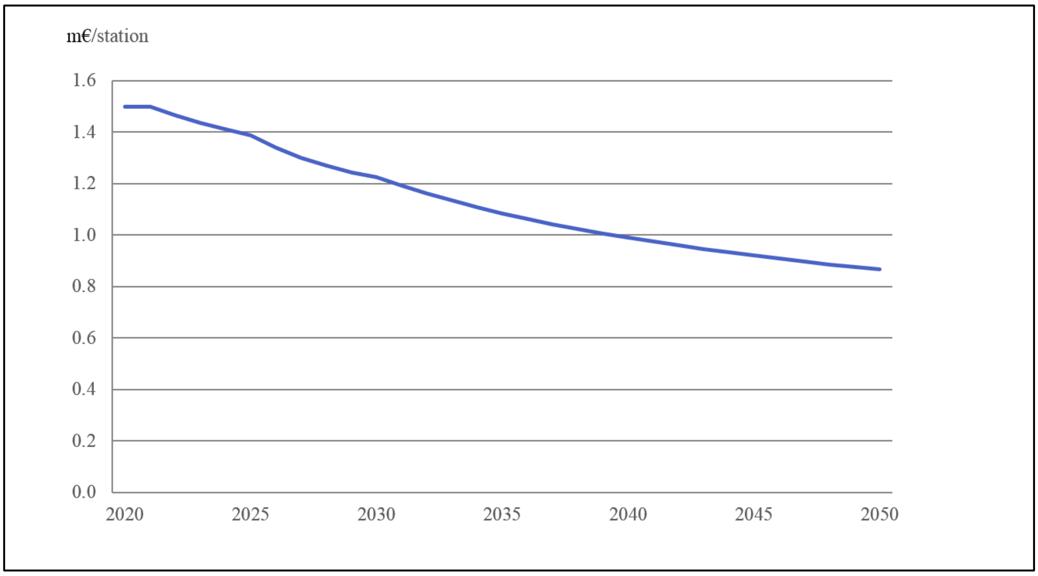
Hydrogen infrastructure costs

There are two assumptions about the investment in hydrogen infrastructure in the HIGH scenario:

- We assume there is an increase in investment in hydrogen production plants, to meet the increase in demand for hydrogen from FCEVs.
- We also assume an increase in investment in hydrogen fuel stations to supply the hydrogen to FCEV drivers.

In the HIGH scenario it is assumed that most of the hydrogen is produced using electrolysis. In line with the pan-European analysis, hydrogen infrastructure costs are expected to be modest, as the distribution process will be centralised, in line with the more traditional petroleum business model. Despite a rising price of electricity (needed for production of hydrogen using electrolysis) and the increased investment in new production plant, there are cost reductions due to learning effects and economies of scale. Therefore, we assume that the price of hydrogen falls slightly over time, reaching around €4.5 per kg in 2050.[26]

Figure 14: Hydrogen fuelling station infrastructure costs (2020-2050)



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[26] The hydrogen price assumptions are taken from the McKinsey study, “A portfolio of power-trains for Europe: a fact-based analysis”. In this study all hydrogen is assumed to be produced by electrolysis and there is assumed to be 80% renewable content in electricity generation by 2050.

6 Fuel Costs

While vehicle prices clearly play an important role in consumers' purchasing decisions, so too does the cost of fuel. For example, one study by the German Energy Agency (DENA) found that fuel efficiency is one of the main criteria for German car buyers[27]. This is consistent with research in other EU countries. One UK study found that car buyers' main concerns were, in order of importance: running cost; size/practicality; price.[28]

A poll of 2,000 consumers by GfK[29] found that German consumers thought that their spending power was being compromised "as an ever-greater proportion of their income is spent on energy, particularly on petrol and diesel, and is therefore not available for other purposes."

By 2020 there is comparatively little difference in energy consumption between the scenarios because there are only five years of more efficient vehicle sales (2015-2020) in the CPI, MED and HIGH scenarios compared to REF. By contrast, in 2030 the vehicle stock is much more efficient in the CPI than the REF scenario as a result of efficiency improvements. There is also some difference between MED and CPI, and considerable difference between HIGH and CPI, both in terms of the mix of vehicles in the stock (see Figure 9) and the average efficiency.

By 2030 total car fuel bills for are reduced by around 16% in the CPI scenario compared to the REF scenario, by 30% in the MED scenario and by 42% in the HIGH scenario. The average annual fuel bill per car in 2030 is therefore reduced from €1,400 in the REF to €1,177 in the CPI scenario, €980 in the MED scenario and €815 in the HIGH scenario (see Figure 5).

There is considerable uncertainty about future energy prices in the long term. For this report, the central assumptions for fossil fuel prices are taken from the IEA's 2013 *World Energy Outlook*, and no changes are assumed in the fuel tax regime. Consequently, petrol prices are €1.90 per litre by 2030 and rise to €2.00 per litre by 2050 (in real terms). Assumptions about electricity prices and hydrogen prices are in line with low-carbon generation methods and also take into account distribution, tax and retail margins. Consequently, electricity prices for road users are around €145/MWh by 2030 and €170/MWh by 2050 (in real terms); hydrogen prices to road users are around €5/kg by 2030 falling to around €4.50/kg by 2050 (in real terms). Electricity prices and oil prices are shown in Figure 3 and Figure 4 in Section 2.

By 2050 there are substantial reductions in annual fuel costs for the average car owner. In the MED and HIGH scenarios, annual fuel costs are between €1,000 and €1,250 lower than in the REF; this quickly outweighs the increased cost of vehicles. To be precise, when vehicles are bought with cash, the investment is paid back in around three

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[27] German Energy Agency (2012): http://www.dena.de/presse-medien/pressemitteilungen/dena- umfrage-autohaendler-unterschaetzen-potenzial-des-pkw-labels.html.

[28] LowCVP Car Buyer Survey (2010): *Improved environmental information for consumers*, Research conducted by Ecolane & Sustain on behalf of the Low Carbon Vehicle Partnership – June 2010.

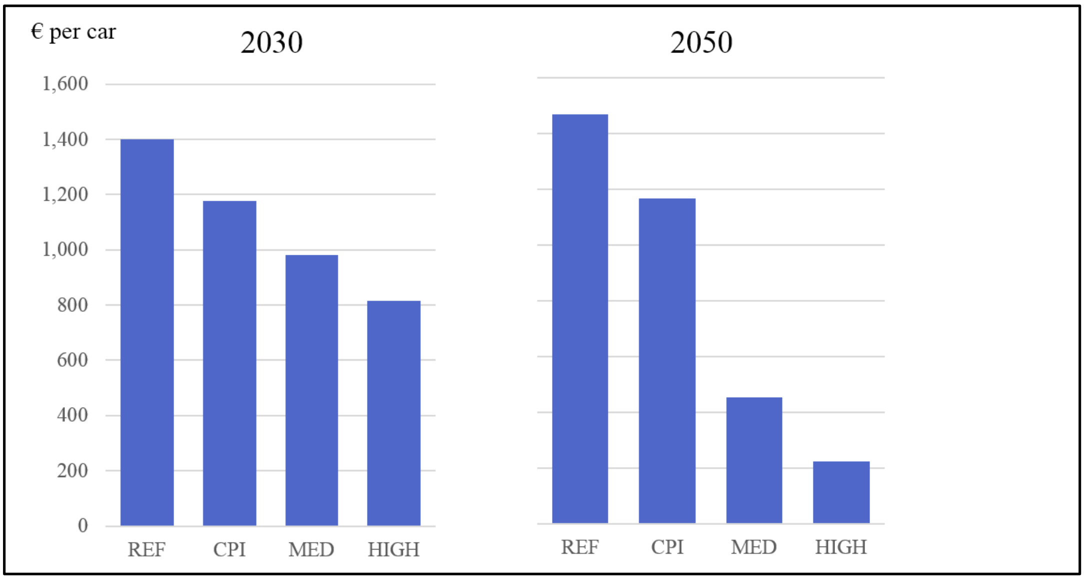
http://www.lowcvp.org.uk/assets/reports/LowCVP-Car-Buyer-Survey-2010-Final-Report-03-06-10- vFINAL.pdf)

[29] http://www.gfk.com/de/news-und-events/presse/pressemitteilungen/Seiten/Hohe-Benzinpreise-belasten-Konsumklima.aspx

to five years and, when they are bought on credit, the budgets of households and businesses could be improved immediately, depending on individual financing rates.

It is important to note, however, that in many cases, consumers use a relatively high discount rate when making purchasing decisions. If households place a low value on future fuel bill savings, then, even if electric vehicles are the most cost-effective option over the lifetime of the vehicle, this may not be sufficient to incentivise households to buy an electric car in preference to a conventional ICE. Drivers expected annual mileage is also likely to affect their purchasing decision. Our analysis is carried out for the average car (travelling 13,317km per year), however, people that use their car much less frequently than average, would realize lower fuel bill savings, and for this group, the incentive to buy an electric vehicle would be lower.

Figure 15: Annual fuel bills for an average vehicle in the stock in each scenario



7 Economic Impact

As explained in the previous chapters, the macroeconomic impact of low-carbon vehicles in the Netherlands will be determined by three factors: the effects of an increase in technology costs; the effects of an increase in infrastructure investment; and the effects of a reduction in fuel costs. The macroeconomic consequences of these three factors are summarized in Figure 16 and Figure 17.

Figure 16 The economic impact of low carbon vehicles (excluding energy sector impacts)

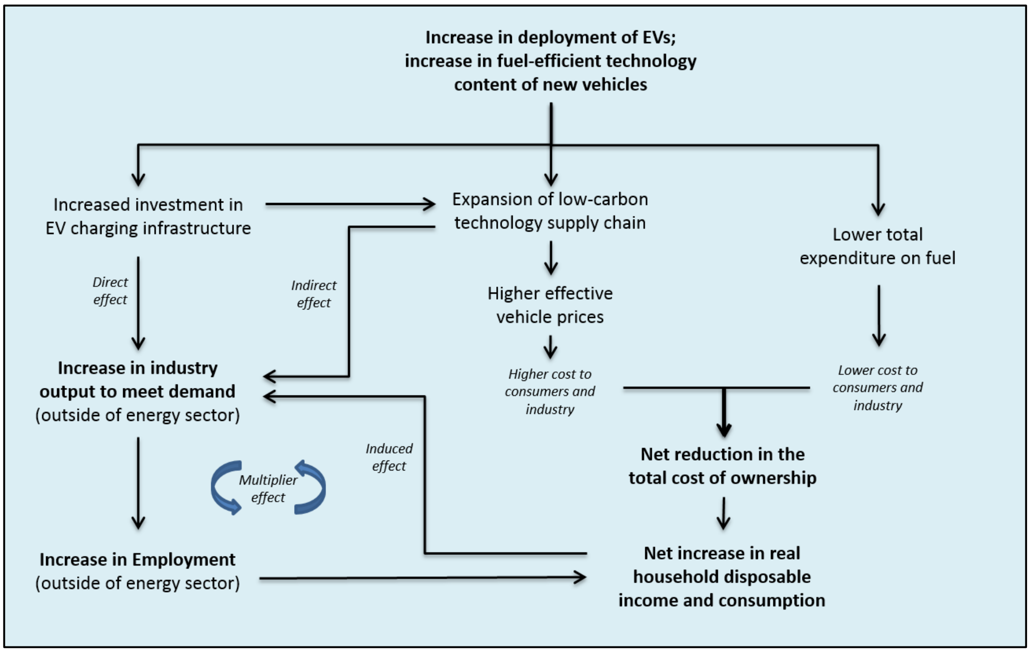
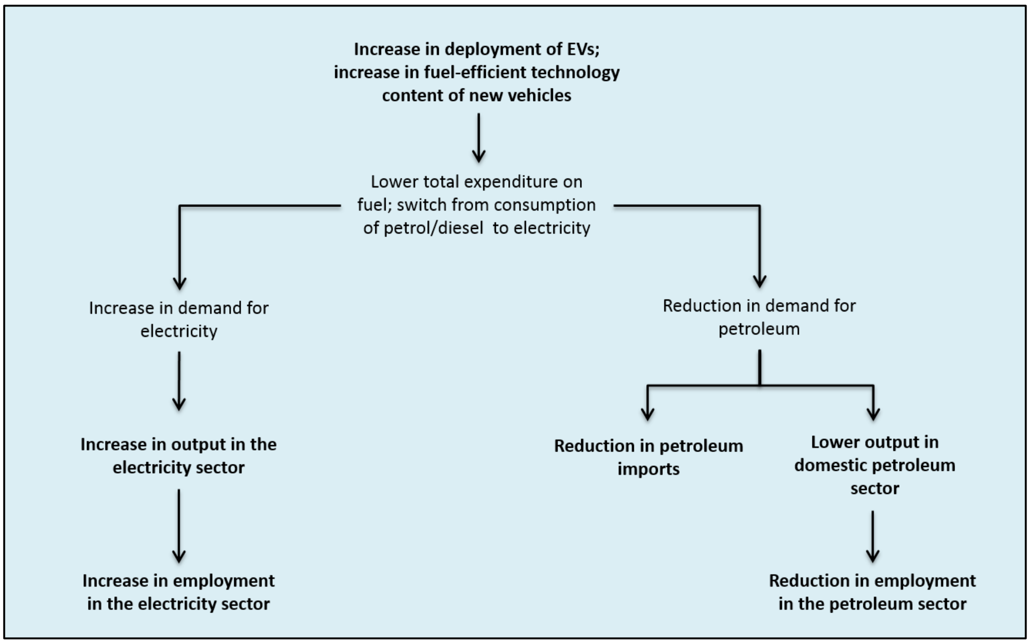


Figure 17 The impact of low carbon vehicles on energy sectors



Impact on consumers

The net impact on consumers depends on the extent to which the increase in vehicle costs and the reduction in fuel costs offset each other. The analysis shows that a transition to a more efficient vehicle fleet will deliver an overall saving in the average lifetime cost[30] of vehicles and, as a result, there will be a net improvement in consumer welfare.

The costs and benefits of more efficient vehicles occur at different points in time, as cars must be paid for (or at least financed) when they are bought, while the fuel savings accrue over the lifetime of the vehicle. Research shows that consumers have a strong time preference, and therefore they undervalue future fuel costs when purchasing a vehicle[31]. Such under-valuation might lead consumers not to buy the vehicles that deliver the lowest total cost of ownership. This market failure would produce a loss of income in the long run.

Macroeconomic impacts

The macroeconomic results in each of the scenarios are presented in Table 3 and Table 4. Our modelling predicts that there would be a 0.4% increase in the domestic level of GDP in 2030, as a consequence of rapid decarbonisation of the vehicle fleet in the Netherlands and wider Europe (as defined in the HIGH scenario). If the Netherlands continued along the low-carbon path in the period to 2050, this would produce further economic benefits, including a level of GDP 0.7% higher in 2050 than in the REF scenario.

There are a number of key drivers of this result:

- Fuel bill savings lead to a transfer of expenditure from oil to other goods and services that have a larger domestic supply chain and a higher labour intensity.
- Higher demand for fuel-efficient technologies (in all decarbonisation scenarios) and higher investment in EV and hydrogen infrastructure (in the HIGH scenario) drive increases in output and employment, which, in turn, lead to further increases in real incomes and consumption. It is important to note that the increase in demand is as a result of expansion of the vehicle supply chain in the rest of the EU, as well as in the Netherlands.
- Counteracting these positive outcomes, the reduction in fuel demand in the Netherlands (and the rest of the EU) drives a reduction in output and employment in the petroleum refining sector.
- There are also multiplier and induced effect due to net increases in incomes and consumer demand.

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[30] In this case, the life-time cost refers to the annualised capital cost of purchasing the vehicle, annual maintenance costs and annual fuel costs, refer to Appendix C for more details.

[31] As shown in several recent studies, including Helfand and Wolverton 2009 (http://yosemite.epa.gov/EE/Epa/eed.nsf/44a8be610f6c5f0885256e46007b104e/51a36d18d3ef67b98525761c004dfa5e/$FILE/2009-04.pdf); Greene 2010 (http://trid.trb.org/view.aspx?id=920593); Alcott and Wozny, 2010 (ftp://wuecon195.wustl.edu/opt/ReDIF/RePEc/mee/wpaper/2010-003.pdf)

Table 3: Macroeconomic results, 2030

	REF	CPI	MED	HIGH
	(2010 prices)	(difference from REF)		
GDP	€795.7bn	€1.2bn (0.2%)	€1.4bn (0.2%)	€3.4bn (0.4%)
Consumption	€335.9 bn	€1.2bn (0.4%)	€1.5bn (0.5%)	€2.6bn (0.8%)
Investment	€184.9 bn	€0.4bn (0.2%)	€0.7bn (0.4%)	€3.3bn (1.8%)
Exports	€757.2 bn	€0.4bn (0.1%)	€0.3bn (0.0%)	€1.3bn (0.2%)
Imports	€738.8 bn	€0.8bn (0.1%)	€1.1bn (0.1%)	€3.7bn (0.5%)
Real income	€405.1 bn	€1.6bn (0.4%)	€1.9bn (0.5%)	€3.2bn (0.8%)

Table 4: Macroeconomic results, 2050

	REF	CPI	MED	HIGH
	(2010 prices)	(difference from REF)		
GDP	€1,112.9 bn	€2.6bn (0.2%)	€3.5bn (0.3%)	€7.2bn (0.7%)
Consumption	€434.6 bn	€3.3bn (0.8%)	€4.8bn (1.1%)	€6.6bn (1.5%)
Investment	€258.0 bn	€0.6bn (0.2%)	€1.5bn (0.6%)	€4.6bn (1.8%)
Exports	€1,456.8 bn	€1.8bn (0.1%)	€2.0bn (0.1%)	€2.8bn (0.2%)
Imports	€1,440.5 bn	€3.1bn (0.2%)	€4.8bn (0.3%)	€6.9bn (0.5%)
Real income	€500.0 bn	€3.8bn (0.8%)	€5.5bn (1.1%)	€7.5bn (1.5%)

There is an increase in employment in the CPI, MED and HIGH scenario due to higher GDP levels and the shift of production from the refining sector to more labour-intensive sectors in the motor vehicles supply chain (see Table 5).

Table 5: Labour intensity in the motor vehicles supply chain and energy sectors

	Jobs per million euros of gross output (2011)
Motor vehicles supply chain	2.1 - 4.5
- Fabricated Metal products	4.50
- Electrical machinery	3.46
- Rubber and plastics	3.83
- Basic metals	2.44
- High-tech manufacturing	2.11
Electricity sector	0.58
Petroleum refining sector	0.12

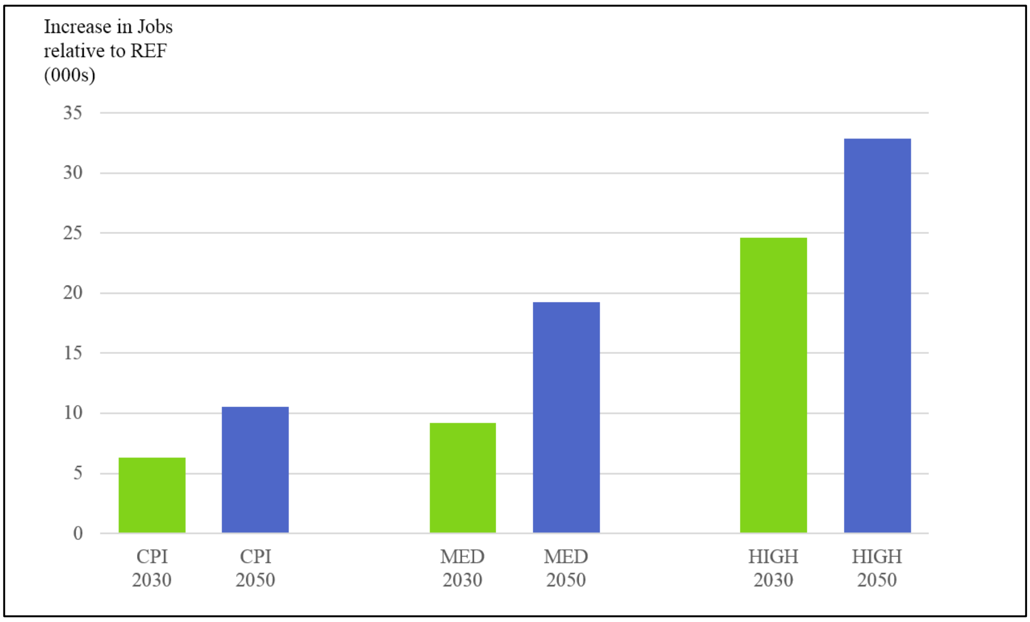
Source: Eurostat Structural Business Statistics and own calculations.

We estimate that the impact of having one million EVs in the stock by 2025 (the government's target), would lead to the net creation of 24,600 additional jobs by 2030. Decarbonising vehicles further in the period to 2050 could lead to 32,800 net additional jobs in the Netherlands. The net job increases are economy-wide figures. They include the induced employment due to higher incomes and spending and also take into account jobs that are lost in this transition, such as in refining, distributing and retailing fuel. Many of the jobs arise in the service sectors as a result of increased consumer spending due to the increase in real disposable incomes, brought about by the reduced annual cost of car ownership.

The new jobs that are created in the CPI, MED and HIGH scenarios are filled by (1) those that would otherwise be unemployed, and (2) those that are drawn into the labour market due an increase in economic activity which leads to higher wage rates. For more information on the labour market treatment in E3ME, refer to Appendix A.8.

The economy-wide employment impact in each scenario (relative to the REF baseline) is shown in Figure 8.

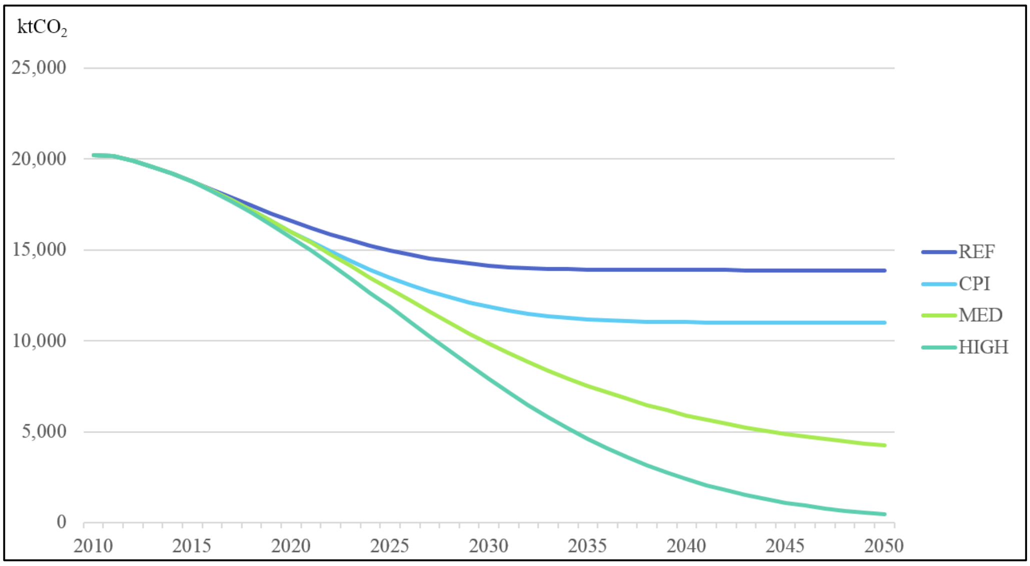
Figure 18 Net increase in jobs relative to the REF baseline



Environmental impact

CO_2 emissions from passenger cars in each scenario are shown in Figure 9. There is a sharp decline in vehicle emissions in the HIGH scenario, because of the almost complete decarbonisation of passenger cars in the Netherlands by 2050. The total cumulative emissions reduction in the HIGH scenario, over the period 2020-2050, is estimated as 258 $MtCO_2$ compared to the REF scenario.

Figure 19 Total CO_2 emissions from passenger cars (tank-to-wheel-basis)



First-mover advantage

In each of the scenarios modelled, the Netherlands leads Europe in the transition to a low-carbon vehicle fleet: emissions from new vehicles in the Netherlands are consistently below the EU average in each scenario. As well as the economic benefits already discussed, the early transition to a low-carbon vehicle fleet in the Netherlands could have further positive implications (not quantified here) for the Dutch economy and, in particular, the motor vehicles sector, because this sector could benefit from first-mover advantage. The relatively high growth in domestic demand for fuel-efficient vehicle technologies in the Netherlands is likely to drive an increase in innovation and industry output. There are already clear indications of such an expansion of research and development to support growth in demand for electric vehicles in the Netherlands:

- The VDL group is leading the way in the development of electric buses and coaches with the development of a vehicle platform to install hybrid, battery, or hydrogen fuel cell systems in buses[32].
- Fastned and ABB are manufacturing and installing thousands of public EV charging posts across the Netherlands.
- The Rotterdam Electric Scooter Factory is a new e-scooter learning facility that will create a knowledge-platform and advanced innovations in the expanding EV industry[33].
- Spijkstaal Elektro is an electric vehicle manufacturer in the Netherlands, with recent production volumes reaching 500 EVs per annum[34].

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[32] NL Agency (2013), *We are Holland ~~a pilot area~~ ready to market e-mobility*, available online: http://nederlandelektrisch.nl/fileadmin/klanten/ivdm/Nederland_Elektrisch/E-mobility_in_the_Netherlands.pdf

[33] NL Agency (2013), *We are Holland ~~a pilot area~~ ready to market e-mobility*

[34] NL Agency (2013), *We are Holland ~~a pilot area~~ ready to market e-mobility*

In short, rapid decarbonisation of the vehicle fleet and the consequent development of a Dutch EV export market could substantially increase the net benefits to the Dutch economy in addition to those quantified in this report.

Impact on the petroleum-refining sector

Although consumers and industries in the motor vehicle supply chain will benefit from the shift towards more fuel-efficient vehicles, some sectors of the economy could be adversely affected. The Netherlands has five large oil refineries run and managed by ExxonMobil, KPC, BP, Shell and Total/Lukoil. In 2011, the capacity for refined petroleum of these five refineries together reached 1.2mb/day[35], and annual turnover in the industry reached €24.4bn[36]. The Dutch refining sector accounts for 2-4% of total GVA[37] and a reduction in fuel demand from passenger cars and vans would have a knock-on impact on output and value added in the sector.

However, around 22% of domestically produced petroleum is used by the Dutch chemicals industry and around 63% is exported directly (mainly to Belgium and Germany via the RAP and RRP pipelines). This leaves only 15% of gross petroleum production that is used by motor vehicles and for other domestic purposes in the Netherlands. Given this low share, the transition to a low-carbon vehicle fleet in the Netherlands is unlikely to affect this industry as much as might be feared. However, as the industry is heavily dependent on export sales, a reduction in demand for petroleum in the rest of Europe could create more severe consequences for the Dutch refining sector.

In this analysis, we assume that the whole of Europe decarbonises the vehicle fleet to similar level. In the HIGH scenario it is assumed that, by 2050, 100% of new vehicle sales in the EU are BEVs and FCEVs. Thus, in the HIGH scenario we forecast that gross output in the refining sector falls by 6% (€2.6bn) in 2050[38] compared to the REF baseline scenario.

Comparison of economic impacts with other countries in the EU

Although the focus of this study was to consider the economic impact of low carbon vehicles in the Netherlands, the ‘Fuelling Europe’s Future’ report quantifies the expected economic impact of these scenarios on the EU economy, and we can use these results to compare the expected economic effects of low-carbon vehicles in the Netherlands, to that in the average country in the EU. The REF, CPI, MED and HIGH scenarios in this study are comparable to the REF, CPI, TECH 1 and TECH 3 scenarios respectively in ‘Fuelling Europe’s Future’, both in terms of the share of PHEVs, BEVs and FCEVs in the vehicle sales mix and the wider efficiency improvements. The results for GDP and employment at the EU level, and the results for the Netherlands are shown in Table 6 and Table 7.

In 2030, the percentage increase in GDP resulting from the transition to a low-carbon vehicle stock in the Netherlands, is broadly in line with the expected percentage increase in GDP for the average EU country (0.4% increase in the HIGH scenario in 2030). The percentage increase in employment is slightly lower in the Netherlands, when compared to the equivalent scenario at the EU level. This is due to greater productivity

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[35] IEA (2012) http://www.iea.org/publications/freepublications/publication/Oil&GasSecurityNL2012.pdf

[36] Eurostat (2013)

[37] Berenschot (2011), ‘Enterprise under Restraint’, available online: http://www.vnpi.nl/Files/file/EnterpriseunderRestraint.pdf

[38] In this analysis, it is assumed that for a given percentage reduction in petroleum demand, there is the same percentage reduction in petroleum imports and domestically produced petroleum.

improvements and higher increases in wage rates in the Netherlands, relative to in the average EU country.

In 2050, the positive economic impact of low-carbon vehicles in the Netherlands is slightly lower compared to the EU average. The reason for this is twofold:

1) The Netherlands is starting from a higher base. The efficiency of new vehicles in the Netherlands is already higher than the EU average, and consumers in the Netherlands are already benefitting from this. As the results are presented as difference from REF, they do not include the benefits of higher efficiency in the REF scenario in the Netherlands.
2) The size of the petroleum refining sector in the Netherlands is relatively large, the reduction in EU-wide demand for petrol and diesel, and the consequences this has for the Dutch refining industry slightly dampens the benefits of low-carbon vehicles to the domestic economy.

Table 6: GDP results

	REF	CPI	MED/TECH 1	HIGH/TECH 3
	(2010 prices)	(difference from REF)		
Netherlands (2030)	€795.7bn	€1.2bn (0.2%)	€1.4bn (0.2%)	€3.4bn (0.4%)
EU (2030)	€17,519.6bn	€36.7bn (0.2%)	€40.7bn (0.2%)	€72.5bn (0.4%)
Netherlands (2050)	€1,112.9bn	€2.6bn (0.2%)	€3.5bn (0.3%)	€7.2bn (0.7%)
EU (2050)	€25,604.5bn	€168.2bn (0.7%)	€223.4bn (0.9%)	€293.1bn (1.1%)

Source: E3ME (EU results taken from ‘Fuelling Europe’s Future’ study).

Table 7: Employment results

	REF	CPI	MED/TECH 1	HIGH/TECH 3
	(jobs)	(difference from REF)		
Netherlands (2030)	8,716,000	6,300 (0.1%)	9,200 (0.1%)	24,600 (0.3%)
EU (2030)	229,980,000	500,000 (0.2%)	660,000 (0.3%)	1,080,000 (0.5%)
Netherlands (2050)	8,403,000	10,500 (0.1%)	19,200 (0.2%)	32,800 (0.4%)
EU (2050)	217,680,000	1,380,000 (0.6%)	1,950,000 (0.9%)	2,350,000 (1.1%)

Source: E3ME (EU results taken from ‘Fuelling Europe’s Future’ study).

8 Modelling Assumptions

As with any forward-looking economic analysis, the results from this study are based on a number of simplifying assumptions. As far as possible, we have used recognized data sources and industry experts to ensure that the assumptions are based on the best currently available information. Where there are conflicting opinions, we have taken a realistic but conservative view.

The key modelling assumptions are described below.

Policy assumptions

One of the most important assumptions is that we do not model the policies that will be required to drive the transition to a low-carbon vehicle stock. We instead assess the macroeconomic effects of three alternative scenarios for the future, and do not assess the policies and incentives that may be required to deliver these futures. The precise definition of the policies will determine the distributional impacts of the low-carbon vehicle transition.

Constant vehicle sales

We assume that the total volume of vehicle sales does not change over time, and remains consistent between scenarios. In the more fuel-efficient scenarios, it could be argued that consumers will reduce their purchases of vehicles due to the higher initial up-front cost. Conversely, it could be argued that there would be an increase in vehicle sales due to the lower lifetime costs of owning and using vehicles. The true effect will depend on consumer preferences and the price and income elasticity of demand. We have not attempted to model these preferences in the present study, but we assume instead that vehicle sales are not affected by a transition to a low-carbon fleet. We also assume that vehicle lifetimes are unaffected after a shift to a more highly decarbonised fleet. The corollary of this assumption is that the total number of vehicles in the stock is also consistent between scenarios.

Domestic growth in the car manufacturing industry

Although we model the expansion of the vehicle manufacturing supply chain as a result of an increase in demand for fuel-efficient technologies and powertrains, we do not model the potential benefits to the Dutch economy of first-mover advantage. Having already achieved substantial vehicle efficiency improvements relative to other EU countries, the Netherlands has the potential to become a leader in fuel-efficient technologies and the development of the supporting infrastructure. Rapid growth in these industries could create opportunities to develop an export market in low-carbon vehicle technologies. However, there is considerable uncertainty around the locality and extent to which these markets will develop and, for that reason, we do not attempt a quantitative assessment of the impact of the Netherlands becoming a market leader and net exporter of low-carbon technologies.

Key sensitivities

There is considerable uncertainty about fuel costs, technology costs and infrastructure costs, especially over the longer term in the period 2030-2050. To present an unbiased and informed view, we have taken our assumptions from robust, independent sources. Although we have not carried out sensitivity analysis for the Netherlands specifically, key sensitivities were tested at the European level as part of the 'Fuelling Europe's Future' report and were not found to substantially affect the overall conclusions.

Fuel costs

The fossil fuel price assumptions for this analysis were taken from the IEA's central scenario. By 2030, real oil prices reach €105 per barrel and rise further to reach €117 per barrel by 2050. Electricity price assumptions are taken from the European

Commission's Roadmap report. They are consistent with an 80% renewable grid and with the assumption that EV users will pay the same price for electricity as households. Hydrogen prices are taken from the McKinsey study, "A portfolio of powertrains for Europe: A fact based analysis"[39]. We use the prices that are derived under a scenario with 80% renewable electricity generation and an assumption that 100% of hydrogen will be produced by electrolysis. By 2020, the hydrogen price reaches €6.6 per kg and falls to €4.4 per kg by 2050.

In the European study, we tested a sensitivity with lower fossil fuel prices and found that the positive impact on GDP in the TECH 3 scenario (equivalent to 'HIGH' in this study), relative to the REF baseline, was reduced by 0.3 percentage points (from +1.2% to +0.9% on the level of GDP in 2050). We would expect lower fossil fuel prices to have a similar impact on the results for the Netherlands.

Technology costs

The technology costs were developed as part of the pan-European study by Ricardo-AEA with input from stakeholders from across industry. These cost data also relied on figures provided by ACEA to the European Commission's Impact Assessment. The technology cost assumptions were also verified by equipment manufacturers and CLEPA (an organisation that represents the companies in the automotive industry supply chain). The learning cost reductions are modest, assuming a 10% reduction in cost for every cumulative doubling of production. In the European study, high and low technology cost ranges were tested, but found to have only modest impacts on the economic results.

Sensitivities around the cost of fuel-efficient technologies and vehicle powertrains were modelled at the European level. The results of this analysis show that under a low technology cost scenario (where the cost of vehicles in the HIGH scenario are around 4% lower than in central projections), the impact on GDP in 2050 at the European level is increased by 0.2 percentage points (from +1.15% to +1.35%). Under a high technology cost sensitivity (where the cost of vehicles in the HIGH scenario are 7% higher than in the central projections), the impact on the level of EU GDP is reduced by 0.4 percentage points in 2050 (from +1.15% to +0.75%).

Infrastructure costs

The assumptions for infrastructure costs were also taken from the 'Fuelling Europe's Future' report. Again, a modest learning rate of 10% is applied to the EV charging infrastructure in order to estimate the likely reduction in future costs.

Infrastructure cost sensitivities were not explicitly modelled for the Netherlands. However, we tested this assumption at the European level and found that the net positive impact on GDP was reduced by 0.6 percentage points (from +1.2% to +0.6%) for the level of GDP in 2050 under an assumption that the required infrastructure investment was at the lower bound of the expected range.

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[39] McKinsey (2010), "A portfolio of powertrains for Europe: A fact based analysis", available online: http://ec.europa.eu/research/fch/pdf/a_portfolio_of_power_trains_for_europe_a_fact_based__analysis.pdf

9 Concluding Remarks

Policies and strategies to decarbonise the economy are environmentally driven. This report assesses the economic implications of different potential decarbonisation pathways to 2050. It aims to inform the evidence base for reaching various environmental policy goals, rather than to advocate economic policy.

Through tax incentives the Netherlands has achieved substantial decarbonisation of cars over the past decade as carbon emissions from new vehicles have fallen from around 175 gCO_2/km in 2001 to 120 gCO_2/km in 2012. Consequently, even without any further policy commitment, emissions from the passenger vehicle stock will continue to fall as new efficient vehicles replace older vehicles that are retired from the stock.

In that context this report presents a scenario analysis of future decarbonisation pathways for passenger vehicles. The scenarios are not projections but four different representations of how low-carbon vehicle technology might evolve:

1. little further improvement (REF)
2. meeting and, in the case of the Netherlands, surpassing current European targets (CPI)
3. emissions reductions through improvements to traditional ICEs and the use of standard hybrids (MED)
4. a market dominated by advanced powertrains in 2030 and beyond (HIGH)

The scenarios are shaped by assumptions about vehicle sales, by formal modelling of the turnover of the vehicle stock in the Netherlands, and by the energy consumption of the resultant stock. From these assumptions two important characteristics of the vehicle stock can be fed into the economic model to assess the macroeconomic impacts:

1. the cost of new vehicles, which increases as new technologies are introduced and the proportion of advanced powertrains increases in the sales mix
2. the energy consuming characteristics of the vehicle stock

Increasing the speed and ambition of low-carbon technology deployment increases the cost of new vehicles, but it also reduces the annual fuel bill for motorists. The macroeconomic results reflect this trade-off.

As the cost of new cars increases, more money is diverted into vehicles. If there were no efficiency savings, this diversion of spending would disadvantage other sectors and therefore the economy overall. However, in all scenarios this negative impact is outweighed by the impact of reduced fuel bills for motorists. The resultant rise in real incomes leads to increased spending in all other sectors of the economy, but to the disadvantage of petroleum supply chains.

Although the impact of efficiency improvements in busses and HGVs was not modelled for this analysis, we would expect decarbonisation of these vehicle types to bring about additional positive benefits to the domestic economy, based on the assumption that the fuel bill savings due to improved efficiency would outweigh the annualised increase in vehicle costs. As commercial vehicles are heavier and travel longer distances than passenger cars and vans in any given year, it is likely that the fuel bill savings will be even greater for these modes of transport. The overall economic impact of low-carbon busses and HGVs, however, will ultimately depend upon the extent to which these cost savings are passed on to final consumers, in the form of lower prices.

The Netherlands differs from many European economies in that it is a major producer and exporter of refined petroleum products, serving German and Belgian markets in particular. A transition towards decarbonised cars in Europe and the Netherlands clearly has a negative impact on the refining sector. However, since much of the value of petroleum products lies in the imported crude oil, the reduced demand for refining is not sufficient to outweigh the positive macroeconomic impacts discussed. In this connection, it should be noted that most of the negative impact on the sector would be a result of improved vehicle efficiency in Germany or Belgium rather than in the Netherlands, since these countries are major importers of petroleum refined in the Netherlands.

The macroeconomic results do not vary greatly between scenarios, although greater efficiency leads to better macroeconomic results. Sensitivity analysis at the European level suggests that the results are robust at most plausible ranges of technology and fuel cost assumptions. We conclude, therefore, that in the long term there would be mild economic benefits from reducing emissions from cars, rather than a net economic cost.

Appendices

Appendix A: The E3ME model

A.1 Introduction

Overview

E3ME is a computer-based model of the global economy, energy systems and the environment. It was originally developed through the European Commission's research framework programmes and is now widely used in Europe and beyond for policy assessment, for forecasting and for research purposes. The global edition is a new version of E3ME which expands the model's geographical coverage from 33 European countries to 53 global regions. It thus incorporates the global capabilities of the previous E3MG model.

Recent applications

Recent applications of E3ME include:

- an assessment of the economic and labour market effects of the EU's Energy Roadmap 2050
- contribution to the EU's Impact Assessment of its 2030 environmental targets
- evaluations of the economic impact of removing fossil fuel subsidies
- an assessment of the potential for green jobs in Europe
- an economic evaluation for the EU Impact Assessment of the Energy Efficiency Directive

This model description provides a summary of the E3ME model and its main assumptions and limiations. For further details, the reader is referred to the full model manual available online at www.e3me.com.

A.2 E3ME's basic structure and data

E3ME is post-Keynesian in nature. There is no underlying assumption about the rationality of agents and hence no conclusion drawn about the efficiency of the outcome delivered by the market or as a result of policy intervention; instead the way that actors respond to economic signals is inferred from econometric interrogation of historical data sets. E3ME does not assume that prices adjust automatically to bring about equilibrium between demand and supply; instead prices are formed as a mark-up on costs and passed on to purchasers or set by world markets, and again the nature of this behaviour is inferred from historical relationships in each industry. This means that there can be excess capacity in the economic system and so an increase in effective demand can lead to higher overall activity rates.

The E3ME modelling approach imposes rather less from economic theory than most other macroeconomic models and sets behavioural responses on the basis of empirical evidence that reflects current and past economic trends. This means that the modelling takes into account real-world factors such as involuntary unemployment (see Section A.8) that are missing from a pure Computable General Equilibrium (CGE) approach. Amongst economists there is some debate about the merits of using these trends to predict future economic behaviour but this is a criticism that can be applied to all modelling approaches (see Section A.9).

The structure of E3ME is based on the system of national accounts, with further linkages to energy demand and environmental emissions. The labour market is also covered in detail, including both voluntary and involuntary unemployment. In total there are 33 sets of econometrically estimated equations, also including the components of GDP (consumption, investment, international trade), prices, energy demand and materials demand. Each equation set is disaggregated by country and by sector.

E3ME's historical database covers the period 1970-2012 and the model projects forward annually to 2050. The main data sources for European countries are Eurostat and the IEA, supplemented by the OECD's STAN database and other sources where appropriate. For regions outside Europe, additional sources for data include the UN, OECD, World Bank, IMF, ILO and national statistics. Gaps in the data are estimated using customised software algorithms.

A.3 The main dimensions of the model

The main dimensions of E3ME are:

- 53 countries – all major world economies, the EU28 and candidate countries plus other countries' economies grouped
- 43 or 69 (Europe) industry sectors, based on standard international classifications
- 28 or 43 (Europe) categories of household expenditure
- 22 different users of 12 different fuel types
- 14 types of air-borne emission (where data are available) including the six greenhouse gases monitored under the Kyoto protocol

A.4 Model inputs and outputs

In this study, the results from the vehicle stock model (stock fuel consumption by fuel type, charging infrastructure investment and average prices of new vehicles) were used as exogenous inputs to the E3ME model for each scenario. Whilst the vehicle stock model assesses the impacts on costs and energy consumption by powertrain type, E3ME models the impact of changes in the average price of vehicles, aggregate fuel consumption, and EV charging infrastructure investment on the Netherlands economy.

As a general model of the economy, based on the full structure of the national accounts, E3ME is capable of producing results for a broad range of economic indicators. In addition there is range of energy and environment indicators. The following list provides a summary of the most common model outputs:

- GDP and the aggregate components of GDP (household expenditure, investment, government expenditure and international trade)
- sectoral output and GVA, prices, trade and competitiveness effects
- international trade by sector
- consumer prices and expenditures
- sectoral employment, unemployment, sectoral wage rates and labour supply
- energy demand, by sector and by fuel, energy prices
- CO_2 emissions by sector and by fuel
- other air-borne emissions
- material demands (Europe only at present)

This list is by no means exhaustive and the delivered outputs often depend on the requirements of the specific application. In addition to the sectoral dimension mentioned in the list, all indicators are produced at the national and regional level and annually over the period up to 2050.

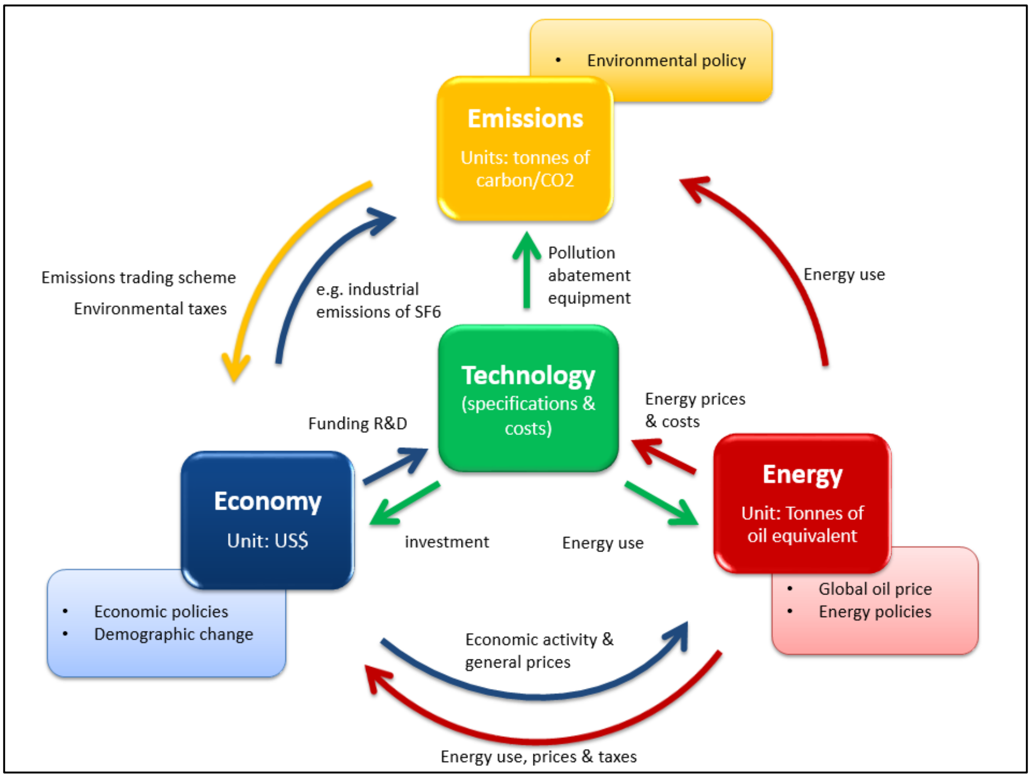
A.5 E3ME as an E3 model

The E3 interactions

Figure A.1 shows how the three components (modules) of the model - energy, environment and economy - fit together. Each component is shown in its own box. Each data set has been constructed by statistical offices to conform with accounting conventions. Exogenous factors coming from outside the modelling framework are shown on the outside edge of the chart as inputs into each component. For each region's economy the exogenous factors are economic policies (including tax rates, growth in government expenditures, interest rates and exchange rates). For the energy system, the outside factors are the world oil prices and energy policy (including regulation of the energy industries). For the environment component, exogenous factors include policies such as reduction in SO_2 emissions by means of end-of-pipe filters from large combustion plants. The linkages between the components of the model are shown explicitly by the arrows that indicate which values are transmitted between components.

The economy module provides measures of economic activity and general price levels to the energy module; the energy module provides measures of emissions of the main air pollutants to the environment module, which in turn can give measures of damage to health and buildings. The energy module provides detailed price levels for energy carriers distinguished in the economy module and the overall price of energy as well as energy use in the economy.

Figure A.1 E3 linkages in the E3ME model



The role of technology

Technological progress plays an important role in the E3ME model, affecting the economy, energy and the environment. The model's endogenous technical progress indicators (TPIs), a function of R&D and gross investment, appear in nine of E3ME's econometric equation sets including trade, the labour market and prices. Investment and R&D in new technologies also appears in the E3ME's energy and material demand equations to capture energy/resource savings technologies as well as pollution abatement equipment. In addition, E3ME also captures low carbon technologies in the power sector through the FTT power sector model[40].

A.6 Comparison with CGE models and econometric specification

An assessment of this type must use modelling tools, as it is not possible to conduct real-life macroeconomic experiments. All models represent a simplified version of reality and are based on assumptions about how agents in the economy behave and interact with each other.

Previous analysis has shown that differences in the assumptions underlying the design of macroeconomic models can cause differences, and sometimes important differences, in the results from model-based analyses. This in turn often reflects the varying assumptions and theories associated with different schools of economic thought. When interpreting the results from an economic modelling exercise, it is therefore important to understand the main underlying assumptions to the analysis.

E3ME is often compared to Computable General Equilibrium (CGE) models. In many ways the modelling approaches are similar; they are used to answer similar questions and use similar inputs and outputs. However, underlying this there are important theoretical differences between the modelling approaches.

In a typical CGE framework, optimal behaviour is assumed, output is determined by supply-side constraints and prices adjust fully so that all the available capacity is used. In E3ME the determination of output comes from a post-Keynesian framework and it is possible to have spare capacity. The model is more demand-driven and it is not assumed that prices always adjust to market clearing levels.

The differences have important practical implications, as they mean that in E3ME, regulation and other policy may lead to increases in output if they are able to draw upon spare economic capacity. This is described in more detail in the model manual which is available online at www.e3me.com.

The econometric specification of E3ME gives the model a strong empirical grounding. E3ME uses a system of error correction, allowing short-term dynamic (or transition) outcomes, moving towards a long-term trend. The dynamic specification is important when considering short and medium-term analysis (e.g. up to 2020) and rebound effects[41], which are included as standard in the model's results.

Our assumptions on the capital and labour markets are described in Section A.7 and Section A.8. In section A.9 we reflect on the 'Luas Critique', which is one of the key criticisms of macroeconomic models.

A.7 Treatment of investment in E3ME

It is a macroeconomic accounting identity that at global level savings must be equal to investment. This identity is respected in all serious modelling approaches, although the assumptions about how individuals save and invest and the way in which differences in intentions to save and invest are brought into global consistency may differ.

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[40] See Mercure (2012).

[41] Where an initial increase in efficiency reduces demand, but this is negated in the long run as greater efficiency lowers the relative cost and increases consumption. See Barker et al (2009).

In the standard CGE modelling approach, capital markets, like all other markets, are assumed to operate efficiently, with a single price (here the interest rate) adjusting so that there is a balance between supply (savings) and demand (investment). Since resources are assumed to be fully employed, it is not possible to increase investment in a specific sector without either reducing investment elsewhere or increasing savings (at the expense of current consumption). If an increase in investment in one product leads to a reduction in investment elsewhere, this is referred to as ‘crowding out’.

E3ME does not assume that resources are fully employed, meaning that investment in EV chagrining infrastructure can be increased without crowding out (with an associated creation of financial assets). The result is typically an overall increase in economic output.

There are three reasons for assuming that energy system investment does not ‘crowd out’ investment that would otherwise take place in the domestic economy. Firstly, many of the energy investment projects are financed by international corporations and, if these companies do not invest in the Netherlands, it is likely that they will invest overseas instead.

Secondly, even if capital projects were not able to access global finance, there is a possibility of spare financing capacity or credit creation in the Netherlands economy, which could become available to fund investment projects. If there is opportunity for returns on capital investment, then firms will have an incentive to engage in capital investment programmes. Alternatively, if the economic outlook is poor, or if there are no profitable investment opportunities, firms may instead invest in existing financial or property assets, which would push up prices of these assets but may not increase activity in the real economy.

Thirdly, the price effects calculated in the model include the prices required to pay for the investment. If the price changes are accounted for, then so should the commensurate changes in investment (and, indeed, the rest of the supply chain).

A.8 Treatment of the labour market in E3ME

Treatment of the labour market is another area that distinguishes E3ME from other macroeconomic models. A basic market-equilibrating approach would suggest that wages adjust automatically so that employment demand matches labour supply and there are no involuntarily unemployed resources. In this case, full employment is achieved automatically and an increase in employment in one sector would necessarily ‘crowd out’ employment in another sector (due to wage rates increasing). However, the experience of persistent involuntary unemployment calls into question the empirical relevance of this kind of equilibrium-based approach.

The wage equations in E3ME take into account the various rigidities in the labour markets and effectively assume that these rigidities remain unchanged in the future. Unless there is a very large stimulus (i.e. enough to achieve full employment), average wage rates will therefore remain above what would be described as an equilibrium value (although, in a Keynesian model, cutting wages may not achieve full employment), meaning that not all labour resources are used. Involuntary unemployment is the result.

If full employment was somehow to be achieved, further demand increases in E3ME would lead to higher wage rates rather than more employment (once the possibilities for higher wages to draw more people into the labour market have been exhausted). This can lead to an inflationary spiral, as has been seen in the past. The difference between E3ME and the standard CGE approach is that this is only one possible (and unlikely) outcome in E3ME, while it is the standard outcome in basic CGE models.

The implication of assuming that unemployment exists in the long run, as is the case in E3ME, is that an economic stimulus, such as the increase in infrastructure investment and the expansion of the supply chain modelled in the low-carbon scenarios, result in both an increase in economic output and an increase in labour demand. Higher demand for labour drives an increase in real wage rates and an increase in employment, as some people move into a more attractive labour market, whilst others move out of unemployment.

Other key assumptions and potential limitations of E3ME in relation to the labour market are outlined below:

- Population is usually given as exogenous in macroeconomic models. In some CGE models, labour supply (the part of the population that enters the labour force) is treated as exogenous as well; in others it is endogenous, as it is in E3ME. The fact that the population is treated as exogenous means that macroeconomic models do not typically model international migration which has, for example, been substantial within the EU in the past decade. Instead, migration is exogenous and unchanged across scenarios. This is partly due to data limitations but also to difficulties in establishing economic relationships. However, in the scenarios modelled in this report, the assumption seems reasonable.
- One of the weaknesses of the labour market treatment in all macroeconomic models is the assumption that any worker is able to fill any job; this is due to limitations in the available data. In some cases this assumption may not hold due to skills shortages and so supplementary off-model analysis is required to assess the impact of possible specific skills shortages. In this report it has been assumed that there are no skills shortages constraining the take-up of new jobs by the existing labour force, so this is a possible area for further analysis.

A.9 The use of historical patterns to predict future behaviour

Most macroeconomic models include a representation of individual behaviour in the form of model parameters. These parameters may be estimated econometrically from a time series of historical evidence, calibrated to fit a single year's data, or inferred from expert judgement or previous research. In the models these parameters are used to determine future behavioural responses.

In the 1970s it was questioned whether it was appropriate to use parameters derived under one set of conditions (e.g. time period or policy regime) to carry out analysis under a different set of conditions. One particular form of this criticism is the 'Lucas Critique'. Although the Lucas Critique could be applied to all modelling approaches, it is particularly relevant to macro-econometric models, where all behaviour, including price formation, is dependent on parameters derived from historical data sets.

This study uses parameters estimated from a data period going back to 1970 in scenarios going out to 2050, with a rather different energy system. This raises the question as to whether the estimated behavioural relationships might change in the projection period.

Our response to this criticism is that there is little alternative available without being able to see into the future. While it is acknowledged that there is considerable uncertainty about model parameters in the long run, the historical estimates represent the best information available on which to base a judgement. It seems preferable to base our estimates on long-term historical experience than merely on very recent experience or on judgements that are not tested against historical experience at all.

In addressing this issue it is therefore important to note that there are uncertainties about the results, particularly the further into the future we go and the further from history that the scenarios take us. However, the fact of uncertainty does not lead to any presumption that the results are biased in any particular direction. Further sensitivity of key parameters and baseline values could be carried out to demonstrate this feature of the results.

Appendix B: Technology costs

The additional cost of vehicles in the CPI, MED and HIGH scenarios incorporates two effects. Firstly, there are improvements to the efficiency of the conventional ICE in all scenarios. Secondly, in the MED and HIGH scenarios, there is a transition to a higher share of more advanced (and more expensive) powertrains (hybrids in the MED scenario, and plug-in hybrids and battery electric vehicles in the HIGH scenario). The cost and fuel savings associated with the efficiency improvements to the conventional ICE were taken from ‘Fuelling Europe’s Future’ and are outlined in Table B.1 below.

Table B.1 Technologies to improve the efficiency of the conventional ICE

Technology	Type	Energy reduction	Cost
Petrol - low friction design and materials	PtrainsE	-2%	€ 39
Petrol - gas-wall heat transfer reduction	PtrainsE	-3%	€ 55
Petrol - direct injection (homogeneous)	PtrainsE	-5%	€ 199
Petrol - direct injection (stratified charge)	PtrainsE	-9%	€ 608
Petrol - thermo-dynamic cycle improvements	PtrainsE	-15%	€ 539
Petrol - cam-phasing	PtrainsE	-4%	€ 88
Petrol - variable valve actuation and lift	PtrainsE	-11%	€ 310
Diesel - variable valve actuation and lift	PtrainsE	-1%	€ 310
Diesel - combustion improvements	PtrainsE	-6%	€ 55
Mild downsizing (15% cylinder content reduction)	PtrainsE	-6%	€ 304
Medium downsizing (30% cylinder content reduction)	PtrainsE	-9%	€ 522
Strong downsizing (>=45% cylinder content reduction)	PtrainsE	-18%	€ 719
Reduced driveline friction	PtrainsE	-1%	€ 55
Optimising gearbox ratios / down-speeding	PtrainsE	-4%	€ 66
Automated manual transmission	PtrainsE	-5%	€ 332
Dual clutch transmission	PtrainsE	-6%	€ 802
Start-stop hybridisation	PtrainE	-5%	€ 235
Start-stop + regenerative braking	PtrainE	-10%	€ 442
Non-specific improvement	PtrainE	-10%	€ 0
Aerodynamics improvement	Aero	-2%	€ 61
Low rolling resistance tyres	Rres	-3%	€ 41
Mild weight reduction ~10% total	Weight	-7%	€ 39
Medium weight reduction ~20% total	Weight	-14%	€ 243
Strong weight reduction ~30% total	Weight	-20%	€ 896
Very strong weight reduction ~35% total	Weight	-24%	€ 1,800
Extreme weight reduction ~40% total	Weight	-27%	€ 3,000
Thermo-electric waste heat recovery	Other	-2%	€ 1,106
Secondary heat recovery cycle	Other	-2%	€ 250
Auxiliary systems efficiency improvement	Other	-12%	€ 498
Thermal management	Other	-3%	€ 166
Long term ICE improvements (stage 1)	Other	-8%	€ 400
Long term ICE improvements (stage 2)	Other	-5%	€ 1,000

Source: Cambridge Econometrics and Ricardo AEA (2013), ‘Fuelling Europe’s Future’.

The share of vehicles that contain the various efficient technologies listed above varies between scenarios and over time, with most vehicles in the HIGH scenario containing most of the efficient technologies listed in Table B.1, as well as the strong reductions in size and weight by 2050. In comparison, in the REF scenario, only a limited share of vehicles incorporate the technologies listed in Table B.1. For each energy-efficient technology, we assume that learning effects leads to a cost reduction of 10% for every cumulative doubling of European sales.

In addition to the increase in energy-efficient technologies installed in new vehicles, the transition to more advanced powertrains further increases the cost of vehicles in the MED and HIGH scenario. Table B.2 shows the cost of the various powertrain types in the HIGH scenario. The cost of a conventional ICE increases slightly over the period to 2050, as the price incorporates the cost of more energy-efficient technologies that are installed in new vehicles. On the other hand, we assume that the cost of BEVs and FCEVs falls substantially over time, as a result of economies of scale and learning effects. By 2050, the price of an average BEV is expected to be around 7% higher than the cost of an ICE in this scenario.

Table B.2 The cost of various powertrains in the HIGH scenario (excl. tax and margins)

Powertrain type	2010	2020	2030	2040	2050
ICE	15.1	16.4	16.9	17.1	17.0
HEV	18.0	17.6	17.4	17.3	17.2
PHEV	26.5	20.6	19.2	18.6	18.2
BEV	31.6	22.4	19.6	18.6	18.2
FCEV	60.0	25.2	20.0	18.8	18.0

Appendix C: Cost of car ownership

This Appendix explains the calculation for the annualised cost of ownership (in 2010 prices) under each scenario, for a new car in 2030 and 2050.

We assume that consumers pay for the vehicle through a series of monthly payments with an interest rate of 10% APR. Based on this assumption, as well as our assumptions on technology costs, fuel costs and annual mileage outlined in Chapter 2, our analysis shows that the annualised cost of new vehicles in the HIGH scenario are slightly lower than in the REF scenario in both 2030 and 2050.

Table C.1 Annualised cost of vehicle ownership for new vehicles in 2030

	REF	CPI	MED	HIGH
Capital cost	€16,279	€16,586	€17,880	€19,859
Annualised vehicle cost (10% APR)	€2,043	€2,082	€2,244	€2,493
Annual fuel cost	€1,120	€889	€482	€258
Annual maintenance cost	€363	€362	€361	€301
Total cost of ownership	**€3,526**	**€3,333**	**€3,087**	**€3,051**

Table C.2 Annualised cost of vehicle ownership for new vehicles in 2050

	REF	CPI	MED	HIGH
Capital cost	€16,243	€16,541	€19,196	€20,491
Annualised vehicle cost (10% APR)	€2,039	€2,076	€2,409	€2,572
Annual fuel cost	€ 1,194	€ 949	€ 314	€ 150
Annual maintenance cost	€345	€344	€343	€248
Total cost of ownership	**€3,578**	**€3,369**	**€3,066**	**€2,970**