AN ECONOMIC ASSESSMENT OF LOW CARBON VEHICLES

cambridge econometrics

RICARDO-AEA

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Executive Summary

Europe faces a significant economic challenge. Ahead lies the task of reigning in public debt, revitalizing stagnant economies and creating new opportunities for millions of jobless workers. At the same time, the European Union has committed to playing a lead role in tackling climate change. Among the EU's headline climate initiatives, the European Commission's Transport White Paper sets a goal of reducing transport CO2 emissions by 60 percent by 2050. It is therefore important to understand the economic impact of the transition to low-carbon vehicles.

This technical and macro-economic study focuses on light duty vehicles -- cars and vans. It has been advised by a broad group of stakeholders in the move to low-carbon transport, including auto producers, technology suppliers, labour groups, energy providers and environmental groups. The resulting fact-base is anticipated to serve as a reference point for discussions around the low-carbon transition.

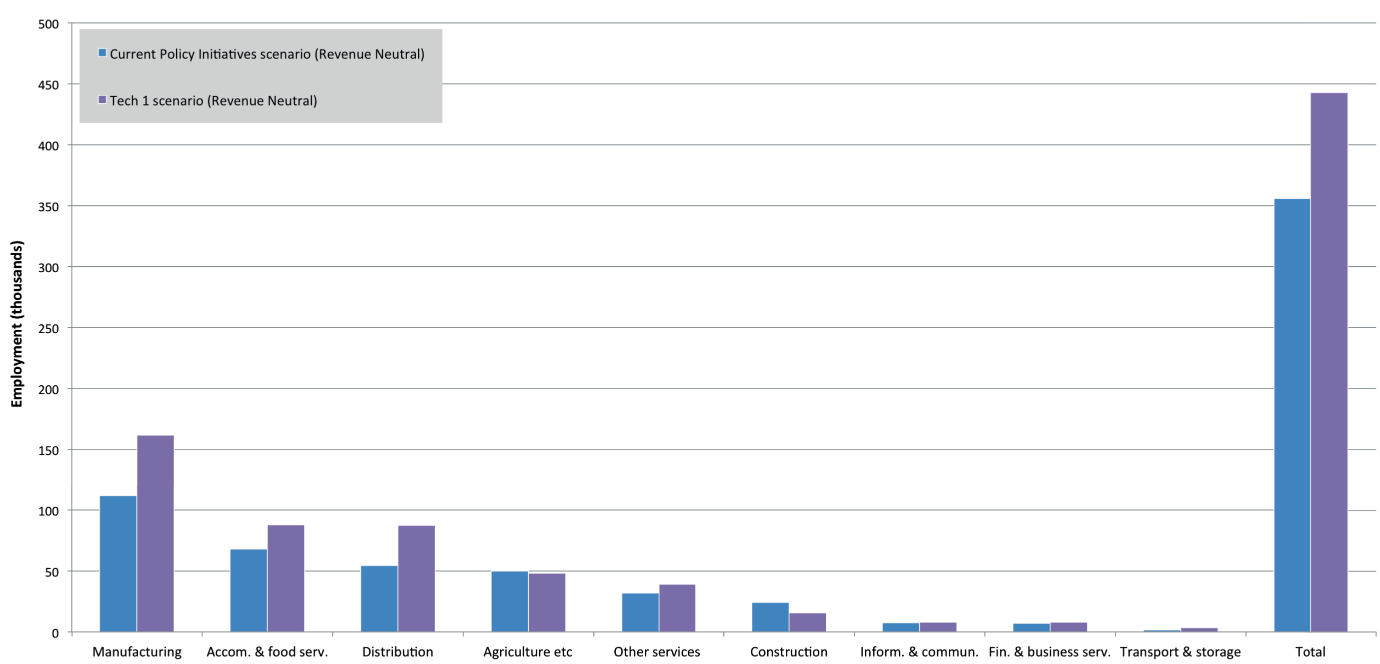
The model results show that a shift to low-carbon cars and vans increases spending on vehicle technology, a sector in which Europe excels, therefore generating positive direct employment impacts. This shift will also reduce the total cost of running Europe's auto fleet, leading to mildly positive economic impacts including indirect employment gains (Fig 1.1).

Data on the cost of low carbon vehicle technology has been largely sourced from the auto industry itself – Industry submissions for the European Commission's impact assessment on the proposed CO2 standards for cars and vans in 2020. This has been supplemented where necessary, for example by data from similar assessments for the UK and US governments.

Fuel price projections are based on the IEA's World Energy Outlook. Technical modelling was done using the transport policy scoping tool SULTAN (developed for the European Commission) and the Road Vehicle Cost and Efficiency Calculation Framework developed by Ricardo-AEA. Macro-economic modelling was done using the E3ME econometric model, which has previously been used for several European Commission and EU government impact assessments.

Fig 1.1 - Employment impact of low carbon vehicle scenarios in 2030

The results include both direct impacts from increased spending on vehicle technology and indirect impacts that result from lower fuel bills across the economy.



Source: Cambridge Econometrics

The project takes a phased approach. The first phase, presented in this report, examines the impact of improving the efficiency with which fossil fuels are burned in vehicles. Efficiency gains are delivered via improvement of the Internal Combustion Engine (ICE) vehicle, including light-weighting, engine-downsizing and hybridization. The second phase, to be presented in mid-2013, examines the impact of gradually substituting fossil fuels with increasing levels of indigenous energy resources, such as electricity and hydrogen.

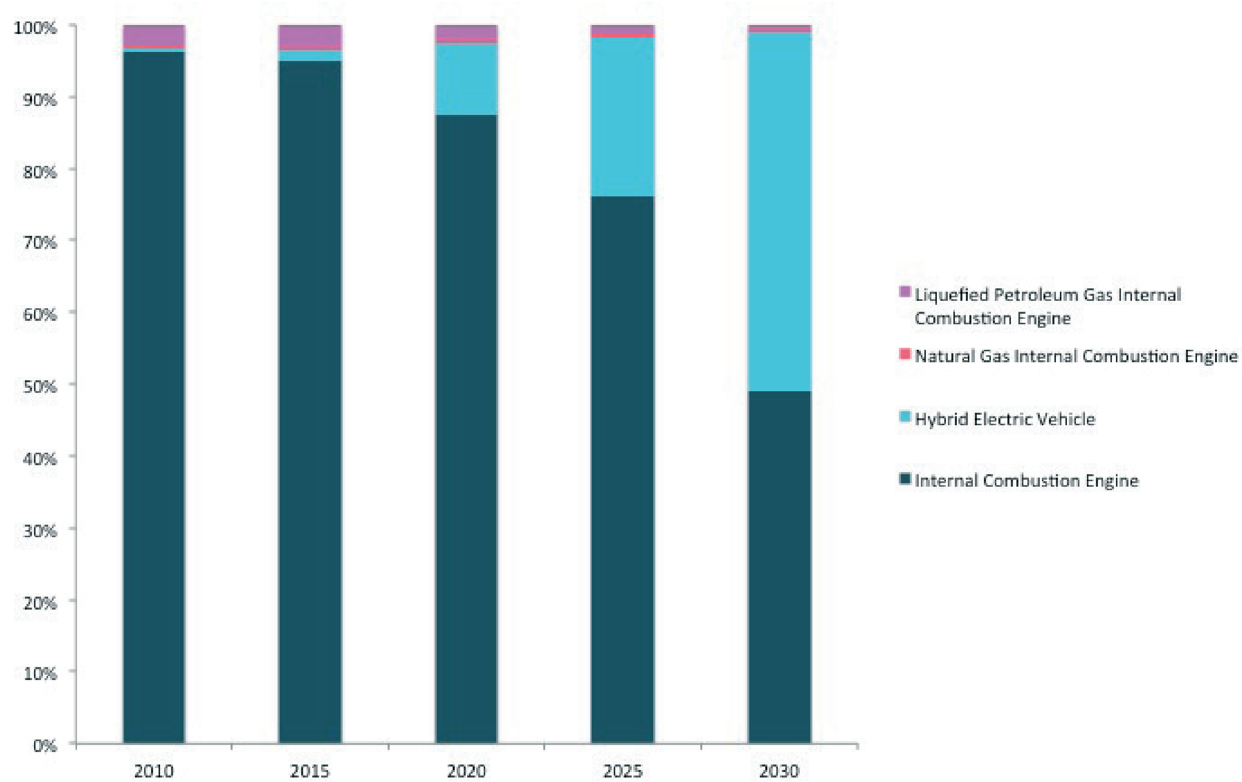
Two scenarios are assessed in this first phase of the project, by comparing them against a reference case in which vehicle efficiency is frozen at the current level. In the first scenario, named Current Policy Initiatives, cars and vans achieve the EU's proposed 2020 CO_2 target of 95g/km and 147g/km respectively, but efficiency improvements moderate to a rate of less than 1 percent per annum thereafter. In the second scenario, Tech 1, cars and vans achieve slightly higher efficiency levels in 2020 and continue along a similar trajectory of around 3 percent annual improvement thereafter. Over-achieving on targets is a plausible scenario, because several automakers have already met their 2015 goals ahead of time.

In the Tech 1 scenario, gasoline and diesel Hybrid Electric Vehicles (HEV) are deployed at an ambitious rate (Fig 1.2). The scenario assumes market penetration of HEVs of 10 percent of new vehicle sales in 2020, 22 percent in 2025 and 50 percent penetration in 2030. The scenarios in this project are not an attempt to predict the evolution of future vehicle markets, which is highly uncertain, but to examine a range of possible future outcomes.

This report from Phase I of the project ignores the penetration of advanced powertrains, such as Battery Electric- or Fuel Cell Electric Vehicles, but this does not mean the group thinks such powertrains will not be deployed before 2030. Scenarios including the deployment of advanced powertrains will be modeled in Phase II of the project.

The model results show that the effect of reduced spending on fuel more than outweighs the impact of increased spending on vehicle technology to reduce carbon emissions.

Fig 1.2 - Rate of technology deployment in the Tech 1 scenario until 2030



Source: Ricardo-AEA

At an individual level, the cost of additional vehicle technology adds about €1,000 - €1,100 to the cost of the average car in 2020, compared to the average 2010-manufactured car. However, this is offset within several years via fuel savings. The owner of the average new car in 2020 will spend around €400 less on fuel each year than the owner of the average 2010-manufactured car.

At the EU level, the capital cost of the car and van fleet rises to €472 billion in 2030, in the Tech 1 scenario, compared to €426 billion in the Reference Case, where fuel-saving technology is frozen at current levels (Fig 1.3). This represents €46 billion of additional capital costs. In this same scenario, the EU fuel bill (excluding fuel taxes and duties) is €166 billion in 2030, compared to €245 billion in the Reference Case. This represents avoided fuel costs of €79 billion (Fig 1.4).

At the EU level, this makes the total cost of running and renewing the EU car fleet in 2030 about €33 billion lower than in the Reference Case. This efficiency improvement feeds through to the wider economy in two ways. Firstly, there is a direct benefit to GDP from reduced imports of fossil fuels, which improves the trade balance. Secondly, there are indirect benefits to households and businesses, as lower operating costs are passed on in the form of lower prices for customers. For households this means an increase in real incomes. For businesses this gives a boost to competitiveness against foreign firms.

Fig 1.3 - Total capital cost of the EU car and van fleet until 2030 under the 3 scenarios modeled (excl tax)

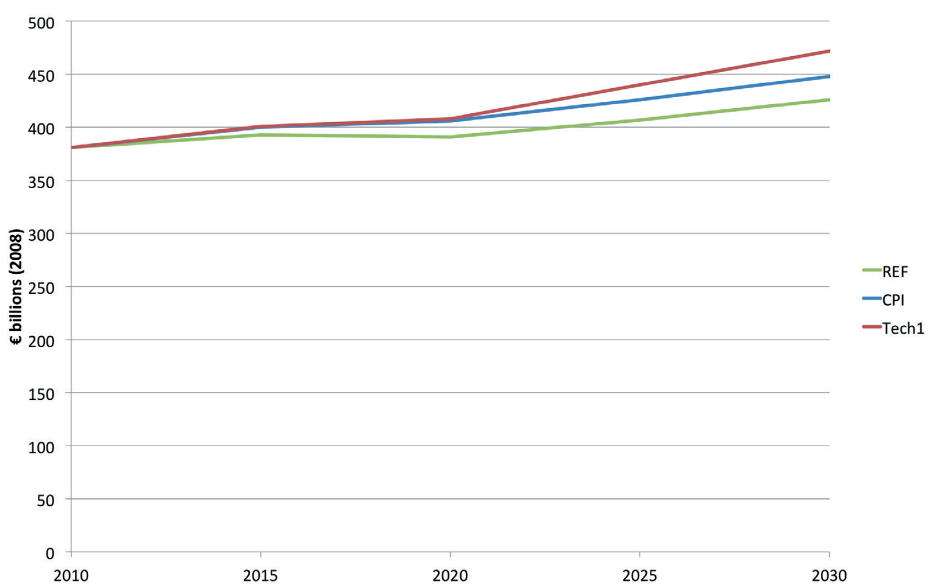
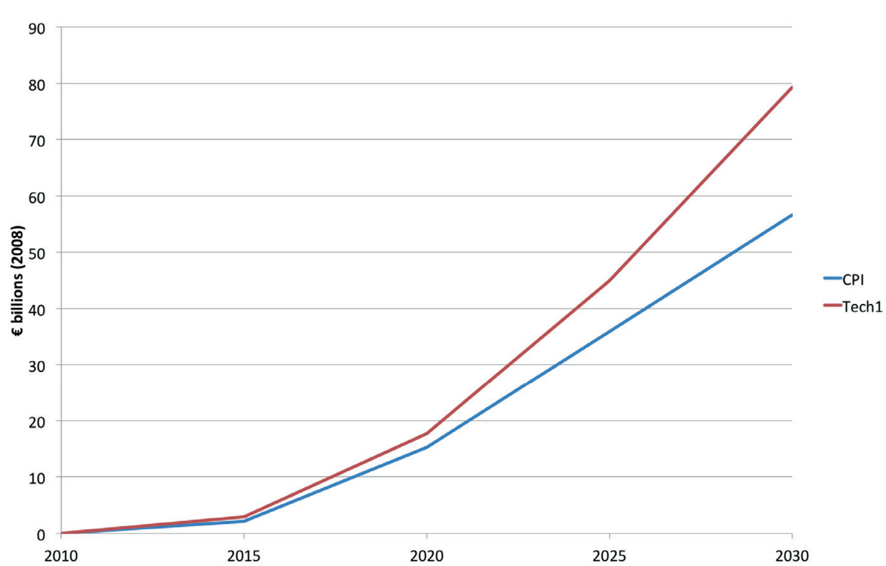


Fig 1.4 - Avoided fuel costs for the EU car and van fleet until 2030, relative to the Reference Case (excl tax)



The E3ME model results show that increased spending on the technology within vehicles leads to job creation. This derives from increased jobs in the manufacturing of fuel-efficient automotive components and from a general boost to the wider economy as a result of decreased spending on imported oil. The Tech 1 scenario could create around 443,000 net additional jobs by 2030, while the CPI scenario creates around 356,000 (Fig 1.1).

The combined impact on GDP is neutral to very mildly positive (+€10 billion to +€16 billion in 2030 in the two scenarios presented here) (Fig 1.5). Even when using the highest-case costs for technology, the GDP impact remains unchanged overall, while around 413,000 net additional jobs are created. This derives from the fact that most of the money spent on fuel leaves the European economy, while most additional money spent on fuel-saving technology remains in Europe as revenues for the technology suppliers. For example, EU companies that supply fuel-efficient start-stop mechanisms would benefit from an increase in revenue, due to an increase in demand for their products.

These economic and employment results are tax-neutral, meaning that total government tax revenues are modelled as equal in all scenarios. The results also take full account of negative impacts in the losing sectors in a low-carbon transition, such as the refining, distribution and retail of fossil fuels.

The positive impact on jobs and GDP was highest in sensitivity analyses with high international oil prices, due to the increased value of avoided fuel consumption. This will become an increasingly important economic factor in Phase II of the project, which looks at the timeframe 2020-2050, when advanced powertrains play an increasing role.

The impacts in Phase II are typified by higher costs of technology and greater avoided fuel costs. In addition, there is a new dimension from the substitution of oil, which is largely imported, with electricity and hydrogen, which are largely generated from indigenous energy resources. The findings will carry particular significance in light of concerns that rising costs of imported energy might act as a brake on Europe's future economic recovery.

Fig 1.5 - Economic impacts in 2030

Monetary figures are shown as absolute difference from the Reference Case (€2008). Results are provisional.

	REFERENCE		CURRENT POLICY INITIATIVE	TECH 1 SCENARIO
Capital cost EU car and van fleet (excl tax)	€426 bln	↑	+€22 bln	+€46 bln
Fuel cost (excl tax, duties)	€245 bln	↓	-€57 bln	-€79 bln
Total cost EU car and van fleet (excl tax) *	€803 bln	↓	-€35 bln	-€33 bln
Employment	230 mln	↑	+356,000	+443,000
GDP	€15,589 bln	→	+€16 bln	+€10 bln

Source: Cambridge Econometrics E3ME

* This number includes annual running costs such as maintenance, which is why it is higher than the sum of the capital cost and the fuel cost.

Contents

Introduction

This report seeks to quantify the impact on society of reducing the consumption of fossil fuels by cars and vans. This transition is anticipated to entail a progressive shift to a mix of low-carbon technologies, primarily efficient Internal Combustion Engine (ICE) vehicles, Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs), Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs). The input data has been largely sourced from the auto industry's submissions to the European Commission's impact assessment on the cost of meeting the proposed 2020 CO_2 standards for cars and vans. This data has been reviewed by a large group of stakeholders in the transition to low-carbon transport, including auto producers, auto technology suppliers, employer groups, academic experts and environmental groups.

The study takes a phased approach. The first phase, presented in this report, examines the impact of improving the efficiency with which fossil fuels are burned in vehicles. Efficiency gains are delivered via improvement of the Internal Combustion Engine (ICE) vehicle, including light-weighting, engine-downsizing and hybridization. The second phase, to be presented in a future report, examines the impact of gradually substituting fossil fuels with domestically produced electricity and hydrogen as energy sources for vehicles. The project will in future also examine the skills and training requirements of this transition, as well as questions about how Europe's automotive industry can remain competitive in the global economy.

This report, from Phase I of the project, examines the timeframe 2010-2030, during which the predominant automotive technologies are the ICE vehicle and the HEV. The impact on the economy is primarily derived from the impact of increasing the fuel-saving technology content in cars and vans, combined with the impact of reducing the consumption of oil, which is largely imported.

2. Policy Context

The use of regulatory standards to control CO_2 emissions has been proven to be a cost-effective measure, and is likely to broaden to other modes of transport in the future. Understanding the wider potential impact of such future standards on the European economy is therefore of particular interest.

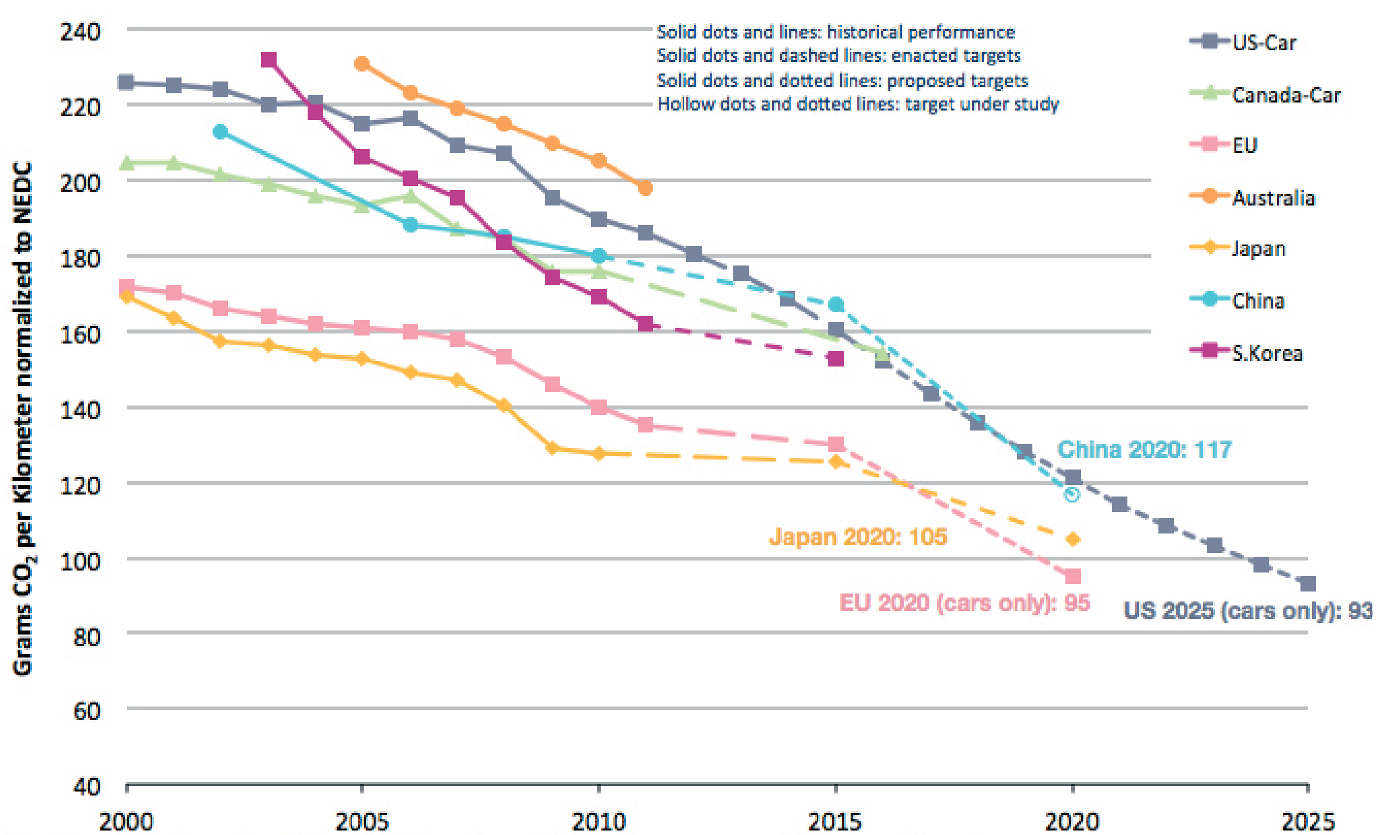
CO_2 emissions targets for light-duty vehicles in the EU were first introduced in 1998 under the voluntary ACEA Agreement. The goal of this voluntary agreement was to reduce CO_2 from passenger cars to 25 percent below 1995 levels (to 140g/km) by 2008/9.

Following under-performance of the voluntary agreement, the EU moved to mandatory CO_2 standards for light-duty vehicles. In 2009, the EU formally adopted Regulation 443/2009, which sets an average CO_2 target for new cars sold in the EU of 130 g/km by 2015 (according to the NEDC Test Cycle), backed up by penalties for non-compliance.

For 2020, Regulation 443/2009 set a target of 95g/km, with an obligation for the Commission to review this target and define the specific modalities for implementation. This was proposed by the Commission in July 2012 and is now undergoing political review by the European Parliament and Council. Similar regulation exists for light commercial vehicles (Regulation No 510/2011), which aims to cut CO_2 emissions from vans to an average of 175g/km by 2017 and to 147g/km by 2020.

Historically, Japan and the EU have led in vehicle emission performance, and this is expected to continue. However, Canada and the US have recently introduced measures to reduce vehicle emissions between 2011 and 2016 by around 4 percent per annum. In 2012, the US agreed a 2025 standard of 107g/km (93g/km for cars alone). As a result, the emissions performance in various vehicle markets is expected to converge towards 2025. A list of global vehicle emissions standards is provided in table 10.1 of the annex.

Fig 2.1 - Global comparison of light duty vehicle fuel economy standards



* China's target reflects gasoline vehicles only. The target may be lower after new energy vehicles are considered.

Source: ICCT

3. Modelling Approach

SULTAN

The Sustainable Transport Illustrative Scenarios Tool has been developed as a high-level calculator to help provide indicative estimates of the possible impacts of EU transport policy on energy consumption, CO_2 emissions, technology costs and energy security. It was developed by AEA Technology plc as part of the European Commission funded project "EU Transport GHG: Routes to 2050 II". For further information see the project website at http://www.eutransportghg2050.eu

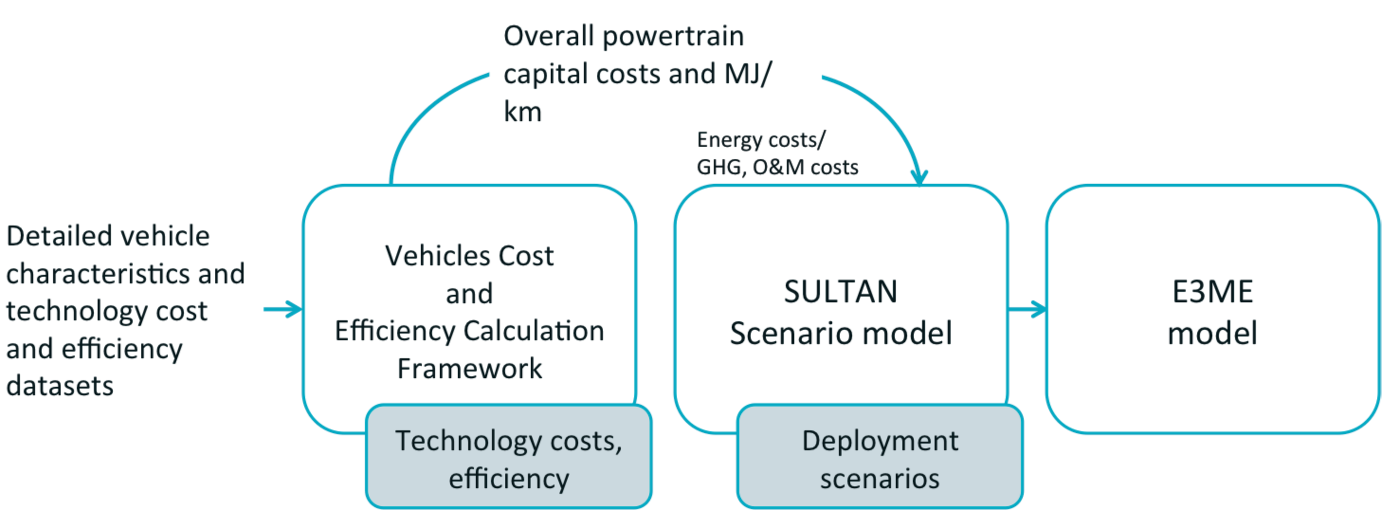
E3ME

E3ME is a macroeconomic model that covers the EU Member States' economies, with linkages to energy consumption and CO_2 emissions. Recently, the model has been used to contribute to several European Commission Impact Assessments, including reviews of the EU Emissions Trading System, Energy Taxation Directive and the Energy Efficiency Directive.

E3ME's historical database covers the period 1970-2010 and the model projects forward annually to 2050. The main data sources are Eurostat, DG Ecfin's AMECO database and the IEA. The E3ME model embodies two key strengths relevant to this project. The model's integrated treatment of the economy, the energy system and the environment enables it to capture two-way linkages and feedbacks between these components. Its high level of disaggregation enables relatively detailed analysis of sectoral and national effects.

Road Vehicle Cost and Efficiency Calculation Framework

AEA Technology plc developed a detailed Excel-based calculation framework to estimate the potential changes in road vehicle capital costs and efficiencies from 2010 to 2050 for the UK Committee on Climate Change in early 2012. The framework facilitates the development of consistent/comparable estimates on vehicle capital costs and efficiencies/energy consumption for a wide range of road vehicle powertrain and options for motorcycles, light duty vehicles and heavy duty vehicles. The overall methodological approach and key information sources used in the calculation framework were previously tested with experts from industry and academia as part of the work for CCC, and has been further developed, refined and tested with experts from the core working group by Ricardo-AEA as part of this current project.



4. Scenario Development

In order to understand the macro-economic impacts of decarbonizing light duty vehicles in the timeframe 2010-2030, three scenarios of technology deployment were developed.

- Reference case – No Further Improvement (REF)
- Current Policy Initiatives (CPI)
- Tech 1 scenario

The scenarios focus on technological improvements alone, on the assumption that vehicle technology becomes the main driver for decarbonizing transport. The scenarios in this project are not an attempt to predict the evolution of future vehicles, which is highly uncertain, but to examine a range of possible future outcomes. This interim report from Phase I of the project ignores the penetration of advanced powertrains, but this does not mean the group thinks such powertrains will not be deployed before 2030. Scenarios including the deployment of advanced powertrains will be modeled in Phase II of the project.

NO FURTHER IMPROVEMENT SCENARIO (REF)

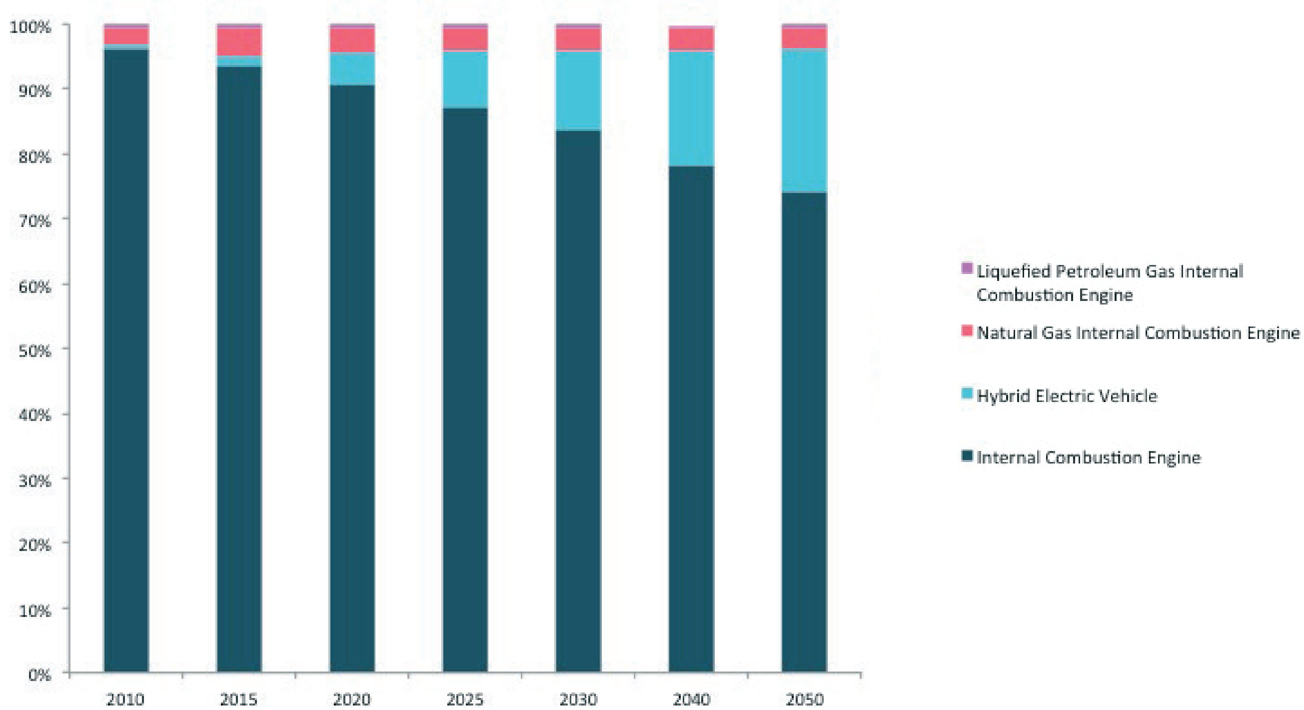
This is the reference case scenario against which the other scenarios are compared in order to establish their potential marginal economic impacts. The scenario assumes that technology in the European vehicle fleet remains at current levels of 135 g/km. It is assumed that the current share of different powertrain types is frozen and no further efficiency improvement technology is added. However, vehicle costs will still increase in the near term due to the application of measures to further reduce air pollutant emissions. This simple reference case has been chosen as it provides a 'clean' baseline against which to compare the other scenarios.

CURRENT POLICY INITIATIVES SCENARIO (CPI)

This scenario assumes that the current EU policy debate leads to the confirmation and achievement of a CO_2 target for cars of 95g/km in 2020 and a target for vans of 147g/km in 2020. It assumes that no further policy targets are set after 2020, but there will be some further improvement in reducing fuel consumption beyond 2020, driven by consumer concern about CO_2 emissions; fuel price pressure and a continuation of the existing momentum in technology development. However, the rate of improvement will be less than 1 percent per annum. In the Current Policy Initiatives scenario, HEV deployment in the new car fleet reaches 5 percent in 2020 and 12 percent in 2030.

This leads to direct CO_2 emissions from cars of 95g/km in 2020 and 85g/km in 2030, according to the test cycle. Vans achieve a CO_2 performance of 147g/km in 2020 and 129g/km in 2030. The relative share of diesel and gasoline and all alternative powertrains is based on the assumptions from the Reference Scenario used in the modelling analysis for the European Commission's Transport White Paper and also for the scenario analysis carried out under its "EU Transport GHG: Routes to 2050 II" project.

Fig 4.1 - Rate of technology deployment in Current Policy Initiatives scenario as a proportion of new vehicle sales



Source: Ricardo-AEA

TECH 1 SCENARIO

This scenario has been adapted and further developed from one of the scenarios used in the European Commission project “EU Transport GHG: Routes to 2050”, which explores various pathways to achieve the Transport White Paper goal of reducing overall transport emissions by 60 percent in 2050. The scenario seeks to explore the impact of pushing HEV deployment to an ambitious extent while taking account of practical limitations. It assumes market penetration of HEVs of 10 percent of new vehicle sales in 2020 and 50 percent penetration in 2030. In this scenario, reductions in CO_2 are driven, but not limited, by the 2020 targets of 95 gCO_2/km for cars and 147 gCO_2/km for vans. The direct CO_2 emissions of cars are 90g in 2020 and 60g in 2030, according to the test cycle. Vans achieve CO_2 performance of 141g/km in 2020 and 99g/km in 2030.

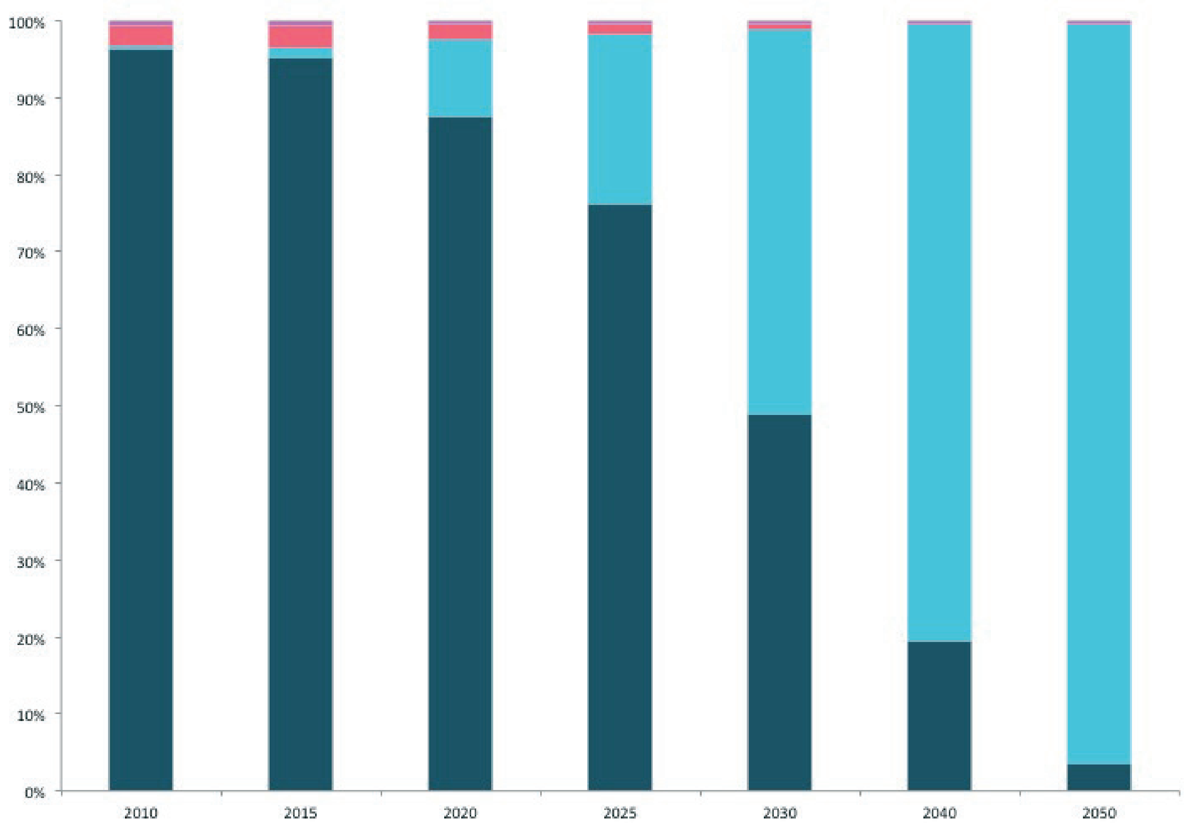
Both the Current Policy Initiatives scenario and the Tech 1 scenario lead to a significant reduction in both fuel consumption and CO_2 emissions in the timeframe considered. However, it should be noted that there is a rebound effect in reality. Higher fuel efficiency means cheaper motoring and more driving. We have modelled zero rebound effect in this phase of the project, but this will be addressed in more detail in Phase II. The results from the macroeconomic model do, however, incorporate indirect rebound effects (household consumption increases, some of which is spent on energy-consuming products)[1].

FUTURE TECH SCENARIOS

Further scenarios have also been developed to assess the economic impact of lower carbon pathways involving the deployment of advanced powertrain technologies and alternative energy carriers. The impacts of these scenarios are typified by higher technology costs than the two scenarios explored to date, but also by higher avoided fuel costs.

These scenarios explore the deployment of BEVs to as much as 3 percent in 2020 and in the range of 5-14 percent in 2030. PHEVs are deployed to as much as 6 percent in 2020 and in the range of 12-28 percent in 2030. Fuel Cell vehicles enter the scenarios after 2020, in the range of 2-8 percent in 2030. The results of the economic assessment of these scenarios will be presented in the final project report.

Fig 4.2 - Rate of technology deployment in the Tech 1 scenario as a proportion of new vehicle sales



Source: Ricardo-AEA

[1] One other indirect feedback is not incorporated. Lower demand for fuels could lead to a reduction in global prices, which would then increase consumption again.

5. Technology Costs

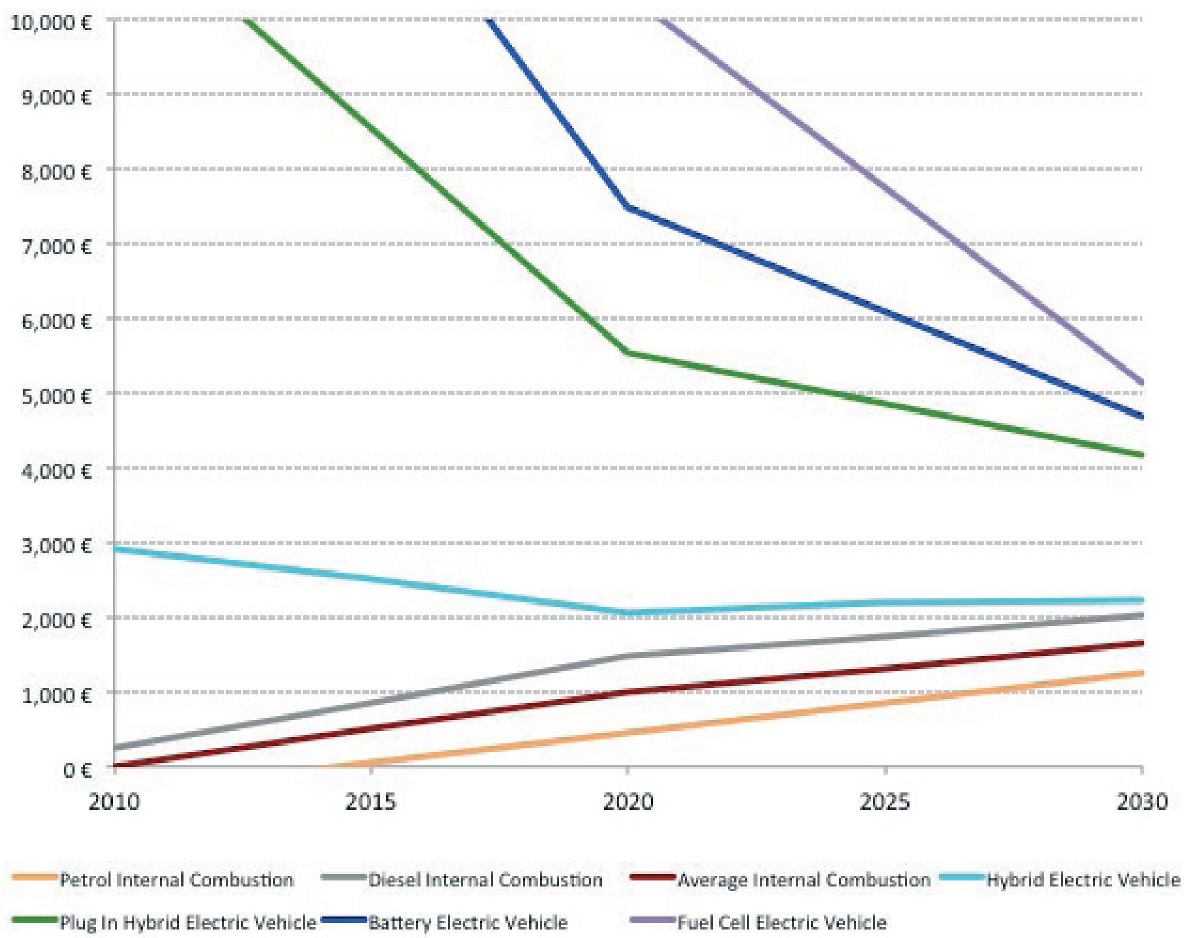
METHODOLOGY

There is significant uncertainty with respect to future developments in the cost and performance of some transport technologies, particularly when projecting out to 2050. The absence of historical data can make it difficult to use learning rates and instead requires a detailed knowledge of the likely sources of potential cost reductions and performance gains at an aggregate vehicle level. This project has taken a conservative approach by basing its technology cost projections on data provided by the auto industry to the European Commission's impact assessment for the proposed 2020 targets.

The starting point for the central-case technology costs and efficiency improvement potentials are from the base case presented in TNO et al (2011)[2] for the European Commission's impact assessment for the proposed 2020 targets. This data was provided to the Commission by the European Automobile Manufacturers Association (ACEA) and the European Association of Automotive Suppliers (CLEPA).

This dataset was reviewed by the project's Core Working Group and modified where evidence indicated the need. In particular, the central-case weight reduction costs and energy reduction potentials take account of vehicle data from the U.S. Environmental Protection Agency. This U.S. data was also presented in Annex D of TNO et al (2011). These figures were used in the alternative Scenario B of TNO et al (2011) and resulted in a similar cost-curve to that of Scenario A, which was used in the Commission's Impact Assessment analysis.

Fig 5.1 - Additional capital costs for cars (central case) under the Tech 1 scenario



Source: Ricardo-AEA

TNO et al (2011) focused on assessing technology costs in 2020. In Phase I of this project it has been necessary to estimate future technology costs as far as 2030. Future cost reductions compared to 2010 technology cost data have been estimated in Ricardo-AEA's calculation framework to factor in the effects of (a) cost reduction due to deployment/mass production using a learning rate approach, and (b) cost reduction over time independent of deployment rates (at 1 percent per year).

Ricardo-AEA used its Road Vehicle Cost and Efficiency Calculation Framework to develop the final technology cost and vehicle efficiency datasets. The methodology and assumptions from this framework were developed through previous work for the UK Committee on Climate Change[3]. These have their sources in a range of major UK and European studies and have been previously tested with experts from industry and academia. The powertrain types covered by the framework include ICEs, HEVs, PHEVs (and related Range Extended Electric Vehicles), BEVs and FCEVs.

As part of the current project, these existing datasets and assumptions were shared and further discussed and agreed with experts from the project's Core Working Group. This took place via a combination of telephone interviews, meetings and other exchanges between Ricardo-AEA and key experts from the Core Working Group (e.g. from Nissan, CLEPA, Better Place, ICCT, EAA, Eurobat etc). Additional feedback was also provided separately from a number of members of Eurobat and CLEPA.

As part of this process, additional evidence from the literature was also identified to support revisions made to key assumptions and calculations. Some of the key amendments to the study assumptions and calculation methodology included the following elements:

- Key technology data assumptions were revised in the central-case, in particular those for the costs of weight reduction, batteries and fuel cells. Central-case ICE data remained unchanged.
- Other elements of the methodology and calculations were revised. A cost reduction factor of 1 percent per annum due to learning over time was applied, to supplement existing volume-related cost reduction factors. Revised assumptions were introduced on battery sizing for different powertrain types, including useable State of Charge (SOC) reserve and range in electric-only mode.
- Long-term (2030-2050) technology options were added e.g. additional levels of weight reduction and as-yet-unidentified potential future technologies to improve ICE efficiency.

A 'technology packages' methodology was also developed to better conceptualise and more consistently build individual technology deployment assumptions. Table 10.2 in the annex provides a summary of the allocation of technologies into a series of eight indicative 'technology packages'. These packages were developed in order to help better conceptualise technology deployment in a more consistent and systematic way.

The packages were developed to achieve nominal efficiency improvement objectives in five-year increments from 2010 to 2040, assuming a challenging, but achievable rate of roll-out of the technologies (based on their relative cost-effectiveness).

The overall deployment of individual technologies in different periods was subsequently estimated based on indicative shares of deployment of these packages under the different scenarios. The assumed package deployment shares under the three scenarios is summarised in Table 10.3 in the annex. Key technology assumptions related to HEVs are summarised in table 10.4 in the annex.

DISCUSSION

ICE improvements

In previous research conducted by Ricardo-AEA involving interviews with very senior R&D decision makers from the automotive industry, there was a strong message that the short to medium term would continue to be dominated by further improvements to internal combustion engine technology (JRC, 2012)[4]. In fact, even in the longer term, high efficiency internal combustion engines are expected to remain important for use in plug-in hybrids and range extenders. Such views are consistent with the technology roadmaps from various organisations including the Automotive Council UK[5] and EUCAR[6].

There remains much more which can be done to improve the efficiency of the internal combustion engine and transmission system, and many of the technologies that are already available on the marketplace can make a significant impact on fuel consumption in the 2020-2025 timeframe. Start-stop technology using advanced lead-based batteries is perhaps the most cost-effective way of achieving reductions of 5-10 percent in CO_2 emissions (depending on whether the system is able to recapture braking energy). Ricardo has estimated that the cost per gram of CO_2 reduction is about half that of improving the fuel efficiency of the internal combustion engine, and less than a quarter of that for hybridisation (Ricardo, 2012)[8]. Other options that are likely to be applied first include engine downsizing coupled with boost (e.g. combination of turbo- and super-charging) and direct injection for petrol engines. For example, there has already been a 31 percent reduction in gCO_2 per km between 2010 petrol Ford Focus variants (at 159 gCO_2/km) and 2012 EcoBoost branded variants (at 109 g/km), achieved mainly through the use of downsized engines (from 1.6 litres to 1.0 litres) with turbo-charging, direct injection and start-stop technologies. Systems combined also with increasing levels of hybridisation offer even greater potential benefits – e.g. 52 percent reduction in CO_2 going from the 2010 petrol Toyota Yaris (at 164 g/km) to the 2012 Toyota Yaris hybrid (at 79 g/km).

Additional improvements will also be possible in later years with more widespread use of further downsized engines, more sophisticated start-stop and direct-injection technologies, and their application in combination with other technologies like variable valve actuation and eventually the use of multi-port injection technologies and low temperature combustion technologies using “auto-ignition”, like HCCI (homogenous charge compression ignition). In the longer term (i.e. 2030-2050) it is reasonable to expect that additional (as yet unknown) options may also become available to further improve ICE efficiencies.

Weight Reduction

All vehicles, regardless of powertrain type, can be made more efficient through reducing weight, aerodynamic drag and rolling resistance. However, weight reduction is the area with perhaps the greatest potential. In the near-term weight reductions are likely to be achieved through a greater focus on minimising vehicle weight in the design process (e.g. in areas such as seating, glazing and interior components), in combination with further increases in the use of high strength steels and aluminium in the vehicle body structures. Simplification of assemblies to reduce the number of components can also achieve weight reductions. Very significant gains are believed to be possible in the short term according to highly detailed analysis by Lotus (2010)[9] and more recently FEV (2012)[10]. These studies demonstrated that achieving up to 20 percent reduction in overall vehicle weight (i.e. across all vehicle subsystems) at minimal or even zero net cost was possible by 2020 while maintaining performance parity relative to the current vehicle. In the longer term more significant weight reduction (~40-50 percent) may be possible (at higher cost) through more extensive use of lightweight materials such as carbon fibre.

The increased focus on improving fuel economy and reducing CO_2 emissions has led to further demand for lightweight materials innovation, with research focused on a range of options for near, medium and longer-term application:

- Carbon fibres, natural/glass fibres.
- High-strength steels and aluminium.
- Magnesium technologies.
- Hybrid materials and bio-plastics [11].

The Automotive Council UK notes that the longer term potential for improving vehicle efficiency includes achieving a 50 percent weight reduction versus 2008 and the introduction of flexible re-configurable multi-utility vehicle concepts[12].

For electrically powered vehicles the benefits of reduced weight, drag and rolling resistance is particularly strong. Electric powertrains are highly efficient and as a result weight, drag and rolling resistance account for a much larger proportion of the total efficiency losses. Reducing these losses may also allow the battery size to be reduced for a given range, further reducing vehicle weight and cost. Therefore these options are seeing more significant and earlier introduction into such vehicles. For example, it is planned for carbon fibre reinforced plastics (CFRP) to be used for body components on BMW's forthcoming i3 battery electric and i8 plug-in hybrid vehicles where it is reported to achieve a 50 percent weight saving over steel and 30 percent over aluminium [12, 13].

In the past, the high cost and time taken to produce and use carbon fibre has limited its use to niche/small scale and high-end applications in vehicles, however recent research has made significant strides in both areas. It is uncertain by when or how much costs might be reduced. Some manufacturers are also looking at alternatives to carbon fibre due to its cost and energy intensive production processes, for example Audi is examining using basalt-fibre or even waste plant-based fibres, and others are looking at lightweight plastics and composites.

A significant transition to lighter-weight vehicles is likely to be restricted unless current policy disincentives are removed. For example the current weight-based standard for CO2 limits ideally needs to be replaced with a size-based standard (e.g. footprint) to provide a sufficiently strong incentive for the full lightweighting potential to be achieved.

Batteries

The principal factor determining the speed of progress for powertrain electrification is battery or energy storage technology. All four battery families (Lead, Nickel, Lithium and Sodium-based batteries) are used in the different levels of powertrain hybridization/electrification. Advanced lead-based batteries provide start-stop functionality (also named micro-hybrid) in almost all new ICE vehicles being placed on the market, while Nickel and Lithium-based batteries are a key determinant of the overall cost and performance of both current HEVs and more advanced plug-in vehicles (i.e. PHEVs, REEVs and BEVs). Improving battery technology and reducing cost is widely accepted as one of the most important, if not the most important factor that will affect the speed with which these vehicles gain market share.

There are four key areas where breakthroughs are needed, which include:

1. Reducing the cost
2. Increasing the specific energy (to improve vehicle range/ performance for a given battery weight or reduce weight for a given battery kWh capacity)
3. Improving usable operational lifetime.
4. Reducing recharging times

In the short- to mid-term lithium ion battery technology is expected to form the principal basis of batteries for use in full HEVs and more advanced plug-in vehicles (i.e. PHEVs, REEVs and BEVs). However, a number of new technologies are being researched. In the medium term lithium-sulphur holds perhaps the most promise (up to five times the energy density of lithium ion) with lithium-air having greater potential (up to ten times lithium ion energy density), but are expected to be many years from commercialisation.

Currently the battery of a plug-in electric vehicle is estimated to cost €6,000 to €16,000 (ACEA, 2011) although this is anticipated to halve in the next decade, and in the longer-term to decrease to around €3,000 to €4,000 (ETC, 2009). Recent detailed analysis for the UK Committee on Climate Change has estimated current costs at ~$700-800/ kWh (~€560/kWh) and predicted a reduction to $318/ kWh (~€245/kWh) by 2020 and $212/kWh (~€160/kWh) by 2030 for a mid-size battery electric vehicle in the baseline scenario (CCC, 2012) . These figures have been used as a basis for the central case estimates used in the technology costs calculations of this study for BEVs, and can be viewed as more conservative estimates compared with other recent estimates from Roland Berger (~US$316-352 /kWh for the total pack by 2015) and McKinsey (US$200 by 2020 and US$160 by 2025 for the total pack), and the EUROBAT R&D roadmap target of reaching €200/kWh (US$260/kWh) by 2020. Such lower cost estimates for batteries fall within the envelope of the low technology cost sensitivity assumptions used within this study.

PHEV batteries cost more than BEV batteries, per kWh. This is because the power requirements place a proportionally larger demand on the smaller battery pack in a PHEV, so batteries with higher power must be used at a somewhat higher cost.

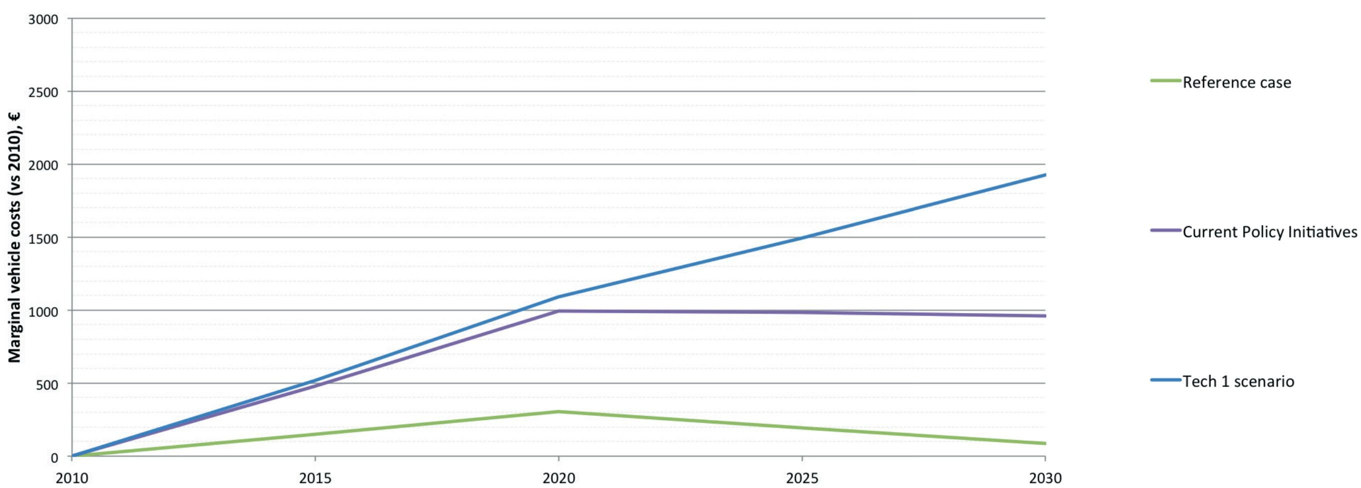
TECHNOLOGY COSTS: RESULTS

The data shows that improving the fuel-efficiency of light duty vehicles will result in additional capital costs. In the Current Policy Initiatives scenario, the additional cost of meeting the 2020 CO_2 target of 95g/km is anticipated to be around €1,000, compared to the 2010 baseline vehicle on average. The slightly more ambitious Tech 1 scenario leads to around €1,100 of additional costs.

This is in the same range as two other studies on the subject. In its study for the European Commission impact assessment on the 95g/km target, TNO (2011) found central-case additional manufacturing costs of €1,159 per vehicle on average, relative to the 130g/km target in 2015. The International Council on Clean Transportation used a tear-down analysis approach, concluding that the 95g/km target would lead to less that €1,000 of additional manufacturing costs, compared to a 2010 vehicle.

After 2020, technology costs continue to rise to meet increased fuel-efficiency requirements in the two scenarios presented here, for example to €1,841 in 2030 to meet a CO_2 performance of 60g/km in the Tech 1 scenario. Detailed estimates for future costs of cars and vans in both scenarios are presented in tables 10.5 and 10.6.

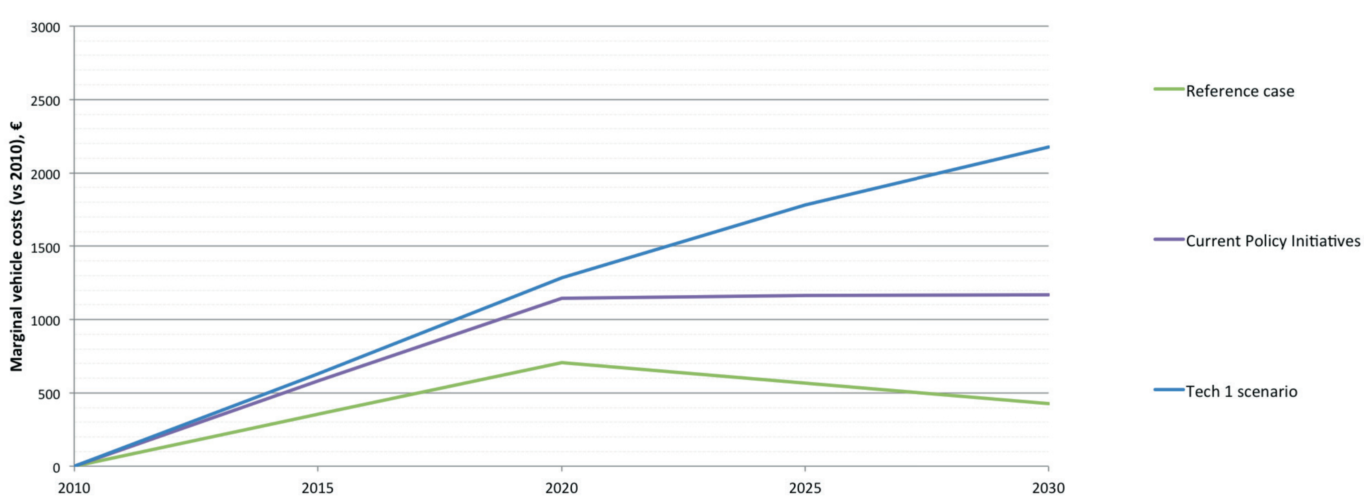
Fig 5.2 - Average new vehicle capital costs for different deployment scenarios (cars)



Source: Ricardo-AEA

* Increased costs in the Reference case include the cost of after-treatment to meet future air quality standards.

Fig 5.3 - Average new vehicle capital costs for different deployment scenarios (vans)



Source: Ricardo-AEA

TOTAL COSTS OF OWNERSHIP

Estimates for the total cost of ownership (TCO) for the consumer are presented for the different car powertrain technologies in the following Figures 5.4, 5.5 and 5.6 for the Tech scenarios.

The analysis presented shows that under the intermediate discounted cash flow assumptions (5 percent discount rate) the TCO of cars are expected to converge by 2020 for the different powertrain technologies – with the TCO of all powertrains being lower than in 2010, despite significant (~30+ percent) increases in fuel prices. The exception is for FCEVs, due to a combination of (i) higher capital costs, (ii) the relatively high anticipated price of hydrogen fuel at this point (compared to petrol and diesel), and (iii) their lower energy efficiency relative to BEVs.

Under the lower social discount rate sensitivity assumption (3.5 percent), BEVs and PHEVs could become more cost-effective on a TCO basis than the average ICEV or HEV by 2020. By 2030, BEVs and PHEVs could have the lowest TCO of all technologies. However, under the higher discount rate assumptions (10%), more typical for private car finance deals, the TCO for HEVs, PHEVs and BEVs is expected to remain significantly higher than for conventional ICEVs by 2020 and 2030.

Furthermore, there are also additional benefits of electrified powertrains that are not accounted for in this analysis, including reduced external costs due to lower levels of air quality pollutant emissions, reduced local noise impacts, etc.

Therefore, policymakers might choose to continue to provide incentives for such vehicles into the medium term to encourage their uptake. Currently there are a range of incentives for various alternative powertrain vehicles applied across Europe, which help to offset the additional capital costs of these vehicles. These include various forms of tax relief, grants to help with vehicle purchase, discounts, or exclusion from local congestion zone or parking costs, etc.

However, it is also important to note that the comparisons presented are also highly influenced by the assumptions on total annual activity of the vehicles (which will be higher or lower for different users), and on future fuel prices. Under conditions where fuel prices or the annual km travelled by the vehicles is higher, the competitiveness on a TCO basis of HEVs, PHEVs and BEVs is further enhanced with these powertrains reaching equivalence with ICEVs much sooner. For example under the high fossil fuel price sensitivity BEVs have the lowest TCO by 2020 using a 5% discount rate, and have a TCO close to equivalence with ICEVs by 2030 even under the higher 10% discount rate assumption. Conversely, under the low fossil fuel price sensitivity assumptions, BEVs continue to have a ~€1,000 higher TCO than ICEVs and HEVs even by 2030 at the intermediate 5% discount rate level.

The TCO calculation has been performed on the basis of time-discounted cash flows using the total car purchase price (including all taxes and margins, annual maintenance costs and fuel costs (including all taxes). Since there is considerable uncertainty on the future residual/resale values of new powertrain technologies in the short-medium term, the analysis has been carried over the lifetime of the vehicle, rather than over 3 or 5 years, which is also common. It should also be noted that uncertainty over re-sale values might act as an obstacle to adoption of advanced powertrain vehicles. Indeed, some of the scenarios in this analysis rely on the assumption that policymakers can provide sufficient investment security for these barriers to be overcome

The European Commission (DG Regio, 2008) , (EC JRC, 2012) typically recommends the use of a 3.5 percent social discount rate for economic analysis and a 5 percent discount rate for financial analysis (for private equity at country level averages). However, interest rates between 10-15 percent are common for financing of private car sales (though typically only for a proportion of the car's full value and over a period well below the full lifetime of the vehicle). We have therefore presented estimates for the TCO of different technologies for three different discount rates in Figures 5.4, 5.5 and 5.6.

In these figures the TCO has been calculated over the full vehicle lifetime (taken to be 12 years), with an annual activity of 12,000 km/yr. In converting from capital costs (i.e. on a manufacturing basis) to capital prices to the consumer, VAT is added at 19% (also to fuel costs), together with an EU average purchase tax of 5.7%, and an additional margin for the manufacturer and dealer. This manufacturer and dealer margin is assumed to be 24.3% for all ICEVs, HEVs across the timeseries. For BEVs, PHEVs and FCEVs the margin is assumed to transition from 0% in 2010 to the same margin for ICEVs and HEVs in the medium-long term, as BEVs, PHEVs and FCEVs become more cost-competitive.

The detailed assumptions on capital costs, maintenance costs, manufacturer and dealer margins and on fuel prices and taxes are provided (in Table 10.7) in the annex.

The current fuel price assumptions include simple approximations for the cost of electric and hydrogen refuelling infrastructure. More detailed estimates for the costs of this infrastructure are being developed in the second phase of this work and will replace these simplified estimates in the final analysis. A further discussion on fuel costs is also provided in the next chapter of this report.

Fig 5.4 - Car Marginal Vehicle TOC (Discount Rate =3.5%, Central Fuel Prices)

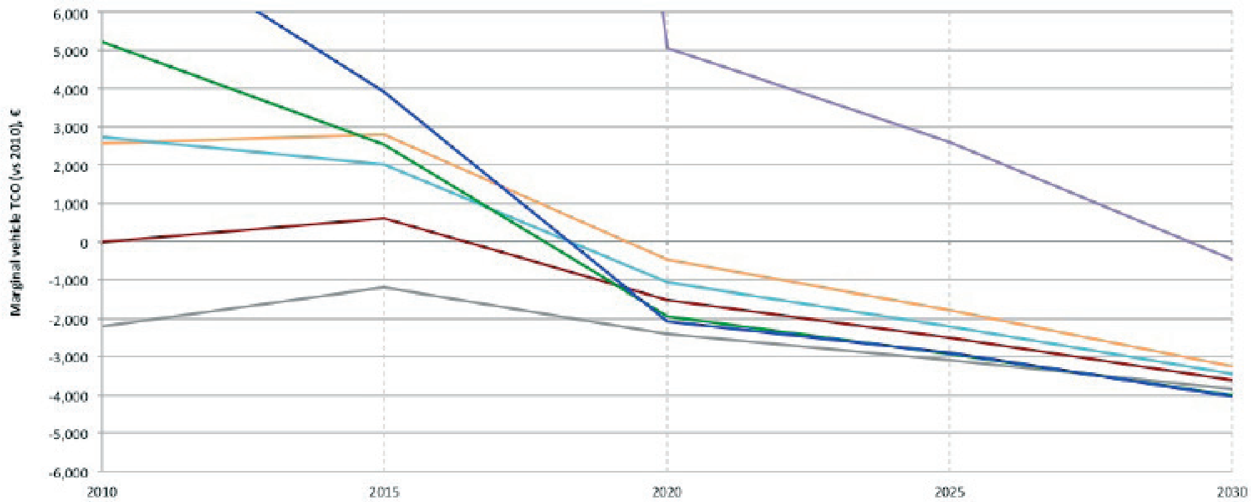


Fig 5.5 - Car Marginal Vehicle TOC (Discount Rate =5%, Central Fuel Prices)

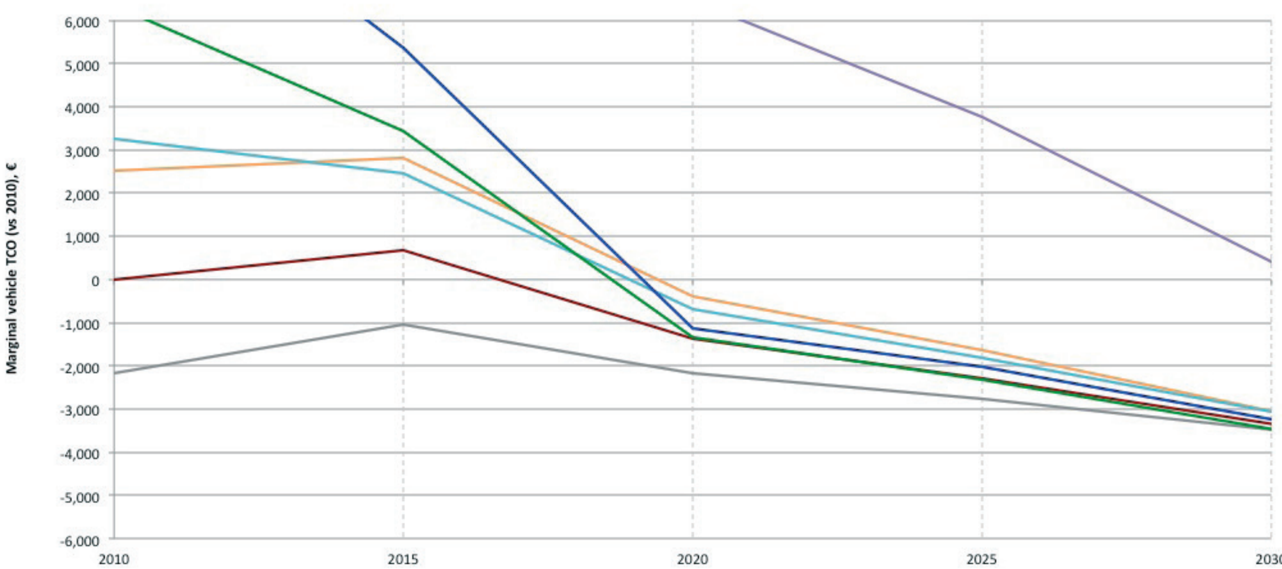
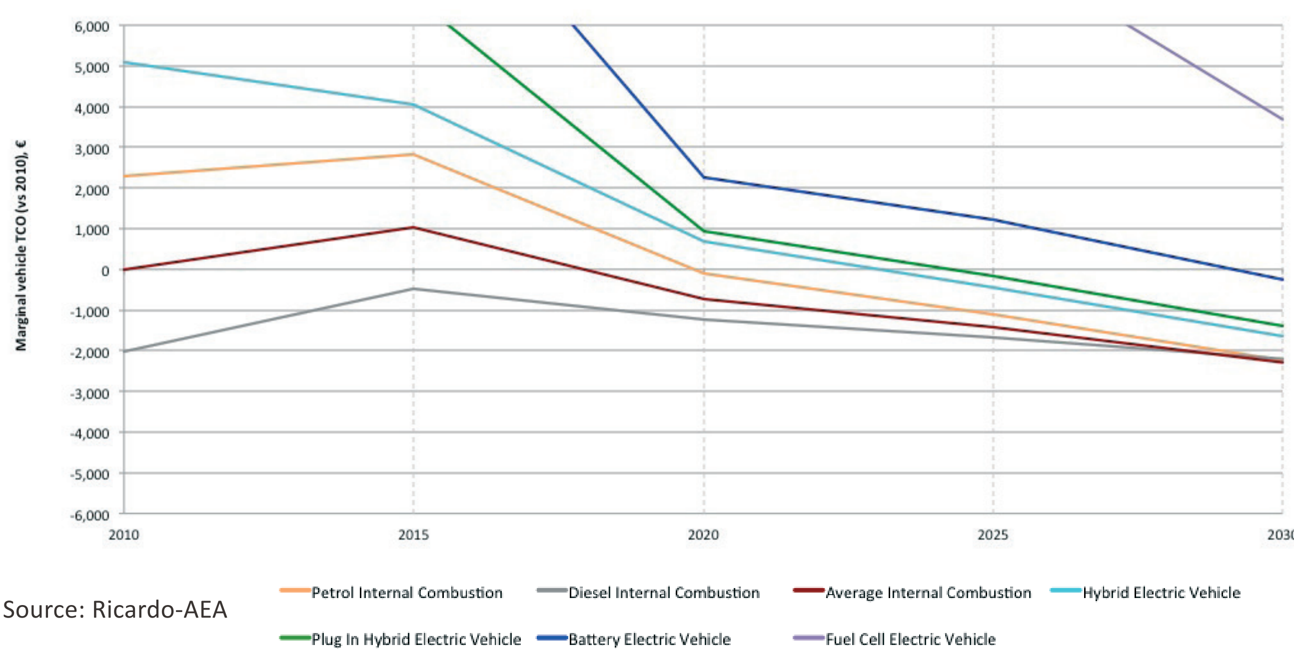


Fig 5.6 - Car Marginal Vehicle TOC (Discount Rate =10%, Central Fuel Prices)



Source: Ricardo-AEA

6. Fuel Costs

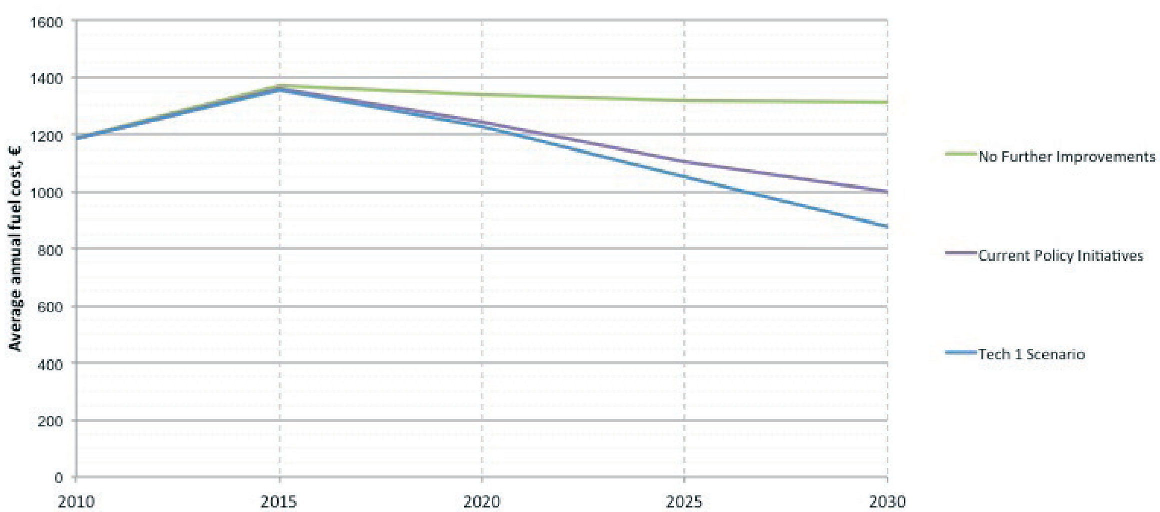
The average motorist's fuel bill is significantly reduced in both the Current Policy Initiatives Scenario and the Tech 1 scenario, when compared with the Reference Case where technology improvements are frozen at current levels.

As an illustration of reduced spending on fuel, in the Current Policy Initiatives Scenario, the owner of the average new car in 2020 will spend around €400 less on fuel each year than the owner of the average 2010-manufactured car. This is based on using constant fuel prices and an assumption of 12,000 km driven annually, which is close to the EU average.

In reality, new cars are driven longer distances than older cars, so the annual savings will likely be higher. However, some of those gains will also be offset because motorists choose to make use of the improved efficiency by driving further. Nevertheless, this example serves to illustrate the impact on fuel costs for motorists.

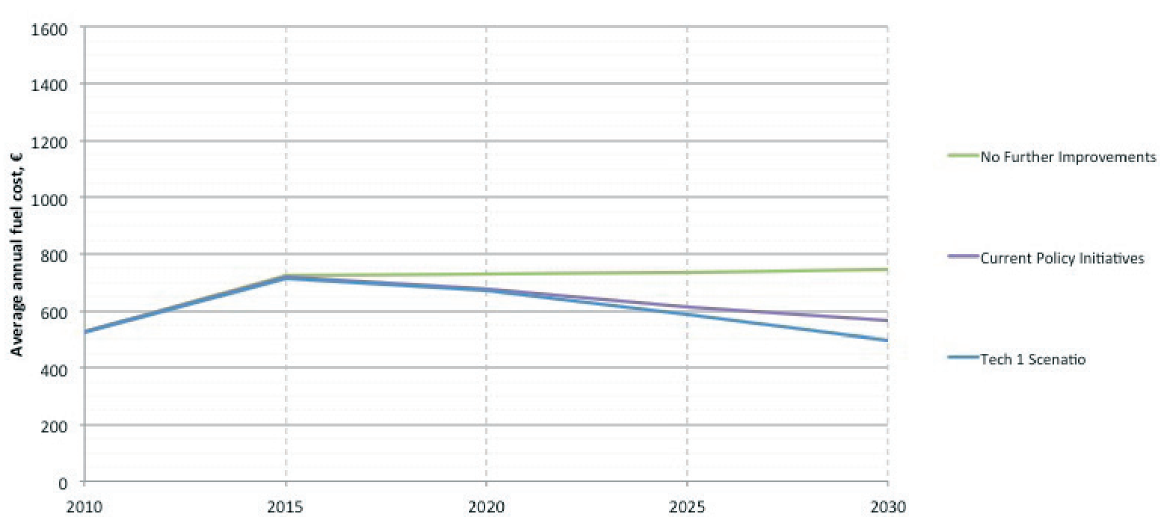
CO_2 standards only apply to new cars and vans sold. Market penetration of new technologies takes time, and there is therefore a time-lag before the whole vehicle fleet reaches the same level of performance as the newest vehicles. For this reason, fuel-savings as an average across the whole EU fleet in 2020 are lower than those for new vehicles.

Fig 6.1 - Average annual fuel costs for motorists (cars) under the three scenarios (including tax, duties)



Source: Ricardo-AEA

Fig 6.2 - Average annual fuel costs for motorists (cars) under the three scenarios once taxes and duties are excluded



Source: Ricardo-AEA

By 2030, the 2020 standards have fed through to most of the fleet, due to the replacement of older vehicles with new vehicles. The average fuel savings in the Current Policy Initiatives Scenario reach €315 euros per vehicle in the EU27, compared to the Reference Case. Under the Tech 1 scenario in 2030, the savings reach €438 euros per vehicle in the EU27, compared to the Reference Case.

At the EU level, the total annual fuel bill for all EU motorists is reduced by €56 billion in 2030 under the Current Policy Initiatives Scenario (excluding taxes and duties). Fuel savings reach €79 billion in 2030 in the Tech 1 scenario.

Fig 6.3 shows how Europe's fuel bill would increase if technology was frozen at current levels (Reference case). The change across each decade is broken down to its three components: changes in activity; changes in oil price, and changes in vehicle efficiency. Fig 6.4 shows how this trend of rising fuel prices is reversed in the Tech 1 scenario.

At present, direct rebound effects (driving is cheaper so people drive more) have not been included in the analysis. This will be added in the second phase of the project. It is also assumed that there is no feedback to world energy prices from reduced rates of fuel consumption. However, the modelling includes as standard the indirect economic rebound effects (people have more money and spend some of it on energy-intensive products). Including the direct rebound effects would mean that the fuel bill savings are reduced, but that is not anticipated to have much impact on the economic results.

Fig 6.3 - Evolution of EU fuel bill (cars only) in Reference scenario (excluding taxes)

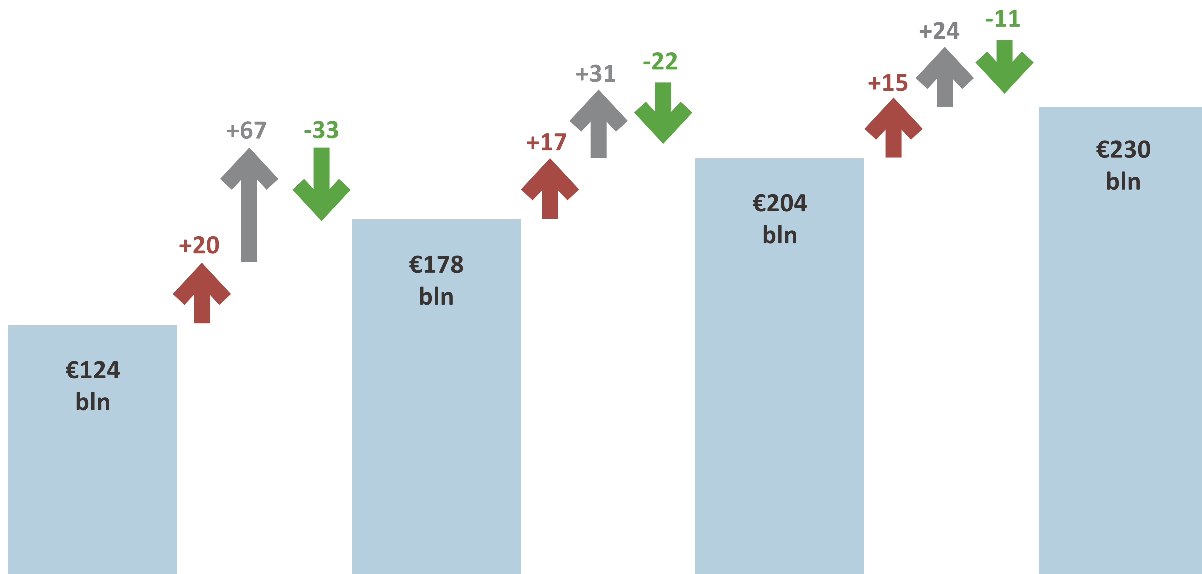
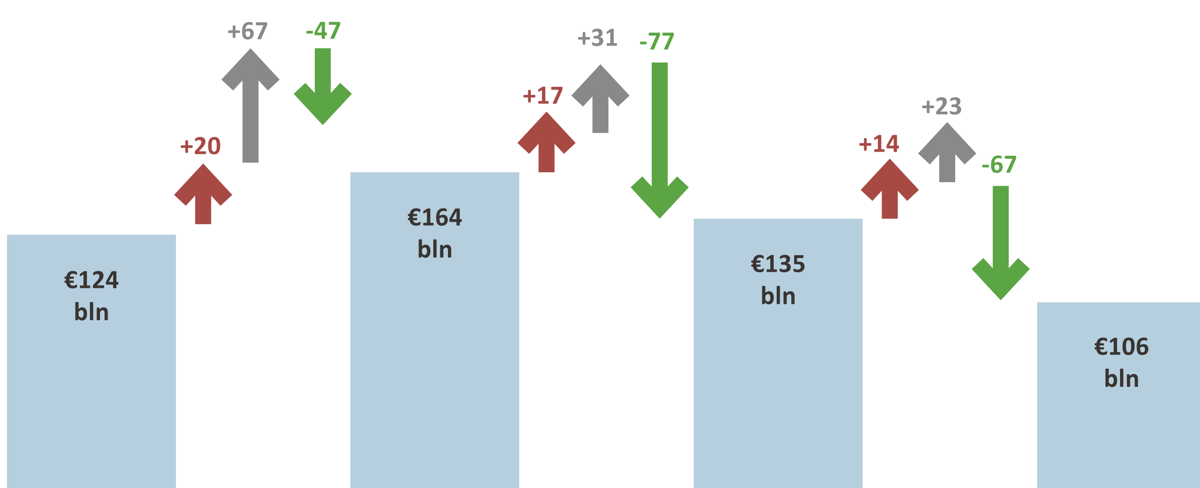


Fig 6.4 - Evolution of EU fuel bill (cars only) in Tech 1 scenario (excluding taxes)



Source: Ricardo-AEA

Cost increase due to higher transport activity | Cost increase due to higher oil prices | Cost decrease due to more efficient vehicles

FUEL COST SENSITIVITY ANALYSIS

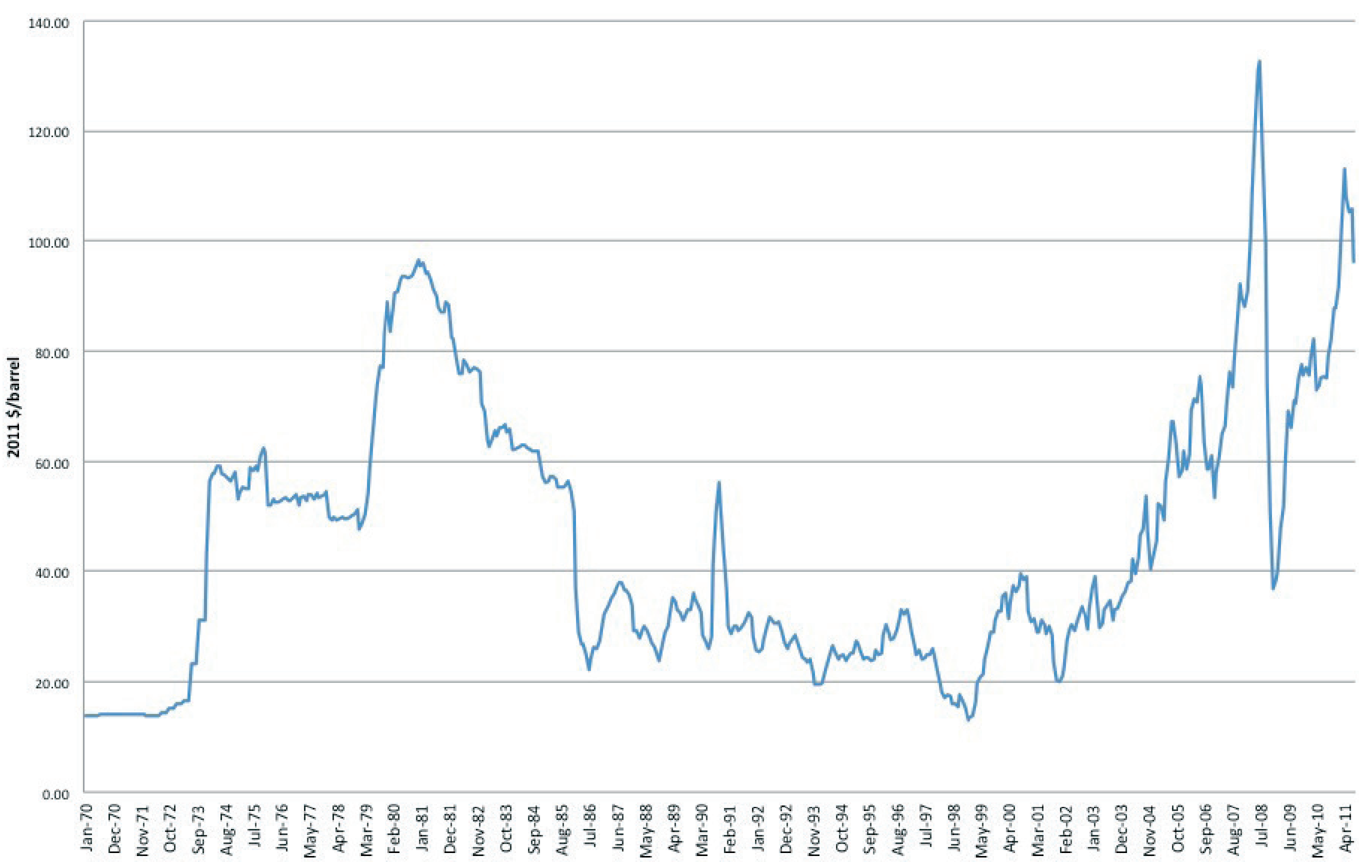
The central oil and gas prices used in the analysis are based on the IEA's World Energy Outlook projections, but high and low fossil fuel price sensitivities were also considered. This enabled the robustness of results to be tested against uncertainty around future fossil fuel prices. A range of +/-25% in oil prices by 2030 was used in these scenarios.

The aim of this exercise is not to predict the impact of a rather arbitrary permanent change in international energy prices on the European economy, but to identify whether or not the results in the previous chapters were specific to a particular set of assumptions. The results are to some extent dependent on energy price assumptions, with the impacts becoming larger if prices are higher (and, conversely, smaller if prices are lower). This makes intuitive sense, as the energy savings from fuel-efficient vehicles become more valuable if energy prices are higher.

This logic also suggests another potentially important result: that the negative economic effects of a high oil price on Europe's economies are reduced if countries invest in more efficient vehicles. The current modelling results are not able to show this, as the impacts are too small, but this is worth exploring in the other (higher technology) scenarios that will be assessed in Phase II of the study, which focuses on the period 2030-2050.

This sensitivity analysis shows reductions to the average annual fuel bill of car owners are expected to range from €260 - €405 per car for the Current Policy Initiatives scenario scenario by 2030, and €365 - €515 per car for the Tech 1 scenario. At an EU-wide level in 2030, these savings would be equivalent to reduction in the total consumer fuel bill in the order of €60 - €100 billion in the Current Policy Initiatives scenario and €85 - €140 billion in the Tech 1 scenario.

Fig 6.5 - Historic oil price data since 1970



Source: Energy Information Administration, September 2011

7. Economic Impact

The net economic impact is a combination of the impact of increased capital costs due to higher spending on technology and the impact of reduced spending on imported oil. The following section isolates the two separate effects.

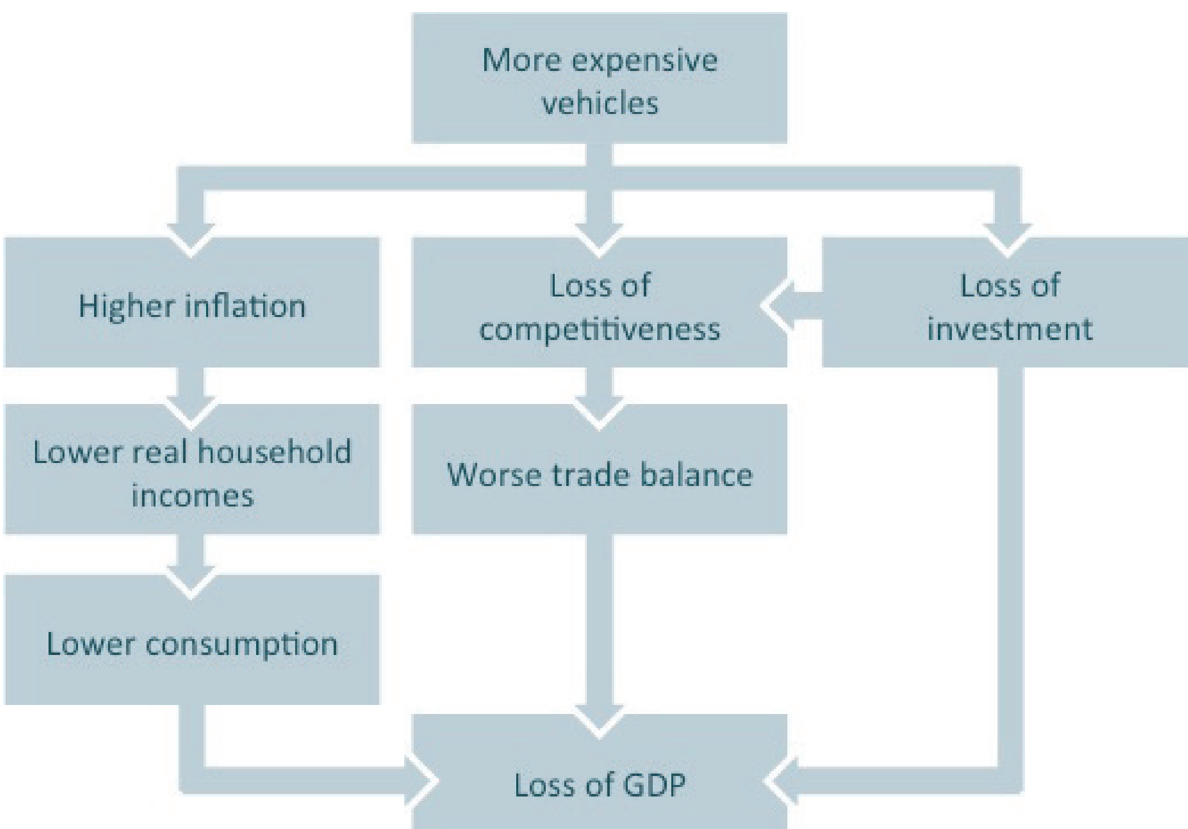
The changes in manufacturing costs were added to the unit costs of production in the motor vehicles sector. It was assumed that all of these higher costs were passed on to final consumers (both in domestic production and imported vehicles) through higher vehicle purchasing prices.

Increased capital costs have a depressing effect on the economy 23. Fig 7.1 summarises how these higher costs may impact on the economy. In the scenarios, it assumed that both domestic and imported vehicles are subject to the same increase in costs.

Given these assumptions, higher costs have negative impacts on household real incomes and consumer spending. The overall costs to the economy are small. This is because even though car manufacturers (and purchasers of vehicles) face higher costs, a substantial share of these costs is in the form of revenues to other European companies. For example, companies that supply fuel-efficient start-stop mechanisms would benefit from an increase in revenue, due to an increase in demand for their products. In this sense, the money remains in the European economy. Generally, the costs increase over time, in line with the number of new purchases of efficient vehicles.

By contrast, reducing fuel consumption in vehicles has a positive impact on the wider economy. Fig 7.2 describes the benefits, which accumulate in two ways. Firstly, there is a direct benefit to GDP from reduced imports of fossil fuels, which improves the trade balance and boosts GDP. Secondly, there are indirect benefits to households and businesses, as lower costs are passed on in the form of lower prices. For households this means an increase in real incomes, leading to higher household spending. For businesses this gives a boost to competitiveness against foreign firms. The benefits of the more efficient vehicles accumulate over time as the vehicle stock improves.

Fig 7.1

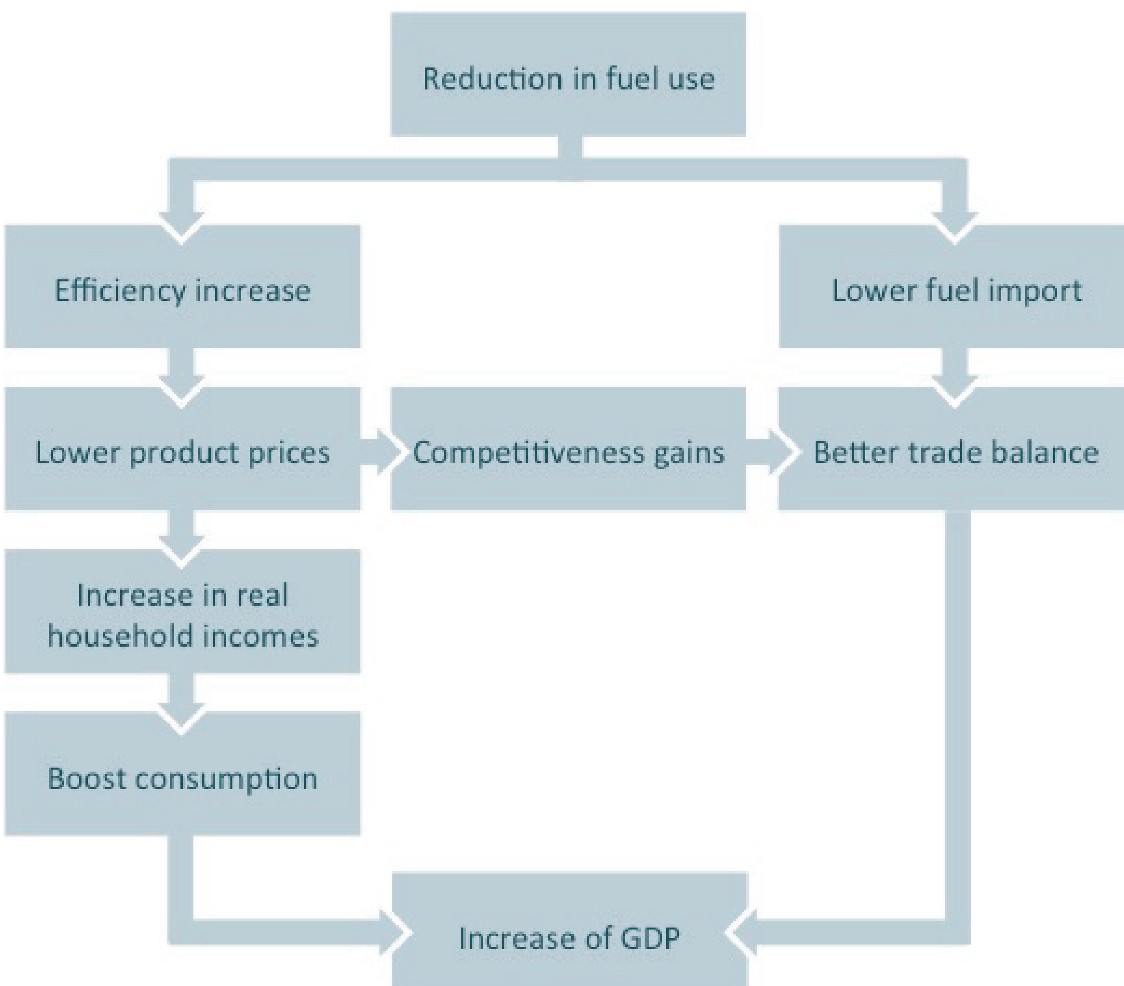


If we apply this approach to the Tech1 scenario, the capital cost of Europe's fleet of cars and vans increases by €46 billion by 2030 (excl. taxes), causing consumers and businesses to switch €46 billion of spending towards vehicles and away from other goods and services, or in the case of businesses profit margins may also be squeezed. However, this added cost does not fully translate to a €46 billion reduction in GDP. On the one hand, real incomes are reduced by increasing prices, but on the other hand there is slightly more European value added for each €billion spent on motor vehicles than if the same €billion was spent elsewhere in the economy, on average. As a result of this, the imposition of €46 billion of additional costs on consumers and businesses only translates to a €37billion reduction in GDP after second order multiplier effects.

The total fuel costs for running Europe's fleet of cars and vans decreases by €138 billion in 2030 (including tax). This is split between €79 billion of avoided spending on fuel and a €59 billion reduction in government receipts from fuel taxes, fuel duties (€36bln) and VAT (€23bln). Of the €79 billion of avoided spending on fuel, part of the value is within the refining, distribution and retail sectors, leaving approximately €60billion of avoided spending on imported crude oil or oil products. Given that domestically produced oil will primarily be consumed in Europe, it is assumed that avoided spending on oil will largely displace imports.

The €138 billion reduction in gross fuel bills impacts GDP in the sense that consumers retain that money and are able to spend it on other goods and services. Companies would be able to take advantage of lower operating costs by increasing other forms of spending. A reasonable proportion of this increased consumer spending leaves the economy in imports but a significant proportion of goods and services are provided domestically
The effect of reduced expenditure on petrol and diesel translates to €66 billion of additional GDP in Europe after second order multiplier effects as modelled in E3ME and generates €29bln of government tax receipts.
Overall GDP has therefore increased by €29bln (up €66bln from avoided fuel costs and down €37bln from higher vehicle prices) and tax receipts excluding lost fuel duty are increased by €14bln.

Fig 7.2



However, governments still have to make up for a shortfall of €22 billion to balance their books (down €36 billion from fuel taxes, but up €14 billion in all other taxes from the net improvement to the economy of a lower cost vehicle fleet). This they could do by increasing debt, but in the current economic situation, they might well increase taxes in Europe to maintain their balance sheets. If higher taxes are implemented, through increases in VAT, this leads to around a €10 billion increase in GDP in the scenario overall after secondary effects in the Tech 1 scenario.

The net GDP impact is therefore a combination of the four following factors:

The GDP impact of increased capital costs
The GDP impact of reduced spending on fuel
The GDP impact of changes to the sources of tax revenues
Second-order and multiplier effects

Furthermore, consumers enjoy a higher standard of living which is not measured by GDP, as they are able to spend their net savings on other items as a result of lower fleet running costs.

The transition to spend more on vehicles, less on fuel, and more in other areas of the economy, also changes the sectoral composition of the economy, leading to a substantial increase in European employment of 443,000 net additional jobs in the Tech 1 scenario. In the CPI scenario, jobs increase by 356,000 overall, while GDP increases by €16 billion. Figure 7.3 shows the main economic impacts.

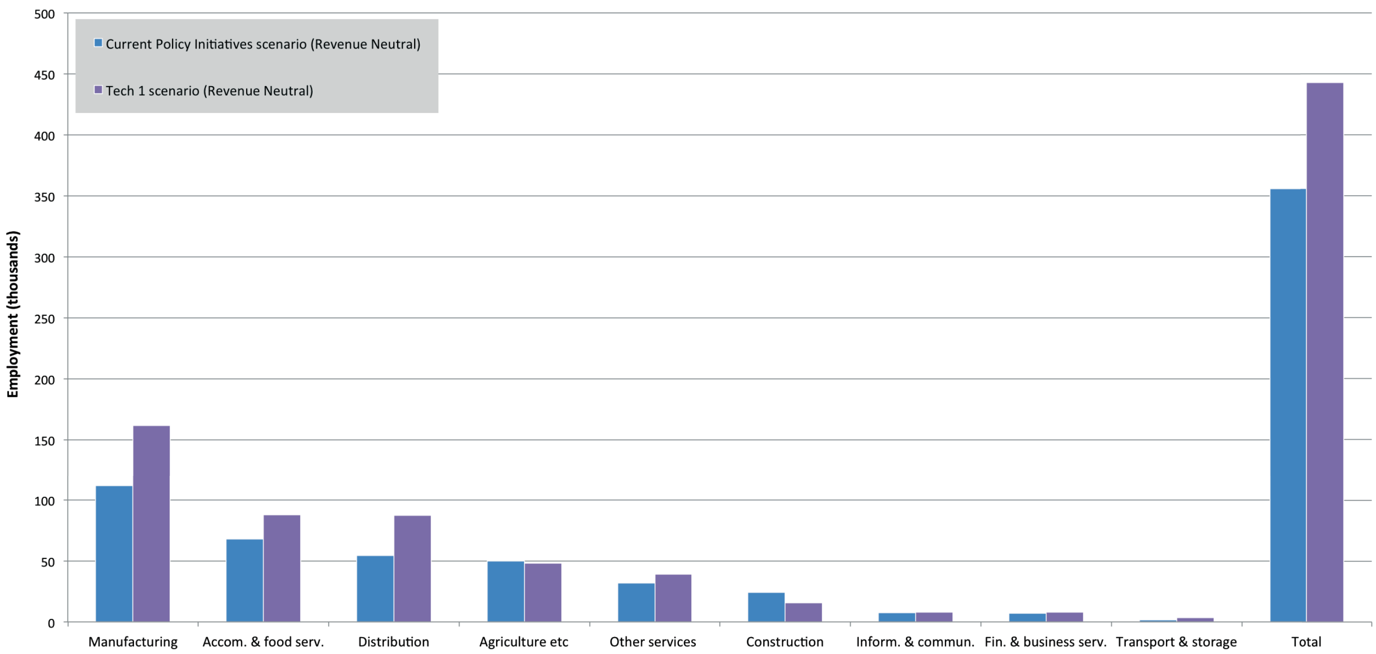
The results are sensitive to the cost of technology modelled, but even with the highest-case technology cost estimates, the GDP impact remains unchanged in the Tech 1 scenario compared to the Reference scenario although there are 413,000 more jobs following the direct and indirect effects of a switch from spending on fuel to technology

Fig 7.3 - Economic impacts in 2030
Monetary figures are shown as absolute difference from the Reference Case (€2008). Results are provisional.

	REFERENCE		CURRENT POLICY INITIATIVE	TECH 1 SCENARIO
Capital cost EU car and van fleet (excl tax)	€426 bln	↑	+€22 bln	+€46 bln
Fuel cost (excl tax, duties)	€245 bln	↓	-€57 bln	-€79 bln
Total cost EU car and van fleet (excl tax) *	€803 bln	↓	-€35 bln	-€33 bln
Employment	230 mln	↑	+356,000	+443,000
GDP	€15,589 bln	→	+€16 bln	+€10 bln

Source: Cambridge Econometrics E3ME
* This number includes annual running costs such as maintenance, which is why it is higher than the sum of the capital cost and the fuel cost.

Fig 7.4 - Employment impact of low carbon vehicle scenarios in 2030



Sources: E3ME, Cambridge Econometrics

8. Limitations of the Analysis

The baseline scenario that is used in the technical economic modelling is of course subject to considerable uncertainty; it is not possible to accurately predict all the long-run economic trends. However, the scenario results are in the main presented as difference from the Reference Case, which offsets this to some extent.

TECHNOLOGICAL ANALYSIS

The costs and performance of different technology options are based on information sourced from the literature and from experts, including members of the project's Core Working Group, which have been combined in a consistent way using Ricardo-AEA's calculation framework. However, this is not a full vehicle simulation tool and so it is only possible to factor in technology overlaps, synergies and dis-synergies in an approximate way. Furthermore there is considerable uncertainty going forwards on the potential rate of deployment of individual technologies, and future cost reduction.

In particular, the potential for future cost reduction in individual technologies will be influenced by a wide range of parameters including, for example, rates of technology deployment (i.e. economies of scale), breakthroughs in fundamental research, future prices of key materials and components, etc. For the purposes of this analysis it was necessary to use a range of simplified assumptions/calculations that were varied to a degree by technology type in order to estimate possible future cost reduction. High/Low cost sensitivities have also been developed to help capture this uncertainty.

For the purposes of consistency in the development of marginal capital cost and fuel consumption assumptions, different powertrains are modelled based on the average car or van. In reality there are (and most likely will continue to be in the future) differences in the characteristics and relative shares of different powertrain/fuel combinations for different vehicle sizes and market segments. In the future it may be anticipated that there may be a shift to smaller (for passenger cars) or larger (for vans) vehicle sizes/segments in response to a range of issues. Furthermore, the very characteristics of future vehicles and how they are used is likely to change (particularly in the longer term) – to an extent that is highly uncertain.

These elements have been fixed for the purposes of this analysis, in part (a) in order to more clearly understand the specific impacts with regards to technological development independent of other factors, (b) because the characteristics and effects of such considerations are highly uncertain. There are also limitations in the way scenarios are modelled within SULTAN in that these do not include feedbacks to transport demand as a result of changes in the costs of motoring (either through improved efficiency or changes in fuel price). Hence different scenarios assume the same level of activity and new vehicle uptake/stock. This will be addressed in Phase II of the project.

ECONOMIC ANALYSIS

There are some limitations in the way the scenarios are implemented in the E3ME macroeconomic model. The strength of E3ME is that it covers the whole economy, but this is necessarily at the expense of detail within sectors. This limits the level of analysis that can be done within the motor vehicles sector itself. For example, the cost increases have been allocated in a rather general way, rather than focusing on specific components.

There are other assumptions that relate to the way the scenarios are defined in the E3ME model. As a European model, international energy prices are given as exogenous, so there are no feedbacks to prices from reduced rates of fuel consumption (another kind of rebound effect). Exchange rates and interest rates are also given as exogenous.

Many of these limitations will be addressed in Phase II of the project. For example, significant attention will be paid to the issue of competitiveness in global markets and to the availability of skills in the workforce available to manufacture low-carbon technologies.

9. Next Steps

REFINING EXISTING RESULTS

Several real-world impacts have not yet been addressed in the study. These include the rebound effect, whereby reduced motoring costs lead motorists to drive further. The study must also take account of the fact that the distance driven by a vehicle annually is not the same across its lifetime. Vehicles cover much larger distances in the first few years of their lives than in the later period. The result of this is that the benefits of improved fuel-efficiency are 'front-loaded' within the vehicle's lifetime.

EXTENSION OF TIMEFRAME TO 2050

The first phase of this project focuses on the timeframe 2010-2030, during which the dominant vehicle technologies are the Internal Combustion Engine and the Hybrid Electric Vehicle. In the second phase, the project will focus on the period 2025-2050, involving the deployment of Plug-in Hybrid Electric Vehicles, Battery Electric Vehicles and Fuel Cell Electric Vehicles, and their associated infrastructure.

ANALYSIS OF INFRASTRUCTURE COSTS

The shift to advanced powertrains generate additional costs for charging infrastructure. This comprises public and private charging posts for all types of electric vehicles and hydrogen refueling infrastructure for Fuel Cell Electric Vehicles. These must be added to the additional vehicle costs when comparing with the benefits due to avoided spending on fuel, the impact on the infrastructure supply chain.

COMPETITIVENESS AND SKILLS

Europe will only be able to capitalize on low-carbon technologies in vehicles if a large part of that value chain is located in Europe. If the majority of this technology is imported, many of the benefits will accrue to the supplier nations. The next phase of the study will examine whether Europe's skill-base is prepared to capture the potential benefits of a transition to low-carbon vehicles. It will also look at the role that Europe's auto producers play in global markets, where relative cost and fuel-economy are two important factors determining future market share.

SYNERGIES WITH POWER SYSTEM

The shift to alternative energy sources for vehicles, such as electricity or hydrogen, can create an opportunity or an additional burden for the power system. Smart charging can provide an opportunity for power suppliers to balance fluctuations in the electricity grid at lower cost than many other balancing options. This will become increasingly important as the share of renewable electricity increases. Dumb charging, by contrast, could create a challenge by leading to greater peaks in electricity consumption at certain points in the 24-hour cycle. Likewise, hydrogen can play an important role in balancing variation in the output from renewable energy sources. The next phase of this project will seek to examine the economic impact of these issues.

10. Annex

Table 10.1 - Global Vehicle Standards

COUNTRY	VEHICLE EMISSION STANDARDS
Australia	In 2005 introduced a voluntary target to reduce national average carbon emissions from light-duty vehicles to 222gCO_2/km by 2010 (under NEDC cycle).
Canada	In 2010 outlined limits on GHG emissions from light-duty vehicles, based on the footprint structure proposed by the US. Average of fleet anticipated to be 153gCO_2/km by 2016 (~154gCO2/km under NEDC).
China	In 2009 introduced Phase III fuel consumption regulation to limit new passenger cars to 7L/100km (~167gCO_2/km under NEDC) by 2015.
EU	Previously had voluntary targets. In 2009 set out a mandatory requirement for average new car fleet to meet target of 130gCO_2/km by 2015. This was later extended to 95gCO_2/km by 2020. The EU also has a mandatory emission target for vans of 175gCO_2/km by 2017 and 147gCO_2/km by 2020.
Japan	Regulation in 2007 to set weight-based binned standards for cars registered in 2015, with fleet average fuel economy limited to 16.8 km/L (~125gCO_2/km under NEDC) by 2015.
Russia	Required to meet European emission standards for manufactured and imported vehicles.
South Korea	In 2010, set out combined fuel consumption and GHG emission standards of 17km/L or 140gCO_2e/km respectively by 2015. This standard is weight-based, and uses the US CAFE cycle, but is equivalent to ~150gCO_2/km under NEDC.
US	In 2010, introduced greenhouse gas emission and fuel economy standards for light duty vehicles between 2012 and 2016. By 2016, limits have been specified as 250 gCO_2e/mile or 34.1 miles per gallon (under the US CAFE combined driving test cycle). This is equivalent to ~172gCO_2/km under the NEDC cycle.

Source: ICCT

Table 10.2 - Summary of the technology package definition, efficiency improvement and cost assumptions used in the study (X = technology applied at 100% level)

SUB-COMPONENT	Type	T#	% Red'n Energy	Mass manufacturing cost	1	2	3	4	5	6	7	8
Petrol - low friction design and materials	PtrainE	1	-2,0%	€ 35	10%	X	X	X	X	X	X	X
Petrol - gas-wall heat transfer reduction	PtrainE	2	-3,0%	€ 50	10%		X	X	X	X	X	X
Petrol - direct injection (homogeneous)	PtrainE	3	-5,3%	€ 180	15%	X	X					
Petrol - direct injection (stratified charge)	PtrainE	4	-9,3%	€ 550	0%			X				
Petrol - thermodynamic cycle imporvements (e.g. HCCI)	PtrainE	5	-14,5%	€ 488	0%				X	X	X	X
Petrol - cam-phasing	PtrainE	6	-4,0%	€ 80	10%	X	X					
Petrol - variable valve actuation and lift	PtrainE	7	-10,5%	€ 280	5%			X	X	X	X	X
Diesel - variable valve actuation and lift	PtrainE	8	-1,0%	€ 280	0%			X	X	X	X	X
Diesel - combustion improvements	PtrainE	9	-6,0%	€ 50	10%	50%	X	X	X	X	X	X
Mild downsizing (15% cylinder content reduction)	PtrainE	10	-5,5%	€ 275	20%	X						
Medium downsizing (30% cylinder content reduction)	PtrainE	11	-8,5%	€ 473	5%		X	X				
Strong downsizing (>=45% cylinder content reduction)	PtrainE	12	-17,5%	€ 650	0%				X	X	X	X
Reduced driveline friction	PtrainE	13	-1,0%	€ 50	5%		X	X	X	X	X	X
Optimising gearbox ratios / downspeeding	PtrainE	14	-4,0%	€ 60	10%		X	X	X	X	X	X
Automated manual transmission	PtrainE	15	-5,0%	€ 300	0%			X	X			
Dual clutch transmission	PtrainE	16	-6,0%	€ 725	0%					X	X	X

SUB-COMPONENT	Type	T#	% Red'n Energy	Mass manufacturing cost	1	2	3	4	5	6	7	8
Start-stop hybridisation	PtrainE	17	-5,0%	€ 213	5%		X	X				
Start-stop + regenerative braking (smart alternator)	PtrainE	18	-10,0%	€ 400	0%				X	X	X	X
Non-specific general improvement	PtrainE	19	-10,0%	€ -	10%	20%	40%	60%	80%	X	X	X
Aerodynamics improvement	Aero	1	-1,8%	€ 55	5%		X	X	X	X	X	X
Low rolling resistance tyres	Rres	1	-3,0%	€ 38	20%	X	X	X	X	X	X	X
Mild weight reduction (~10% total)	Weight	1	-6,7%	€ 35	10%	X						
Medium weight reduction (~20% total)	Weight	2	-13,5%	€ 220	3%		X	X	X			
Strong weight reduction (~30% total)	Weight	3	-20,2%	€ 810	0%					X		
Very strong weight reduction (~35% total)	Weight	4	-23,5%	€ 1.800	0%						X	
Extreme weight reduction (~40% total)	Weight	5	-26,8%	€ 3.000	0%							X
Thermo-electric waste heat recovery	Other	1	-2,0%	€ 1.000	0%					X	X	X
Secondary heat recovery cycle	Other	2	-2,0%	€ 250	0%				X	X	X	X
Auxiliary systems efficiency improvement	Other	3	-12,0%	€ 450	15%			X	X	X	X	X
Thermal management	Other	4	-2,5%	€ 150	10%			X	X	X	X	X

Sources: Ricardo-AEA

Table 10.3 - Deployment of technology packages to meet CO2 reduction target in 2010-2050

PACKAGE		2010	2015	2020	2030	2040	2050
No Further Improvements							
1	~2010 ICE	100%	90%	90%	90%	90%	90%
2	~2015 ICE		9%	9%	9%	9%	9%
3	~2020 ICE		1%	1%	1%	1%	1%
Current Policy Initiatives							
1	~2010 ICE	100%	50%	5%			
2	~2015 ICE		45%	20%	10%	5%	
3	~2020 ICE		5%	60%	60%	50%	40%
4	~2025 ICE			10%	23%	34%	44%
5	~2030 ICE			5%	6%	8%	10%
6	~2035 ICE				1%	2%	3%
7	~2040 ICE					1%	2%
8	~2050 ICE						1%
All Technology Scenarios							
1	~2010 ICE	100%	40%	5%			
2	~2015 ICE		50%	10%			
3	~2020 ICE		10%	70%	5%		
4	~2025 ICE			10%	20%		
5	~2030 ICE			5%	60%	5%	
6	~2035 ICE				10%	20%	
7	~2040 ICE				5%	65%	10%
8	~2050 ICE					10%	90%

Table 10.4 - Summary of the key technology assumptions related to ICE, HEV, BEV, PHEV, FCEV

Area	Category	Unit	2010	2020	2030
Basic energy consumption reduction (per km) vs equivalent ICE (8)	Petrol HEV (and PHEV, REEV in non-electric mode)	%	25.0%	25.6%	26.2%
	Diesel HEV (and PHEV, REEV in non-electric mode)	%	22.0%	22.6%	23.3%
	BEV (and PHEV, REEV in all-electric mode) (vs Petrol ICE)	%	76.0%	76.5%	76.9%
	FCEV (vs Petrol ICE)	%	63.1%	65.0%	66.8%
All-electric range (5) (6)	HEV	km	2	2	2
	PHEV	km	30	35	40
	REEV	km	60	70	80
	BEV	km	120	160	200
	FCEV (H2FC)	km	5	4	3
Battery usable SOC for electric range (3) (4)	HEV	%	50%	55%	60%
	PHEV	%	60%	65%	70%
	REEV	%	70%	75%	80%
	BEV	%	80%	80%	85%
	FCEV (H2FC)	%	50%	55%	60%
Derived battery size (cars) (9)	HEV	kWh	1.35	1.05	0.84
	PHEV	kWh	8.89	8.14	7.45
	REEV	kWh	15.24	14.10	13.03

Area	Category	Unit	2010	2020	2030
	BEV	kWh	26.67	29.36	28.82
	FCEV (H2FC)	kWh	2.73	1.59	0.88
BEV battery system (cars) (1)	Central cost	€/kWh	558	245	163
	Low cost	€/kWh	558	165	125
	High cost	€/kWh	558	307	201
BEV battery system (vans) (1)	Central cost	€/kWh	504	221	147
	Low cost	€/kWh	504	149	113
	High cost	€/kWh	504	277	181
Battery system cost increase over BEV (2)	HEV	%	100%	100%	100%
	PHEV	%	50%	50%	50%
	REEV	%	25%	25%	25%
	BEV	%	0%	0%	0%
	FCEV (H2FC)	%	100%	100%	100%
Electric motor system	Central cost	€/kW	41	22	14
	Low cost	€/kW	41	14	13
	High cost	€/kW	41	31	22
Electric powertrain (HEV) (7)	Additional cost (excl. battery, motor)	€	1014	890	800
Electric powertrain (Others) (7)	Additional cost (excl. battery, motor)	€	1282	1031	930

Summary of the additional technology assumptions for fuel cell electric vehicles (FCEVs)

Area	Category	Unit	2010	2020	2030
Fuel cell system cost	Central cost	€/kW	880	100	55
	Low cost	€/kW	880	80	45
	High cost	€/kW	880	150	80
H2 storage cost	Central cost	€/kWh	59	16	10
	Low cost	€/kWh	59	13	6
	High cost	€/kWh	59	20	13

Updated assumptions for the base costs of 2010 conventional internal combustion engines (ICE), before the addition of further technological improvements

Area	Category	Unit	2010	2020	2030
Petrol ICE	Central cost	€/kW	26	25	24
	Low cost	€/kW	22	21	20
	High cost	€/kW	28	27	26
Diesel ICE	Central cost	€/kW	34	32	31
	Low cost	€/kW	33	31	30
	High cost	€/kW	37	35	34

Table 10.5 - Car Marginal Capital Costs compared to 2010 reference vehicle

	2010	2015	2020	2025	2030
Reference case	€ 0	€ 152	€ 304	€ 194	€ 85
Current Policy Initiatives	€ 0	€ 478	€ 996	€ 987	€ 959
Tech 1 scenario	€ 0	€ 519	€ 1.091	€ 1.494	€ 1.926

Source: Ricardo-AEA

Table 10.6 - Van Marginal Capital Costs compared to 2010 reference vehicle

	2010	2015	2020	2025	2030
Reference case	€ 0	€ 352	€ 705	€ 566	€ 427
Current Policy Initiatives	€ 0	€ 582	€ 1.145	€ 1.166	€ 1.168
Tech 1 scenario	€ 0	€ 630	€ 1.284	€ 1.782	€ 2.176

Source: Ricardo-AEA

Table 10.7 - The TCO has been calculated for cars from the following elements:

Total purchase price (i.e. including all taxes and margins), discounted over the full life of the vehicle at a defined rate (e.g. 3.5%, 5% and 10%).
+ Annual maintenance cost x lifetime of the vehicle (12 years)
+ Total fuel costs (prices including duty and VAT) over the lifetime of the vehicle (i.e. factoring in future increases or decreases in fuel prices)

Further details on the assumptions used in the calculation of the TCO are provided in the tables below.

	2010	2015	2020	2025	2030	2040	2050
Petrol ICE	€ 14.483	€ 14.890	€ 15.297	€ 15.701	€ 16.106	€ 16.435	€ 16.585
Diesel ICE	€ 15.095	€ 15.709	€ 16.323	€ 16.596	€ 16.869	€ 17.084	€ 17.131
Petrol HEV	€ 17.552	€ 17.098	€ 16.643	€ 16.699	€ 16.754	€ 16.844	€ 16.907
Diesel HEV	€ 17.982	€ 17.749	€ 17.516	€ 17.446	€ 17.377	€ 17.365	€ 17.334
Petrol PHEV	€ 26.242	€ 23.206	€ 20.169	€ 19.528	€ 18.887	€ 18.370	€ 18.126
Diesel PHEV	€ 26.539	€ 23.570	€ 20.602	€ 19.870	€ 19.138	€ 18.579	€ 18.289
BEV	€ 31.583	€ 26.966	€ 22.349	€ 20.942	€ 19.534	€ 18.681	€ 18.225
FCEV	€ 98.690	€ 61.940	€ 25.191	€ 22.589	€ 19.987	€ 18.794	€ 18.077
LPG ICE	€ 15.948	€ 16.089	€ 16.229	€ 16.443	€ 16.656	€ 16.824	€ 16.914
NG ICE	€ 15.948	€ 16.089	€ 16.229	€ 16.443	€ 16.656	€ 16.824	€ 16.914

Margin applied to vehicle purchase (manufacturer and dealer margin applied on top of the manufacturing cost)

	2010	2015	2020	2025	2030	2040	2050
Petrol ICE	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%
Diesel ICE	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%
Petrol HEV	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%
Diesel HEV	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%
Petrol PHEV	0,0%	6,1%	12,2%	15,2%	18,2%	22,0%	24,3%
Diesel PHEV	0,0%	6,1%	12,2%	15,2%	18,2%	22,0%	24,3%
BEV	0,0%	6,1%	12,2%	18,2%	24,3%	24,3%	24,3%
FCEV	0,0%	6,1%	12,2%	18,2%	24,3%	24,3%	24,3%
LPG ICE	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%
NG ICE	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%

Annual maintenance cost assumptions

	2010	2015	2020	2025	2030	2040	2050
Petrol ICE	€ 373	€ 370	€ 367	€ 363	€ 360	€ 350	€ 340
Diesel ICE	€ 387	€ 383	€ 380	€ 377	€ 373	€ 367	€ 360
Petrol HEV	€ 373	€ 370	€ 367	€ 363	€ 360	€ 350	€ 340
Diesel HEV	€ 387	€ 383	€ 380	€ 377	€ 373	€ 367	€ 360
Petrol PHEV	€ 313	€ 310	€ 307	€ 303	€ 300	€ 293	€ 287
Diesel PHEV	€ 320	€ 317	€ 313	€ 310	€ 307	€ 302	€ 297
BEV	€ 254	€ 250	€ 247	€ 243	€ 240	€ 237	€ 233
FCEV	€ 321	€ 311	€ 300	€ 290	€ 280	€ 273	€ 267
LPG ICE	€ 373	€ 370	€ 367	€ 363	€ 360	€ 350	€ 340
NG ICE	€ 373	€ 370	€ 367	€ 363	€ 360	€ 350	€ 340

Fuel cost and tax assumptions for central/low/high fossil fuel cost scenarios

FUEL COSTS (EXCL. TAX)	2010	2015	2020	2025	2030	2040	2050	Taxes	
Central €/MJ	2010	2015	2020	2025	2030	2040	2050	VAT	DUTY
Petrol	0.016	0.024	0.026	0.027	0.029	0.030	0.032	19%	0.018
Diesel	0.015	0.023	0.025	0.026	0.027	0.029	0.030	19%	0.012
Electricity	0.035	0.038	0.041	0.042	0.043	0.040	0.040	19%	0.000
Hydrogen	0.025	0.031	0.034	0.039	0.044	0.053	0.057	19%	0.000
LPG	0.016	0.024	0.026	0.028	0.029	0.031	0.032	19%	0.004
CNG	0.013	0.019	0.021	0.022	0.023	0.024	0.025	19%	0.002
Low €/MJ	2010	2015	2020	2025	2030	2040	2050	VAT	DUTY
Petrol	0.016	0.022	0.023	0.022	0.021	0.019	0.016	19%	0.018
Diesel	0.015	0.021	0.022	0.021	0.020	0.018	0.015	19%	0.012
Electricity	0.035	0.038	0.041	0.042	0.043	0.040	0.040	19%	0.000
Hydrogen	0.025	0.030	0.031	0.034	0.040	0.051	0.057	19%	0.000
LPG	0.016	0.023	0.023	0.023	0.022	0.019	0.016	19%	0.004
CNG	0.013	0.018	0.018	0.018	0.017	0.015	0.013	19%	0.002
High €/MJ	2010	2015	2020	2025	2030	2040	2050	VAT	DUTY
Petrol	0.016	0.025	0.029	0.033	0.036	0.041	0.048	19%	0.018
Diesel	0.015	0.024	0.028	0.031	0.034	0.040	0.046	19%	0.012
Electricity	0.035	0.038	0.041	0.042	0.043	0.040	0.040	19%	0.000
Hydrogen	0.025	0.032	0.036	0.040	0.047	0.055	0.057	19%	0.000
LPG	0.016	0.026	0.030	0.033	0.036	0.042	0.049	19%	0.004
CNG	0.013	0.020	0.023	0.026	0.029	0.033	0.038	19%	0.002

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