STUDY

Integrated Fuels and Vehicles Roadmap to 2030+

April 27, 2016

Table of Contents

Table of Figures

Glossary

Index of abbreviations

ACEA	European Automobile Manufacturers' Association
B7	Diesel blend with a proportion of 7% FAME
BEV	Battery electric vehicles
BTL	Biomass-to-liquid
CAM	Customer acceptance model
CCS	Carbon capture and storage
CNG	Compressed natural gas
DAFI/AFID	Deployment of Alternative Fuel Infrastructure
E5	Gasoline blend with a proportion of 5% ethanol
E10	Gasoline blend with a proportion of 10% ethanol
E20	Gasoline blend with a proportion of 20% ethanol
E85	Gasoline blend with a proportion of 85% ethanol
ETS	Emissions Trading Scheme
EU	European Union
FAME	Fatty acid methyl ester
FC	Fuel cells
FCV	Fuel cell vehicles
FFV	Flex-fuel vehicles
FH	Full hybrid
FQD	Fuel Quality Directive
GHG	Greenhouse Gas
GVW	Gross vehicle weight
HDT	Heavy duty truck
HEV	Hybrid electric vehicle
HVO	Hydrotreated vegetable oil
ICCT	The International Council on Clean Transportation
ICE	Internal combustion engine
IEA	International Energy Agency
IET	Institute of Energy and Transport
ILUC	Indirect Land Use Change Directive
JRC	Joint Research Centre
LCV	Light commercial vehicle
LC	Lingo-Cellulosic – Composition of carbohydrate polymers and aromatic polymers
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MDT	Medium duty truck
MH	Mild hybrid

NEDC	New European Driving Cycle
NG	Natural gas
NGO	Non-governmental organization
NOx	Nitrous oxide
O&M	Overhead and maintenance
OEM	Original Equipment Manufacturer
PC	Passenger car
PHEV	Plug-in hybrid electric vehicles
PM	Particulate Matter
R33	Diesel blend with a proportion of 7% FAME and 26% HVO (meets EN 590, is “drop-in")
RB	Roland Berger
RDE	Real Driving Emissions
RED	Renewable Energy Directive
RME	Rapeseed oil methyl ester
SMR	Steam methane reformer
SNG	Synthetic natural gas
SOx	Sulfur oxides
SUV	Sports utility vehicle
TCO	Total cost of ownership
TTW	Tank-to-wheel
WEO	World Energy Outlook
WLTP	Worldwide Harmonized Light Vehicles Test Procedure
WTT	Well-to-tank
WTW	Well-to-wheel

Executive Summary

EU road transport sector decarbonization and regulation post-2020 is undefined

In October 2014, the European Heads of States communiqué agreed on the 2030 Climate and Energy Policy Framework. This framework set binding targets for the reduction of greenhouse gas (GHG) emissions and non-binding targets for renewable energy consumption and improvements in energy efficiency. The overall GHG emissions reduction target of -40% (-43% for ETS sector and -30% for non ETS sector) in 2030 below 2005 levels was in line with both the ambition to reduce GHG emissions in the European Union (EU) by 80-95% below 1990 levels by 2050 and the vision of the EU White Paper on Transport.

The Communiqué did not set any specific sectorial target for road transport decarbonization between 2020 and 2030. It did however state that the Commission should "further examine instruments and measures for a comprehensive and technology neutral approach for the promotion of emissions reduction and energy efficiency in transport, for electric transportation and for renewable energy sources in transport also after 2020".

The current regulatory framework for vehicle emissions, carbon intensity of fuels and use of renewable fuels is only valid until 2020/2021 and the absence of any transport decarbonization polices post 2020 is making investors wary of low carbon vehicles and fuels. To help foster an informed debate, it was considered useful to develop a view on possible GHG abatement measures in the road transport sector and supporting policy elements that would deliver decarbonization to 2030 and beyond in a sustainable way. This also included assessing potential measures regarding technical achievability, infrastructure requirements, customer acceptance and costs to society, needed to incorporate fuel and vehicle technologies.

An independent evaluation of fuel and vehicle technologies has been undertaken

For this purpose, Roland Berger has been commissioned by a coalition of automotive companies and fuel suppliers[1] to define and produce an Integrated Roadmap for EU Road Transport Decarbonization to 2030 and beyond. The study was commissioned to identify possible reductions in GHG emissions by considering the key elements of technical achievability, infrastructure needs, customer acceptance and which policies, currently being pursued, would lead to greater integration between the automotive and fuel sectors in order to meet the challenging decarbonization goals set out to 2030 and beyond. This study aims to provide an integrated roadmap taking into account the feasibility of all fuel and vehicle technologies along with infrastructure needs and the recommended policy framework beyond 2020. A key consideration was to identify a roadmap with the lowest, achievable GHG abatement costs to society[2].

This study incorporates existing data and views from a very broad range of studies and stakeholders from across the vehicle and fuel industries, research organizations, NGOs and EU

[1] The EU Auto Fuel Coalition (Coalition) is comprised of BMW, Daimler, Honda, NEOT/St1, Neste, OMV, Shell, Toyota and Volkswagen.
[2] For details refer to chapter 2.2

policymakers. Nonetheless, one must acknowledge that evaluating developments until 2030 and beyond is rife with uncertainty and led to assessments, which were made as transparent as possible by means of variability ranges or sensitivity analysis.

A realistic reference case based on current regulation was developed for the EU until 2030

Based on projected fuel and vehicle costs for conventional internal combustion engines, mild and full hybrids, plug-in hybrids, battery electric vehicles, natural gas vehicles and fuel cell electric vehicles, a powertrain mix was derived for 2030 which constitutes a reference case based upon the current unaltered regulatory framework. This reference case predicts within two different scenarios expected market developments under the current regulatory framework without any additional policies after 2021 beyond prevailing legislation with increasing alternative powertrain[3] and fuel penetration in addition to the existing high penetration of improved ICE powertrains.

After comparing the transport sector's emissions under the current regulatory framework with 2030 GHG emissions reduction targets[4], technologies were identified to achieve additional GHG abatement at the lowest cost to society. In order for these technologies to contribute to the abatement of the road transport sector's GHG emissions, the recommended policies need to address the current obstacles facing these technologies.

SUMMARY OF STUDY OUTCOMES

1) *The reference case shows that maintenance of the existing vehicle efficiency and fuels regulations to 2030 will lower tank-to-wheel GHG emissions from road transport to 647 Mton representing a 29% reduction compared to 2005 levels, achieving almost aspired level for 2030[5].*

Based on assumptions developed in conjunction with a wide range of stakeholder input and reference studies regarding vehicle fleet development and the current regulatory framework, the road transport sector will reduce tank-to-wheel GHG emissions by 29% until 2030 (compared to 2005) and bring down tank-to-wheel emissions close to reference level of -30% vs 2005.

Transport will also deliver tank-to-wheel emissions savings of 191 Mton CO_2e between 2015 and 2030 to reduce the total well-to-wheel GHG emission in 2030 to 862 Mton CO_2e. The well-to wheel-emission savings comprise a 23% reduction in tank-to-wheel emissions and a 22% reduction in well-to-tank emissions.

Optimized ICEs (Gasoline and Diesel) are the major contributor to the reduction of passenger car GHG emissions with significant improvements until 2020 and the subsequent penetration of effective technologies into the fleet. Despite the expected reduction in cost of alternative technologies, their share of new car sales will remain relatively small and their influence on overall emissions currently remains marginal. Efficiency technologies such as improved diesel combustion

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[3] i.e. PHEV, BEV. FCV

[4] The Climate & Energy Policy Framework from 2014 aims to achieve a 30% reduction in GHG emissions below the 2005 level until 2030 in non-ETS sectors. The 2011 White Paper for Transport defines transport emissions on a tank-to-wheel basis.

[5] For details refer to chapters 3.1 to 3.3

employed in commercial vehicles including light commercials, buses and trucks as well as use of LNG will likely over compensate for the effect of significant increases of transport volumes on the GHG emissions side based on the modelling scenarios. Biofuels also contribute significantly to the reductions in GHG emissions of both passenger cars and commercial vehicles.

2) *GHG abatement in road transport sector will cost approx. 150 - 200 EUR per ton of* CO_2*e avoided*[6]

Bringing optimized ICEs as well as alternative fuels and powertrain technologies to market, represents a major challenge for the oil and auto industries and will account for EUR 380-390 bn of cumulated incremental powertrain costs from 2010 until 2030[7]. However, these incremental powertrain costs make reductions in GHG emissions possible and will reduce the cost to society over the longer term through till 2030. The overall effects are

> Accumulated GHG abatement of approx. 1,090 Mton CO_2e,
> Fuel cost savings between EUR 170 and 220 bn and
> Average societal abatement cost of approx. ~ 150-200 EUR/ton CO_2e after deduction of fuel savings

3) *To further abate GHG emissions in road transport by 2030, more biofuels and hybrid powertrains for passenger cars as well as more biofuels and new truck concepts for commercial vehicles are a cost effective way of delivering more GHG savings from transport and with supportive polices they can deliver an extra 34 Mton* CO_2*e by 2030.*[8]

From the GHG abatement cost perspective, it is most efficient for society to promote the following specific technologies until 2030:

> Full deployment of the E10 grade, to reach the 7% energy cap of conventional biofuels
> Higher advanced ethanol blends for gasoline such as E20
> Drop-in advanced biofuels for diesel such as R33[9]
> Hybridized powertrains, such as mild hybrids and full hybrids

These technologies have not yet realized their full GHG reduction potential in terms of deployment under the current regulatory framework and come at costs of 0–100 €/ton-CO_2 abated. The additional abatement potential of these technologies is approx. 34 Mton CO_2e (WTW).

In commercial vehicle segments, additional cost-efficient GHG abatement is possible through

> Higher uptake of drop-in advanced biofuels for diesel in all segments
> New heavy duty truck (HDT) concepts with increased gross vehicle weight and higher maximal length for improved aerodynamics (having negative GHG abatement costs)
> Improved efficiencies of current ICEs and hybridization of powertrains for Light Commercial Vehicles (LCV) such as mild and full hybridization (MH, FH) and HDT (FH)

Alternative powertrain measures in these segments are currently very costly due to high adaptation costs.

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[6] For details refer to chapters 3.4
[7] Significant additional cost for production of biofuels accrues also.
[8] For details refer to chapters 4.1
[9] Diesel fuel with 7% FAME, 26% HVO

As a longer-term requirement (beyond 2030) for the EU road transport sector[10], the study indicates that the only fuel and vehicle combinations technically suited to achieving "ultra-low carbon emission mobility" are:

> Highly-efficient conventional powertrains (Mild- and full-Hybrid) fuelled with advanced and waste based biofuels/-gases (for passenger cars (PC) and commercial vehicles (CV))
> PHEVs fuelled with advanced biofuels and low carbon, renewable electricity (for PC)
> BEVs fuelled with low carbon, renewable electricity (for PC)
> FCVs fuelled with low carbon, renewable hydrogen (for PC)

The latter powertrain technologies also offer the advantage of zero pollutant emissions.

4) Policy makers should adopt an integrated approach in policy design and promote the deployment of cost-efficient GHG abatement technologies post-2020[11]

The current regulatory framework does not fully address all the barriers preventing a higher penetration of biofuels and hybrids for passenger cars to achieve the 2030 GHG reduction target. It is recommended that additional policies are introduced to provide greater investor certainty and improve consumer demand for these lower cost abatement options.

In many commercial vehicles the implementation of efficiency technology in powertrains is TCO-driven – Only in LCVs, the implementation of fuel-saving measures segment is supported by the current regulatory. But, at vehicle level, an adaption of the regulatory framework on current vehicle length and weight limitation is necessary.

Until 2030, demand- and supply-side policy measures are needed at EU and member state level to address obstacles faced by more cost-efficient technologies enabling them to make greater inroads into the market.

Policy makers need to implement consistent policies and balanced measures that provide incentives to both demand and supply alike by addressing fuel suppliers, OEMs and customers equally. Such an integrated approach aims to:

> Create long-term sustainable market (demand side-) to:
  – Encourage consumers to buy carbon-saving vehicle technologies
  – Convince fuel customers to choose low carbon fuels by introducing CO_2 based taxation components for fuels
  – Improve customer awareness of the benefits of biofuels concerning GHG emissions as well as the technological benefits of efficient powertrains and their cost-attractiveness
> Create planning security for investments by fuel suppliers and OEMs (supply-side) to
  – Enable development of advanced biofuel production by providing a strong and sustained price signal for the product at least until the advanced biofuels is commercially mature. This signal can be the tax exemption of biofuel content in market fuels in or via a fuel taxation bonus depending on the biofuel content. Both can be combined with a CO_2 based taxation component
  – Support for use of the Innovation Fund for investments in innovations in low carbon technologies. The Innovation Fund should be used to fund capex and opex for initial advanced biofuel plants (fuel supplier/biofuel supplier)

[10] For details refer to chapters 4.3
[11] For details refer to chapters 5.1 to 5.3

- Increase production of vehicles which are societally cost-efficient with highly efficient conventional technologies and fuel compatibility of vehicles (OEMs)
- Counting the renewable share of the fuel that the vehicle is compatible with (above 10% volume ethanol or 7% volume FAMEs) as zero-CO_2 tailpipe emissions to enable the further integration with regard to fuels and vehicles and accelerate the fleet deployment of vehicles compatible with higher biofuel blends

5) *Placing fuels in a market based system (MBM) will provide a potential source of funding for the demand side measure needed to 2030 and will also lead to GHG abatement becoming an economy-wide rather than a sectorial issue based on the lowest cost to society.*[12]

It is recommended that policy makers consider placing fuels in a MBM as complementary policy to vehicle CO_2 standards, fuels and infrastructure policies. Initially, the MBM should be designed to recycle the revenues from the sale of allowances for fuels to provide the funding needed to bring new low carbon fuels and vehicles to market. Once low carbon fuels and vehicles can be deployed affordably en masse, then the MBM can be the primary GHG reduction policy and other policies (vehicle efficiency, fuels etc.) can be removed.

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[12] For details refer to chapters 5.3

1. Background and motivation

1.1 Motivation for the study

The challenge faced by the EU concerning rising greenhouse gas emissions (GHG) in the transport sector is significant as it is the only economic sector in the EU in which GHG emissions have risen since 1990.

The ongoing road transport regulation and policy debate in the European Union is complex. Binding targets for the reduction of GHG emissions in the road transport sector are still being discussed and as such have not been agreed on by the European Commission. In 2014, the Council Conclusion on the 2030 Climate & Energy Policy Framework calling on the European Commission to develop an integrated and technology neutral approach to reduce GHG emissions in transport and "to consider measures to improve energy efficiency, promote e-mobility and the use of renewable energy sources" was adopted. Consequently, legislative initiatives to implement the 2030 framework will be developed by the new European Commission. Furthermore, legislative initiatives by the European Commission will be developed until 2016 to implement the "2030 Climate and Energy Policy Framework". This framework aims to reduce overall GHG emissions by 40% in 2030 compared to 1990 levels. Specifically, this target should be met by a reduction of GHG emissions in sectors subject to the Emissions Trading Scheme (ETS) of 43% compared to 2005 and by the other non-ETS sectors such as road transportation by 30%. Additionally, the 2011 Transport White Paper defines reduction targets for 2030 of 20% compared to 2008 and 60% in 2050 compared to 1990.[13]

It is also recognized that policies set in motion a number of years ago are beginning to demonstrate benefits. For instance, transport emissions caused by three significant air pollutants (SO_x, NO_x and particulate matter (PM)) decreased in the period from 2000 to 2013 with all transport modes except aviation contributing to this decline. This decline is attributable to the introduction of EU emission standards (affecting NO_x and PM emissions) and fuel quality (affecting SO_x) in road transport. Therefore, it is recognized that once introduced, policies need sufficient time and consistency to enable change to come about and certainty with regard to business investment strategies and consumer behaviour. In addition, there can be a number of unintended consequences of policies which should be considered such as:

> Lack of desired GHG reduction benefits (where a primary energy source such as coal supplies electricity) in the short term until renewable sources emerge.

> Premature technology introduction leading to a failure of sound, viable options due to lack of aligned expectations and what may be technically or economically feasible

> Lack of customer uptake due to poor transition from early adopters to full-scale deployment including lack of customer awareness of risks and benefits, lack of fuelling infrastructure to support emerging technologies and unfavorable market conditions.

Prospects

This study provides a range of detailed information and data to support policy makers and inform other stakeholders as it has integrated a number of existing studies. It will also suggest potential policy measures needed to deliver a cost-effective and acceptable process that builds on integrated policies for fuel providers and automakers. The study will also support the development and evaluation of integrated policies for the reduction of GHG emissions in the road transport sector.

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[13] These GHG emissions reduction targets are the basis on which the road transport sectors are defining their own reduction plans.

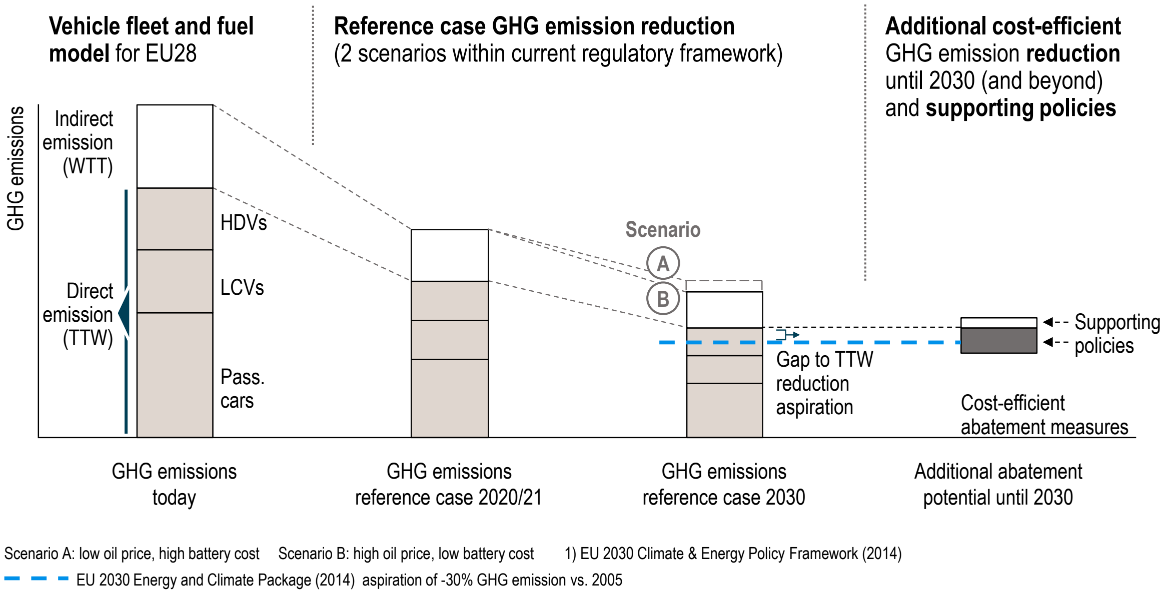
Approach

A comprehensive model has been developed calculating direct GHG emissions for Passenger cars (PC), Light Commercial Vehicles (LCV) and Heavy Duty Commercial vehicles (HDV) as well as upstream GHG emissions.

The reduction in GHG emissions in the reference case that will be achieved until 2030, under the current regulatory framework (i.e. current policies will be applied until 2030, no additional policies beyond the policies agreed in 2020 will be introduced) has been calculated as a reference case (refer to figure 1). Thereby, the increasing penetration of available fuel and vehicle technologies into the vehicle fleet has been examined in two scenarios. In scenarios A and B, parameters with a high uncertainty regarding their development and a high impact on penetration of fuel and vehicle technologies (oil price and battery cell cost) are presented with differing variables. (Refer to Chapter 2 and 3).

To ensure compliance with the 2030 reduction in GHG emissions reduction targets (as defined by the EC Framework), cost-efficient technologies have been evaluated based on their GHG abatement costs following the principle of lowest costs to society. Supporting policies were then recommended on the strength of this evaluation. (Refer to Chapter 4 and 5).

Figure 1: Approach for development of integrated roadmap



Source: Roland Berger

1.1.1 Current regulation

A number of EU regulations and directives target GHG emissions in the road transport sector. Current regulations are specifically aimed at vehicles and fuels and do not form an integrated approach to reduce emissions across the transport sector following a WTW approach.

Fuel Quality Directive – FQD 7a [Directive 2009/30/EC]

The fuel supply industry is regulated via the FQD. The FQD 7a set minimum 6% reduction in GHG intensity is mandatory by 2020 for road transport fuels compared to 2010. This is accompanied by a definition of sustainability criteria for biofuels (e.g. ethanol, HVO).

Renewable Energy Directive - RED [Directive 2009/28/EC]

EU member states are mandated by the RED that requires defined national action plans to provide at least a 10% energy share of all transport fuels to come from renewable resources by 2020. (e.g. biofuels, electricity, etc.).

Indirect Land Use Change Directive - ILUC [Directive 2015/1513]

The ILUC directive has set a 7% target (of energy consumption) on conventional biofuels counting towards the RED and FQD 7a targets and adds a 0.5% non-binding target for advanced biofuels. The ILUC directive also enables multiple counting for categories of advanced feedstock defined within the directive, while feedstock of non-biological origin counts towards the 7% targets.

Directive on the Deployment of Alternative Fuels Infrastructure – DAFI/AFID [Directive 2014/94/EU]

EU member states are required to develop national frameworks to create the required infrastructure for alternative fuels. The DAFI/AFID establishes the necessary common framework of measures for the deployment of that infrastructure.

Vehicle CO_2 emissions [EC 333'/14 and EC 253'/14]

CO_2 emissions from vehicles are regulated via obligations on OEMs (original equipment manufacturers, i.e. car makers) via vehicle CO_2 emissions targets. This affects fleet CO_2 emissions of new passenger cars and vans. Average CO_2 emissions for all new passenger cars are to be lowered from 130g (2015) to 95 g/km by 2021[14]. This reduction is a step-by-step approach until 2021 and represents a reduction of 40% compared with the 2007 fleet average emission of 158,7gCO_2. Light commercial vehicles need to meet a target of 175g/km by 2017 and 147g in 2020.

Car Labelling Directive [1999/94/EC]

To raise consumer awareness on fuel use and CO_2 emissions of new passenger cars, EU member states are required to ensure that relevant information is provided to consumers. This label indicates a car's fuel efficiency and CO_2 emissions acting as an additional incentive encouraging manufacturers to take steps to reduce the fuel consumption of new cars.

Worldwide Harmonized Light Vehicles Test Procedure WLTP

Along with CO_2 emissions reduction up to 2021, a new test procedure aimed at measuring fuel consumption and vehicle CO_2 emissions will replace the existing New European Driving Cycle (NEDC): The Worldwide Harmonized Light-Duty Vehicles Test Procedure (WLTP) is currently under development with implementation planned after an introduction phase starting in 2017. The introduction of the WLTP aims to reduce the gap between CO_2 emissions certified in the laboratory

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[14] The industry CO2 emission depends on development of average fleet weight and may vary from 95 g CO2/km.

and those experienced under real driving conditions. Until 2020 WLTP will have no effect on the average emissions target defined by NEDC.

EU Emissions Trading System - ETS [Directive 2003/87/EC]

GHG reduction for energy providers and industries is addressed by the EU ETS covering approximately 45% of all GHG emissions in the EU. The first phase was launched in 2005. The system is currently under review for Phase IV to be effective 2021 to 2030. While aviation is the only transport sector that is subject to the ETS, other transport sectors including road transport are not currently part of the EU ETS.

Other vehicle emissions [Regulation 715/2007 and Regulation 595/2009 together with Regulation 582/2011] – these regulate emissions associated with local air quality[15]

The current Euro 6 regulation limits local air pollutant emissions (e.g. NOx, PM) of passenger cars and light commercial vehicles from 2015 onwards. Medium duty and heavy duty trucks are regulated in a similar way and have had to meet Euro VI standards since 2013. A regulation for compliance of Real Driving Emissions (RDE) will become effective for passenger cars and light commercial vehicles in 2017/18.

INFOBOX – Emission evaluation schemes

There are two different types of evaluation schemes for passenger vehicle emissions proposed in the EU. NEDC is the current emissions evaluation scheme in place and NEDC will be replaced by WLTP from September 2017 onwards evaluating pollutant and CO_2 emissions; RDE will be introduced and valid from September 2017 onwards as well to evaluate exhaust emissions under real driving conditions (such as NOx, PM, etc) and is more severe than WLTP.

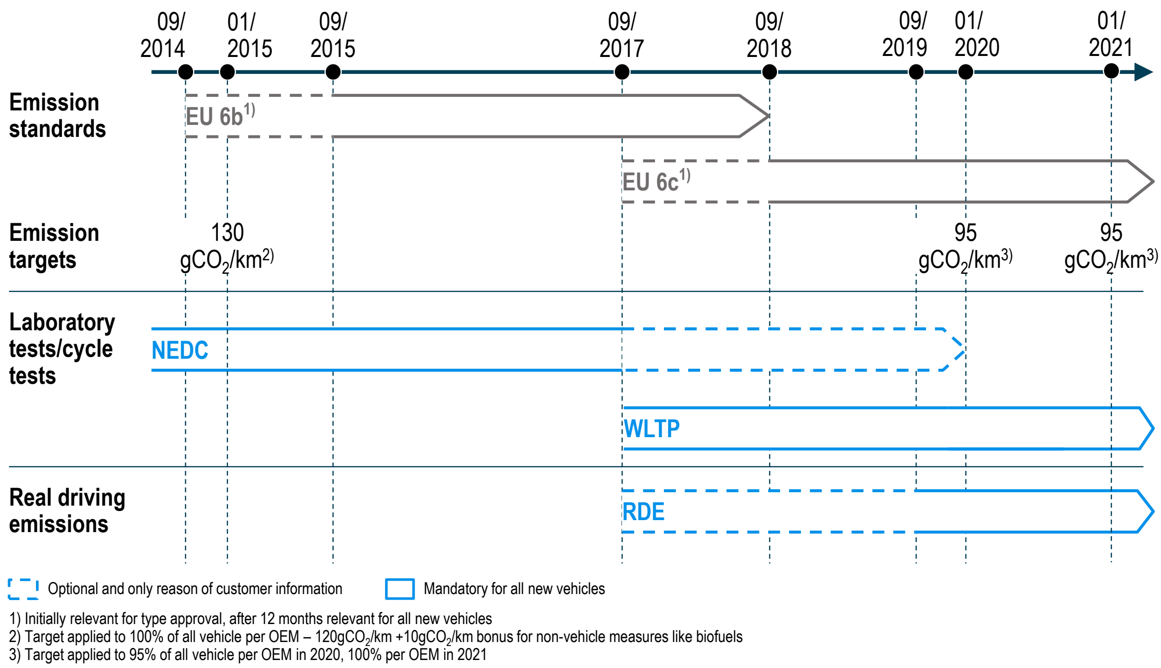
NEDC – Current emission standard for fuel consumption (CO_2 emissions) as well as for exhaust emissions will be relevant up to 2021. The CO_2 emission target for 2020/21 and onwards has been set at 95gCO_2/km

WLTP/WLTC – Introduction planned from September 2017 onwards; obligatory standard for fuel consumption (CO_2 emissions) as well as for exhaust emissions from January 2020 onwards. It differs from NEDC in terms of test cycle, driving profile and test conditions (meaning longer driving profile, higher acceleration rates, usage of lighting, air conditioning, etc.). Hence the 2020/21 CO_2 emissions target will be measured acc. to NEDC testing cycle. A conversion between WLTP and NEDC is required and will be provided by the end of 2016

RDE – mandatory test for new types of current vehicles from 09/2017 and for new vehicles by September 2019 to test exhaust emissions under real world vehicle operations; Evidence must be given for the laboratory findings considering a conformity factor (until 2020: 2.1; after 2020: 1.5 and annually reviewed with the intention to move to 1.0)

[15] In general regulations differentiate between local air quality and GHG emissions. The focus of this study is on GHG emissions

Figure 2: Introduction of vehicle emissions schemes



Source: Roland Berger

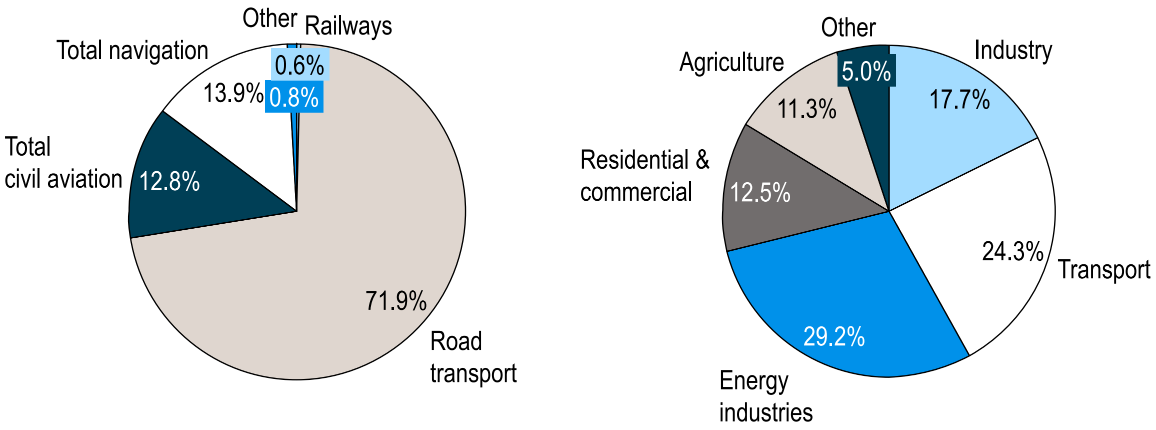
1.1.2 Transport emissions in the EU

GHG emissions in the transport sector including road transport continue to be a political, social and industrial challenge for the EU.

Greenhouse gas emissions by sector

As of 2012, the entire transport sector represents the second largest source of GHG emissions in the European Union. The sector contributes almost one quarter (24.3%) of all GHG emissions and is only surpassed by the energy sector (29.2%). Within the transport sector – including aviation, rail and maritime transport - road transport accounted for almost 72% of the GHG emissions in 2012 (refer to figure 3). Road transport alone emits 17.8% of all GHG emissions in the EU.

Figure 3: Road transport GHG in the EU by vehicle segment, 2012 [%]



Source: European Commission

Transport GHG emissions rising

The transport sector in the EU 28 – despite distinct reduction targets and investments by vehicle manufacturers and fuel suppliers to achieve these targets – has not yet been able to reduce its GHG emissions compared to 1990 figures. EU28 road transport sector's GHG emissions increased by 36% in 2007 compared to 1990 due to the increase in GDP and driven passenger and tonne kilometres. An additional key driver behind this development was a general increase of the Eastern European transport performance. Hence the majority of passenger and tonne kilometres resulting from older, less fuel-efficient vehicles from Western Europe was not offset by widely increased efficiency of the newer Western European vehicle fleet. Transport sector GHG emissions only dropped after 2008 as a result of external factors in the wake of the financial crisis. This caused slower mobility growth and was accompanied by a peak in oil prices. In contrast, other sectors reduced their respective GHG emissions by 15% from 1990 to 2007 and by 18% overall from 1990 to 2012 (Energy -23%, Agriculture -24% and Industry -31%).

1.2 Scope of the study

Geographical scope

This study includes analysis of the European Union (EU) consisting of 28 member states, hence all analysis and results are presented on an aggregated EU level. It has to be acknowledged that differences regarding results and implications of the study exist at member state level.

Emissions scope

Furthermore, this study focuses on GHG emissions, in the main, CO_2, CH_4, N_2O. Other air pollutants that are produced by transport activities, such as HC, NO_x, PM, SO_x, are not part of the scope of this study. However it is recognized that the non-GHG emissions may influence any future policy debate on GHGs.

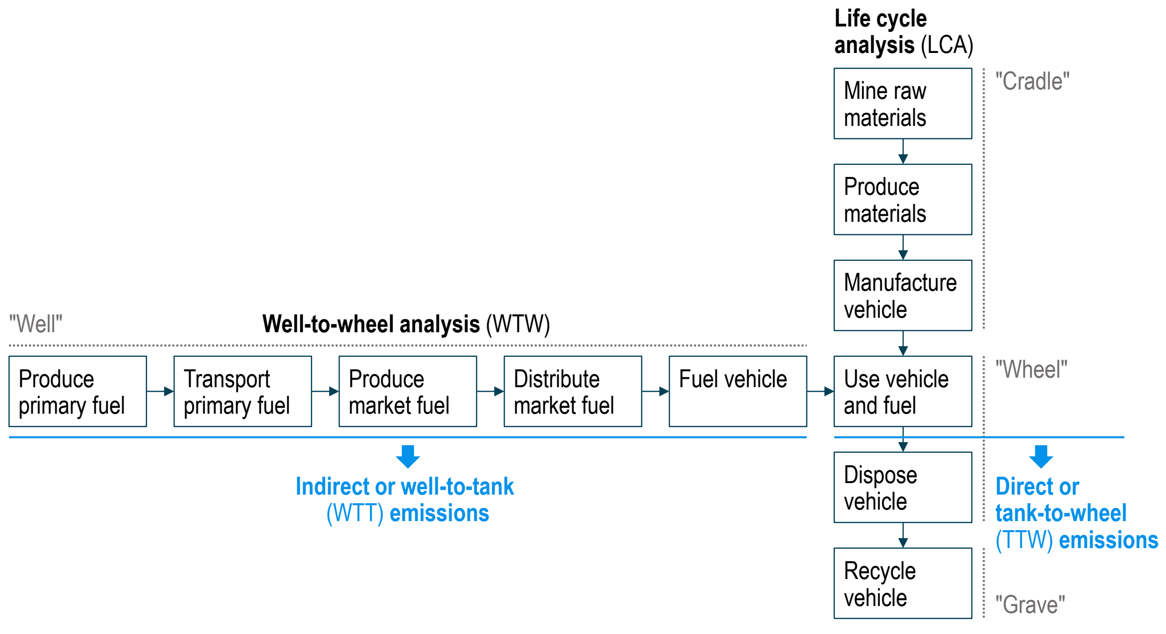
Sectorial scope

From a sectorial perspective, the road transport sector and parts of the energy sector are within the scope of the study. More specifically, the following road transport segments are covered: passenger cars (PC), light commercial vehicles (LCV), and medium- and heavy-duty trucks and buses. Motorcycles are excluded as they only contribute to 1% of all transportation GHG emissions in EU28. Other non-road transport sectors, such as domestic and international aviation or marine are outside of the scope of this study, as well as other non-transport related sectors.

Well-to-wheel (WTW) vs. lifecycle analysis (LCA)

Finally, this study estimates transport sector GHG emissions on a well-to-wheel basis considering direct emissions arising from the combustion of fuel by vehicles and indirect emissions arising from the production of a fuel (including electricity). A complementary method would be to carry out a lifecycle analysis. A lifecycle analysis extends the scope towards emissions arising over the course of a vehicle's lifecycle, from production to disposal (refer to figure 4). Studies such as the JEC Wheel-to-Wheels Report (JRC, 2014b) recognize that LCA emissions can be significant, yet also document challenges with respect to data availability, complexity, transparency and comparability, especially with regard to new technologies. For the purpose of this study, the well-to-wheel method consistent with the JEC and the relevant emissions in scope of the IPCC classification for the transport sector was applied.

Figure 4: Concepts of well-to-wheel (WTW) and lifecycle analysis (LCA)



Source: van Essen, JEC, Roland Berger

Fuels and powertrains

The following powertrains are considered for the aforementioned vehicle segments (sectorial scope):

> Port Injection / Direct Injection Spark Ignited ICE (Gasoline)
> Direct Injection Compression Ignited ICE (Diesel)
> Gasoline Mild Hybrid (MH), ≤20 kW electric power
> Diesel Mild Hybrid (MH), ≤20 kW electric power
> Gasoline Full Hybrid (FH), ≥20 kW electric power, no external battery charging
> Diesel Full Hybrid (FH), ≥20 kW electric power, no external battery charging
> Gasoline Plug-In Hybrid (PHEV)
> Diesel Plug-In Hybrid (PHEV)
> Battery Electric Vehicle (BEV)
> Fuel Cell Electric Vehicle (FCEV)
> Flex Fuel Vehicle (FFV)
> Port Injection / Direct Injection Spark Ignited ICE (LPG)
> Port Injection / Direct Injection Spark Ignited ICE (CNG)

The following market fuels are considered in combination with the above powertrains:

> Gasoline (E5)
> Gasoline (E10)
> Gasoline (E20)
> Gasoline (E85)
> Diesel (B7)
> Renewable Biodiesel (R33)
> Hydrotreated Vegetable Oil (HVO)
> Liquefied Petroleum Gas (LPG)
> Compressed Natural Gas (CNG)
> Liquefied Natural Gas (LNG)
> Electricity
> Hydrogen (H2)

1.3 Options for GHG reduction in road transport sector

There are three traditional levers that may be used to reduce GHG emissions reductions in the road transport sector: powertrain and energy efficiency, GHG intensity of fuel, and mobility demand and activity. A fourth lever is currently arising from technological advances in smart mobility and autonomous driving, but is not considered within this study due to the current uncertainty in terms of time frame of implementation.

Powertrain and energy efficiency

Current technical developments to increase the energy efficiency of existing powertrain technologies and vehicles involve increasing the thermodynamic efficiency of combustion engines using hydrocarbon (HC) based fuels (e.g. gasoline, diesel and compressed natural gas (CNG)) as well as their hybridization. Energy efficiency also addresses new powertrain-technologies such as in battery-electric vehicles and the efficient storage and use of electric power. Emerging alternative fuels such as hydrogen will also need to be used efficiently. The success of the above technological approaches to reduce GHG emissions depends greatly on customer acceptance and their willingness to use or switch to new technologies.

Greenhouse gas intensity of fuels

A well-to-wheel approach analysis is needed to compare the full GHG intensity related to the fuel consumption in different fuel-powertrains combinations. As part of this approach, TTW emissions of biofuels are set to zero while their production generates CO_2e emissions. Hence the required energy along the manufacturing process (WTT) is considered within the WTW analysis. Furthermore hydrocarbon fuels can have differing chemical compositions and differing degrees of GHG intensities depending on how they are produced. The same applies to BEVs and FCVs as TTW GHG emissions are zero, though GHG are emitted in the production and distribution of electricity and hydrogen. An increased proportion of renewable electricity and hydrogen will reduce the WTW emissions of both pathways.

Transport / mobility demand and activity

A shift in demand of various transport types can lead to the reduction of GHG emissions in the road transport sector. In urbanized metropolitan areas, public transport can absorb the mobility demand that was previously met by individual mobility solutions. This modal-shift in mobility demand could be amplified by a reduction of overall transport demand due to demographic change with elderly citizens tending to drive less and younger citizen's increasingly substituting individual mobility needs with public transport or other activities altogether.

Smart mobility

Non-powertrain and non-fuel related measures such as smart mobility and platooning for commercial vehicles, accelerate modal shift and are expected to have a significant impact on road transportation GHG emissions. For example, smart mobility concepts such as car-to-car and car-to-infrastructure communication can help reduce CO_2-emissions by providing more fuel-efficient navigation with traffic-sensitive routing options. Autonomous driving technology can help to operate vehicles in the most energy-efficient way. However, an enhancement of these measures is not the focus of this analysis and hence do not feature here. With respect to the development of average annual mileage, a certain modal shift will be considered, but not by assuming any supporting policies or incentives.

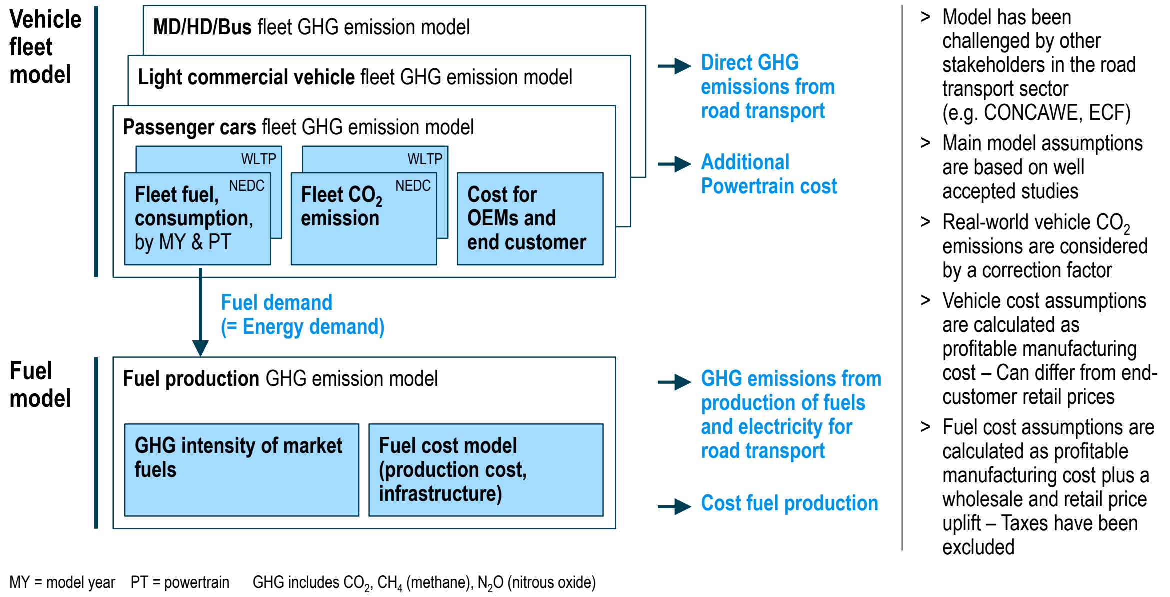
2. Modelling approach and assumptions for reference case

This study uses an integrated modelling approach to estimate WTW GHG emissions and associated costs (refer to figure 5). WTT and TTW emissions are combined with detailed analysis through to 2030 based on relevant and significant publicly available information and acknowledged recent studies. These have been scrutinized for plausibility and, if required, adapted accordingly.

The TTW energy demand is calculated by the size and composition of vehicle fleets, their respective fuel efficiency and the average total distance driven by each vehicle. The GHG emissions are calculated based on the testing cycle fuel consumption and its adjustment with a real world driving factor of 1.149 (JRC, 2014a, p. 67). This real world energy demand is used as input for the calculation of the required production of fuel and electricity and their related GHG emissions as well as production costs and additional investments.

A single market scenario is retained through to 2021 since the development of GHG emissions over this time frame is driven by current regulation with little room for uncertainty. A greater degree of uncertainty in market development is assumed for the period 2022 to 2030. Two different market scenarios, A and B[16], representing the reference case have been developed to reflect this.

Figure 5: Overview road transport decarbonization model



Source: Roland Berger

[16] For overview of basic assumptions for both scenarios refer to figure 8

2.1 Considered Scenarios for 2021-2030

Two market scenarios, named A and B, are based on the current regulatory framework and macro-economic situation as well as the regulation of incentives with differing assumptions on fuels and energy (such as high and low oil prices). These reflect slow and fast technological progress in powertrain technology including battery costs. Both scenarios see a gradual change in customer mind set including prioritizing of environmental aspects, different attitudes towards mobility solutions or better availability especially in urban environments resulting in a gradual modal shift to public transport, car sharing or other new mobility services. As explained below, variable factors have been selected that could be either influenced by vehicle manufacturers or fuel suppliers or have a significant, proven effect on a technology's market penetration. As other factors do not vary between the two scenarios and therefore have little influence on technology, the price of oil was defined as a variable factor with differing values in both scenarios. OEMs continue to develop new, electrified powertrains, while fuel suppliers plan the expansion of their infrastructure depending on how the price of oil develops. On top of this, battery costs continue to differ in both scenarios as their price and performance development remain uncertain.

(Refer to figure 6 market scenarios)

2.1.1 Macro economy and regulatory framework considerations

Both scenarios do not make any specific assumptions on economic or demographic developments and are based on the current economic and demographic forecasts. Naturally, forecasts used by IHS or Prognos use economic and demographic figures to determine the development of annual vehicle mileage etc. Both scenarios apply equally the following regulatory framework, referred to as the reference case in equal measure:

With regard to emissions regulations, it is assumed that the CO_2-emissions targets of 95 gCO_2/km for passenger cars and 147 gCO_2/km for light commercial vehicles, measured in the EU NEDC test cycle, will remain valid after 2020 extending through to 2030. Also, with regard to RDE, no further tailpipe emissions targets are assumed, EU6 (EU VI) emissions levels are expected to remain and an introduction of EU7 (EU VII) emissions levels is not anticipated.

It is further assumed that no EU-wide city restrictions of traffic and transport such as low emission zones, urban road tolls, traffic limited zones and traffic restrictions will be introduced by regulators. These are seen as measures-addressing local air quality concerns related to current emission levels for NOx and fine particulate matter (PM).

Fuel, fuel quality and biofuels play an important part in the regulatory framework considerations (see 2.2 Current Regulation). The Fuel Quality Directive FQD (minimum of 6% reduction in GHG emissions by 2020) is assumed to remain in effect without change until 2030.

The RED (minimum 10% renewables in transport fuels[17] is also assumed to remain unchanged until 2030. For these scenarios, it is also assumed that the corresponding mandatory blending of biofuels with fossil fuels will be continued until 2030 supported by the deployment of an alternative fuels infrastructure (DAFI/AFID). Since the adoption of DAFI/AFID by the European Parliament and Council in 2014, member states are currently being asked to develop and implement national policy frameworks.

The EU ETS, in line with the EU Climate and Energy Framework and covering about 45% of all GHG emissions in the European Union. Phase IV runs from 2021 until 2030, will continue to exist

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[17] E.g. France, Finland and Germany have already published policies requiring more than 10% bioenergy in 2030.

until 2030. This framework will also secure additional support for renewables-based electricity generation.

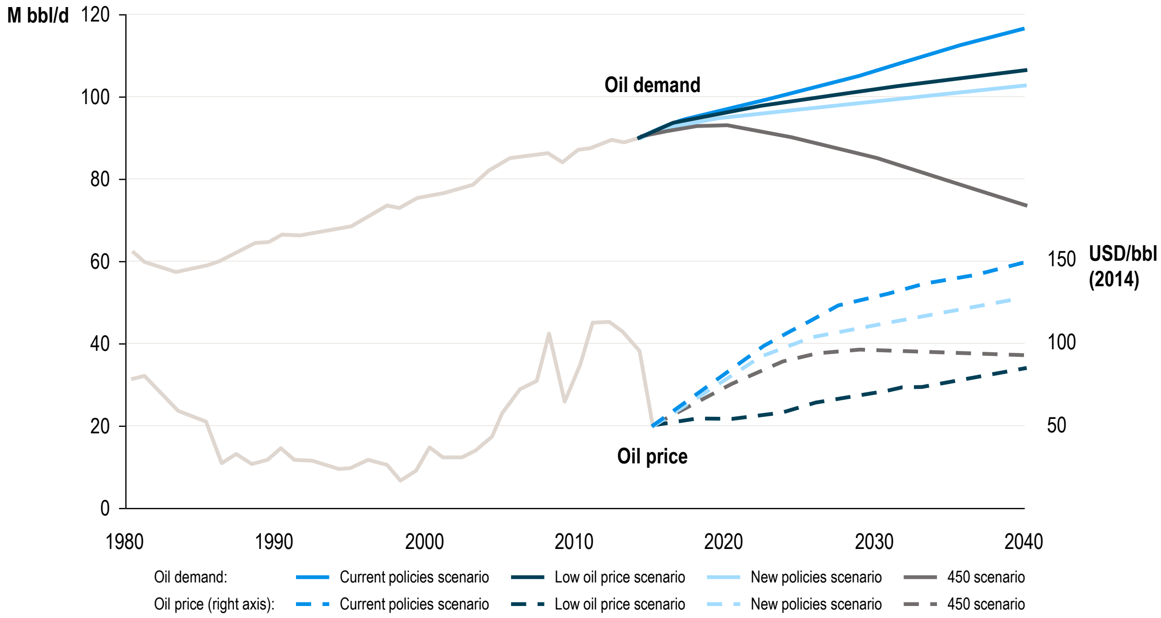
No additional incentives for electric vehicles (battery electric, plug-in hybrids or fuel-cell) are considered.

The Worldwide harmonized Light vehicles Test Procedure (WLTP) will replace the NEDC as of September 2017. WLTP narrows the gap between CO_2 tailpipe emissions measured in the laboratory and those experienced under real world driving conditions. It is assumed that the WLTP will not be tightened 2030.

2.1.2 Fuel and energy considerations

Crude oil, natural gas, and electricity forecast prices through 2030 are based on the scenarios in the 2015 World Energy Outlook (International Energy Agency, IEA) (refer to figure 6), which is one of the most comprehensive forecasts for energy resources available. While the 2015 World Energy Outlook offers four different price scenarios, the "Low Oil Price Scenario" and the "New Policies Scenario" were selected, as both provide a full set of energy data making them comparable without assuming too many measures such as the 450 scenario.

Figure 6: Illustration of IEA WEO 2015 fuel price scenarios[18]



Source: IEA, Roland Berger

[18] All scenarios are published by IEA and include certain assumptions regarding the worldwide implementation of climate policies. The "450 scenario" is the most aggressive scenario and assumes that the 2°C climate warming target – passed at the 2015 Paris climate conference (COP21) – will be reached. Hence various advanced assumptions have been considered by the IEA including changes of policy and regulatory frameworks

Scenario A is based on the IEA ”Low Oil Price Scenario” with a moderate increase in price for fossil fuels assuming oil prices at 70 USD per barrel (bbl) and EU gas prices at 8.9 USD per MBtu (million Btu) in 2030. Scenario B is based on the IEA “New Policies Scenario” and assumes a distinct price increase for fossil fuels up to 113 USD per bbl for crude oil and 11.1 USD per MBtu for gas in 2030.

Figure 7: Overview of scenarios by fuel in IEA WEO 2015 [2014 USD and EUR[1)]]

		IEA Low oil price scenario		IEA New Policies Scenario	
	Unit	**2020**	**2030**	**2020**	**2030**
Crude oil	USD/bbl	55	70	80	113
	EUR/bbl	50	64	73	103
Natural gas					
European imports	USD/MBtu	5.9	8.9	7.8	11.1
	EUR/MBtu	5.4	8.1	7.1	10.1
USA wholesale	USD/MBtu	4.7	6.2	4.7	6.2
	EUR/MBtu	4.3	5.6	4.3	5.6
Electricity[2)]	USD/MWh	n/a	n/a	267	273
	EUR/MWh	n/a	n/a	243	248
		Scenario A: Low oil price		Scenario B: High oil price	

1) Exchange rate: 1,1 USD/EUR 2) European household prices, including taxes

Source: IEA WEO 2015, Roland Berger

As the IEA World energy outlook lacks detail (refer to figure 7), one electricity price forecast is the basis for both scenarios (0.168 EUR/kWh). It is assumed that an increasing share of renewables in electricity generation will lead to a further increase in the price of electricity.

Additionally, various feed stocks for biofuel are considered in the study with these assumptions:

Rapeseed wholesale prices stay at 2014 levels based on historic Bloomberg data (used to make regression analysis for FAME)

Maize wholesale prices slightly decrease from ~170 EUR/ton to 160 EUR/ton in 2024 and thereafter remaining flat until 2030 (used to make regression analysis for ethanol)

Further details can be found in the appendix.

INFOBOX – Background information for IEA oil price scenarios

"The **New Policies Scenario** (NPS) is the central scenario of this Outlook (IEA – World energy outlook 2015). In addition to incorporating the policies and measures that affect energy markets and that had been adopted as of mid-2015, it also takes account of other relevant intentions that have been announced, even when the precise implementing measures have yet to be fully defined. This includes the energy-related components of the Intended Nationally Determined Contributions (INDCs), submitted by national governments by 1 October 2015 as pledges in the run-up to the United Nations Framework Convention on Climate Change Conference of the Parties (COP21). We take a generally cautious view in the New Policies Scenario of the extent and timing of which policy proposals will be implemented. This is done in view of the many institutional, political and economic circumstances that could stand in the way. These policies include programs to support renewable energy and improve energy efficiency, to promote alternative fuels and vehicles, carbon pricing, reform of energy subsidies, and the introduction, expansion or phase out of nuclear power."

Quote from IEA – World Energy Outlook 2015 p. 661

"Five main factors differentiate the **Low Oil Price Scenario** from the New Policies Scenario, three relating to oil supply, two affecting oil demand:

– A long-lasting shift in OPEC strategy. The New Policies Scenario incorporates the assumption that, once the market starts to rebalance as non-OPEC production growth stalls, OPEC countries revert to a strategy that modulates output in an attempt to maintain prices at the levels judged desirable for producers, while still tolerable for consumers. The Low Oil Price Scenario, by contrast, assumes a lasting shift in policy, with different strategic priorities to the fore: to minimize substitution away from oil by the main global consumers and to provide sufficient room in the market for OPEC member countries wishing to expand output, without curtailing production from other members. In other words, OPEC adopts a long-term strategy that prioritizes the preservation of oil's share in the energy mix and of OPEC's share in the oil market.
– A benign view of geopolitical developments, such that the future is less marked by disruptions to oil supply than in the past. This includes favorable assumptions about the resolution of current conflicts, e.g. in Libya, Syria and Iraq, and the ability of the main oil-dependent producing regions to weather the impact of lower hydrocarbon revenues.
– Stronger resilience of some key non-OPEC sources of supply, notably US tight oil, to a lower oil price environment. There are greater downward pressures on costs in non-OPEC supply than those seen in the New Policies Scenario, lowering breakeven prices; and the tight oil resource base proves larger and the pace of technology learning faster. The tight oil situation is discussed in more detail later in this chapter.

And on the demand side:

– A lower rate of near-term economic growth, concentrated in some countries in developing Asia, parts of Africa and North America, reflecting downside risks to parts of the world economy from factors that include the fall in commodity prices, the shift to higher interest rates in the United States and China's transition to a less investment intensive model of growth. For the projection period as a whole, this translates into global gross domestic product (GDP) in 2040 that is some 1% lower in the Low Oil Price Scenario than in the New Policies Scenario. The impact on oil demand is offset in part by an assumed weakening of policy support for alternative fuels (in particular biofuels), due to lower oil prices.
– A faster pace of reform of fossil-fuel consumption subsidies among net importers and some net exporters of oil. These moves are assumed to be politically more feasible, because the price fall reduces the gap between the level of subsidized and market driven prices but also – in the case of net exporters of oil – necessary because of the pressure on public finances caused by reduced oil export revenues."

Quote from IEA – World Energy Outlook 2015 p. 155

2.1.3 Vehicle/powertrain technology considerations

Two future technological development scenarios model the impact of vehicle and powertrain technology with slow and fast technological progress respectively.

Scenario A assumes slow technological progress with more conservative estimates regarding battery performance and cost improvements. Scenario B assumes greater speed and more innovation coming from technological successes with huge impact on both battery and fuel cell performance leading to dramatic improvements in related costs.

Both scenarios share a number of assumptions (refer to figure 8). It is to be expected that gasoline and diesel engines will improve with respect to efficiency and emissions. Also, based on known technological potential and in both scenarios, alternative powertrains are expected to become more efficient, generate fewer emissions and cost less. Another assumption for both scenarios is that battery performance is not a limiting factor for any electric vehicle (plug-in hybrid, battery electric and fuel cell vehicles). With variable battery costs and other costs remaining constant, it is expected that system costs for electric vehicles will improve overall. Although fuel cell vehicles are expected to drop in price, it is assumed that the current low levels of production will not change before 2030. Hence OEMs and fuel suppliers need to improve the cost competitiveness of fuel cells by progressing technological performance and hydrogen supply infrastructure at the same time.

2.1.4 Customer considerations

Customer behaviour and mind set are important factors in the development and subsequent acceptance of technologies reducing GHG emissions. A gradual change in the customer's mind set is to be expected in both scenarios. Increasing awareness of environmental technologies as well as their benefits and cost savings will lead to a gradual change in the perception of mobility. Customer mobility patterns will remain relatively stable with a slight shift towards smart and connected mobility. Demand for individual mobility and freight transport will remain at the same level as 2015. For individual mobility, the passenger car will remain the preferred mode of transport so a possible modal shift to public transport or mobility on demand will only happen gradually. Specific age groups will show a more rapid change in mind set with the younger generation being the biggest influencer in mobility changes.

Price, performance, comfort and safety are assumed to be the main drivers of transport preference, as only a small group of consumers has been willing to sacrifice comfort and cost in favour of eco-friendly transport.

Figure 8: Market scenario development for road transport 2030

	Scenario A	Scenario B
Macroeconomy	**Macroeconomic growth** > Economic and demographic trends are taken as given	
Regulatory framework Emission regulations	**Unaltered regulatory environment beyond 2020/2021 (assumption)** > PC 95 g_{CO2}/km and LCV 147 g_{CO2}/km targets will be valid until 2030 > No further tailpipe emission targets are considered > FQD obligation (6% GHG intensity reduction in road transport) will be valid until 2030 > RED obligation (10% RES-T) will be valid until 2030 > ETS for Energy sector continues to exist until 2030 > No Euro 7/VII introduction considered > Tyre noise reduction and rolling resistance regulation will be introduced > No EU-wide city restrictions are considered	
Support regulations	> No additional xEV incentives are considered > Existing blending mandates (e.g. for biofuels) will be continued until 2030 > DAFI/AFID will be implemented	
Test-cycle	> WLTP replaces NEDC as of 01.09.2017 (correction factor to be applied)[1]	
Fuels and energy	**High fossil fuel prevalence** > Moderate price developments for fossil fuels and energy	**Lower fossil fuel prevalence** > High prices of fossil fuels provide incentives for consideration of alternatives
Fossil fuels	> Price levels of crude increase moderately	> Price levels of crude increase significantly
Bio-/synthetic-fuels	> Bio-/synfuels show cost improvement, but low fossil prices limit attractiveness	> Bio-/synfuels show cost improvements due to higher investments and become more attractive
Electricity mix	> Low energy prices contribute to fossil share dominance in electricity generation; continuous support for renewables, electricity prices rise only moderately	> High energy prices contribute to renewables share increase in electricity generation; continuous support for renewables, electricity prices rise more significantly
Alt. fuels infrastructure	> Charging/ fueling stations expands in line with EC's alternative fuels infrastructure deployment directive	
Vehicle/PT technology	**Slow technical progress** > Technological progress in terms of specific performance for batteries is only moderate	**Fast technical progress** > Successes in technological progress lead to accelerated innovation speed with high impact on battery and fuel cell costs
Gasoline/ Diesel	> Improve in terms of efficiency/emissions	
Alternatives[3]	> Improve in terms of efficiency/emissions and costs (technological potential is known)	
Battery performance	> Performance development of batteries is not a limiting factor for xEVs	
Battery costs	> Battery costs improve moderately	> Battery costs improvement accelerates
xEV system costs	> xEV system costs (excl. battery costs) improve regardless of battery costs	
FCEVs	> Improve in terms of costs, but remain in small-scale serial production due to relatively low cost-competitiveness compared to ICE (relatively independent of amount of R&D investments)	
Customer	**Gradual change in mobility mindset** > Customers change their mobility gradually by becoming more aware towards environmental technologies, yet mobility behavior remains relatively similar to today > Younger generation with adapted mobility mindset influences mobility behavior of average customer group	
Mobility/ transport need	> Demand for individual mobility and freight transport remains strong	
Modal shift	> Modal shift will not change dramatically – car is preferred mode of personal transport[2]	
Vehicle buying criteria > Ease of use > Price/costs > Environmental friendliness	> Price, performance, comfort, safety are generally superior over environmental friendliness > Only few customers are willing to make sacrifices for environmental friendliness over ease of use and price/ costs when buying a new vehicle	

1) Needs to be reflected for cycle-emissions and real driving emissions
2) Modal shift between two scenarios is not varied for reasons of results comparability
3) CNG, LPG, FFV, B7+, etc.

Source: Roland Berger

2.2 GHG emissions reduction costs

Costs resulting from reducing GHG emissions were analyzed separately in the contexts of fuel and vehicle.

GHG abatement costs and costs to society

In order to assess and compare the cost-benefit relationship of the various GHG-reducing technologies, calculations have been made on the strength of GHG abatement costs. These are derived by calculating the net present value (NPV) of a technology's lifetime fuel cost saving, deducting the latter from the incremental investment required for the technology and dividing this result by the technology's lifetime GHG emissions reduction. GHG abatement costs, in this study, are viewed from a societal perspective (refer to figure 9). Consequently, costs are exclusive of taxes[19]. Costs considered in this study however do reflect margins (profited manufacturing costs) as they comprise entrepreneurial risk and can be viewed as a "real cost to society" (See also CE Delft, "GHG reduction in transport: an expensive option?", 2009). The societal discount rate chosen is 4%. The evaluated technologies that show the lowest abatement costs per ton CO_2e emissions avoided can be regarded as generating the lowest costs to society. In this case, the related technology should be favored from an overall economic perspective.

Figure 9: Calculation formula for CO_2e abatement costs (lifetime)

$$\text{CO}_2\text{e abatement costs [EUR / ton CO}_2\text{e]} = \frac{\text{2030 Incremental capital costs for alternative powertrain technology vs. base technology} - \text{NPV of lifetime fuel cost savings}}{\text{WTW Lifetime CO}_2\text{e emission reduction}}$$

Source: CE Delft; Roland Berger

How the formula for CO_2 abatement costs works?

A simplified illustration: A BEV with a battery suitable for a short range driving profile costs additional EUR 4,500 compared to an optimized gasoline engine powered vehicle in 2030. Furthermore the BEV causes around EUR 60 NPV of additional electricity cost during the vehicle‘s service life compared to the optimized gasoline vehicle[20]. In terms of CO_2 emissions, the BEV saves around 20.5 tons of CO_2 over lifetime. From the society's perspective, the cost effectiveness is then (4560/20.5 = plus EUR 222/ton CO_2. From the end-users perspective taxation on fuels and electricity would needed to be considered and would therefore lead to negative abatement cost.

2.2.1 Fuel prices

For the fuel price modelling, the development of fuel production costs is combined with an uplift for retail infrastructure and additional distribution costs. Based on the costs to society approach, prices are modelled excluding taxes and levies.

[19] Though not reflected in this study, abatement costs for the end-user perspective would normally include taxes.

[20] NPV of lifetime cost for gasoline and electricity is calculated without fuel and electricity taxation.

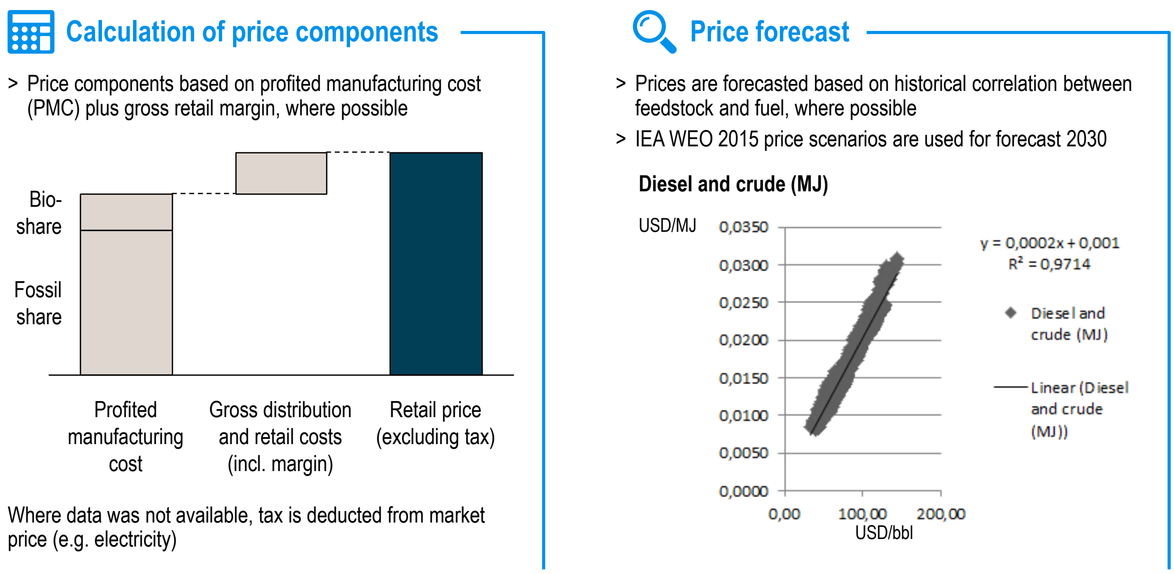
2.2.1.1 Fuel production costs

Prices of market fuels that are potentially available at the fuel station are modelled based on the market prices of their respective major components. These basic fuel price calculations include profited manufacturing costs (PMC), i.e. wholesale price, plus distribution and retail costs. While profited fuel production costs are calculated based on the IEA oil price forecast, the additional costs (such as distribution and retail) are calculated from available historic data and are assumed to remain constant until 2030.

To forecast of gasoline and diesel fuel prices, the statistical analysis methodology known as linear regression has been applied to the historical dataset. A significant correlation between oil and gasoline/diesel price development was identified (R^2=0.9714), with the price development of gasoline and diesel being derived directly from the IEA oil price forecast. (Refer to figure 10 and to appendix 6.3). Taxes and levies are excluded from costs to society calculations. Post-tax fuel prices were only used for total cost of ownership (TCO) calculations where taxed prices affect directly the customers' decision. The biofuels cost forecast is based on the historical correlation of crude price and commodity prices.

For more detailed information on fuel price assumptions and biofuel cost forecast see appendix 6.4.

Figure 10: Fuel price calculation – illustrative for diesel



Source: Roland Berger

2.2.1.2 Fuel distribution and infrastructure cost

Future infrastructure investments are assumed to be covered by the margin at the respective part of the supply chain for established fuels. For new and emerging fuels (e.g. electricity, liquefied natural gas (LNG), CNG and hydrogen) a calculation of an additional infrastructure cost is required that covers investments in necessary new infrastructure. This additional cost was calculated separately for LNG, CNG and hydrogen. For more information on these assumptions and calculations please refer to the appendix 6.4.

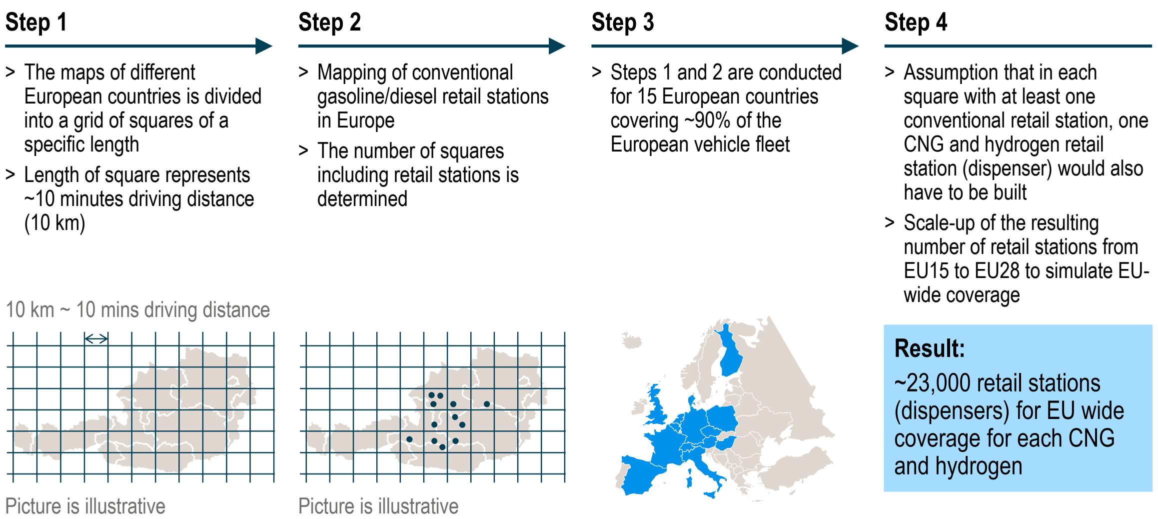
INFOBOX – Retail infrastructure investment cost

Readily available and conveniently usable infrastructure is essential for the customer's acceptance of new technology: Unlike early adopters, the majority of customers expect the infrastructure to be available - anytime, anywhere - if it is to be accepted. Modelling for the retail infrastructure, investments and respective costs for CNG, hydrogen and EV retail infrastructure was conducted based on this assumption.

CNG and hydrogen: For customers to experience good coverage (i.e. that refueling is available anywhere, at any time), retail stations for compressed natural gas (CNG) and hydrogen should be within 10 minutes driving time on average from each other. This equates to a distance of 10 kilometers. This model covers Europe with a virtual grid of 10 km-squares. It is assumed that for each square with at least one conventional gas station a new retail station for alternative fuels is required. For Europe this resulted in 23.000 new retail stations offering alternative fuels out of a total number of 114,431 petrol stations in EU28 as of end 2014 (refer to figure 11).

This figure is based on a two-step approach: in the first step, the amount of CNG and hydrogen stations is calculated by the method for EU 15 described above (see map in Step 3). In the second step, the total number of cars for EU15 and EU28 are evaluated and put into context. The total number of CNG and hydrogen stations for EU28 is calculated based on that proportion and the calculated number of CNG and hydrogen stations for EU15.

Figure 11: Methodology to estimate size of EU-wide retail station network – Illustrative



Source: Volkswagen, Roland Berger

Electric charging: Different customer needs for fast and public charging are assumed for the purposes of this study. For DC fast charging, it is assumed that recharging stations are available every 60 km along the European highway system (data for this calculation was taken from Eurostat). For AC public charging it is assumed that for every 1.000 inhabitants (urban and intermediate regions) access to 13 public charging points is necessary to meet the aforementioned customer needs (refer to figure 12). This is in line with previous JEC studies (Nemry & Brons, Plug-in Hybrid and Battery Electric Vehicles Market penetration scenarios of electric drive vehicles (2010)). Private chargers are excluded from this calculation. The resulting calculation of annualized investment costs includes annuities overheads and maintenance (O&M) in 2030, giving an EV infrastructure uplift of approx. 8 EURct/kWh (refer to figure 13).

Figure 12: Assumptions for number of EV chargers

	Urban/Intermediate Area			Motorways		
Key assumptions	Number of available retail stations today	~10,750	EC	Number of available retail stations today	~2,000	chademo.com
	Urban population	221,239,015	Eurostat	Length of Motorways in EU	71,405 km	Eurostat
	Intermediate population	175,339,388	Eurostat	Posts per charging station	8	RB assumption
	No. of charger/inhabitant	0.013	JRC	Average Distance between chargers	60 km	Coalition
	Only level II public chargers will be installed			Only DC fast chargers will be installed		
Required number of EV chargers	**5,025,500 Required level II public chargers**			**9,520 Required DC fast chargers**		
Additionally required number of EV chargers	**5,014,750 Additional required level II public chargers**			**7,520 Additional required DC fast chargers**		

Source: Eurostat, JRC, Roland Berger

Figure 13: EV charging infrastructure cost allocation

EV infrastructure cost uplift
> 8.01 EURct/kWh
> 0,0223 EUR/MJ

Share of charging type[1]			Assumptions: Investment cost [EUR]	[source]	[cost decrease]	O&M cost [%]	Lifetime [years]	Utilization[1] [%]
83%	**Private**	**EURct/kWh 2.47**	520	DAFI[2]	0.3% p.a.	12	10	8
3%	**Semi-private** (e.g. companies)	**EURct/kWh 15.8**	2,500	VDA[3]	0.3% p.a.	12	10	6
10%	**Public**	**EURct/kWh 31.9**	5,280	DAFI[2]	0.3% p.a.	12	10	2
4%	**DC Fast**	**EURct/kWh 65.1**	41,000	JRC[4]	0.3% p.a.	5	10	3

1) Based on actual data from the 'EV Project'; in line with DAFI that ~10% of infrastructure should be public
2) EU Directive: Deployment of alternative fuel infrastructure 3) VDA: Ladestationen für Elektroautos 2015 4) Plug-in Hybrid and Battery Electric Vehicles 2010

Source: Roland Berger, DAFI, VDA, JRC, EV Project, coalition feedback

2.2.2 Vehicle costs

Technology costs for each powertrain type per vehicle segment from mini cars (segment A) to luxury cars (segment F) are calculated in the following way: The assumptions for calculations are based on available studies (e.g. CO_2 Emission Reduction Potential for Passenger Cars and Light Commercial Vehicles Post 2020 by IKA and BMWi, Vehicle technology costs: Estimates vs. reality by ICCT, A portfolio of powertrains for Europe: a fact-based analysis by McKinsey) which we aligned with existing Roland Berger knowledge from more than 100 vehicle powertrain technology-related projects with vehicle manufacturers and automotive suppliers over recent years[21]. The resulting model assumptions were then discussed anonymously among coalition members with confidentiality ensured by Roland Berger acting as clearing instance. The same procedure was applied for commercial vehicles (e.g. Marginal Abatement Cost Curves for HDVs by CE Delft, Pathways to a Low-Carbon Economy – Version 2 of the Global Greenhouse Gas Abatement Cost Curve by McKinsey).

2.2.2.1 Powertrain costs

Individual methodologies were developed to forecast powertrain costs until 2030 for gasoline and diesel engines (Internal Combustion Engines (ICE)), Hybrids (Mild Hybrids (MH) and Full Hybrids (FH)) and alternative drivetrains (Battery Electric Vehicle (BEV), Plug-in Hybrid-Electric vehicles (PHEV), Compressed Natural Gas vehicle (CNG), (Fuel Cell Vehicles (FCV)).

ICE: For diesel and gasoline powertrains, concepts and new features to increase efficiency and decrease GHG emissions (e.g. downsizing, thermal management and selective cylinder shut-off) were analyzed and their attributed costs calculated from available studies and OEMs' anonymized data. The influence of these concepts and features on overall powertrain costs until 2021 depends on features cost development and their penetration in each vehicle segment. It is assumed that in the period up to 2030 an increase of these costs of 0.5% p.a. for evolutionary efficiency improvements is required due to on-going OEM competition.

MH, FH: Forecasts for additional cost of MH and FH components are based on Roland Berger project experience and have been aligned with coalition vehicle manufacturers. In comparison to other frequently used studies (e.g. IKA), the assumptions on incremental cost required for MH and FH based on RB experience are often lower than in other studies.

BEV, PHEV, FCV: For electrified alternative powertrains, the cost of electric components (e.g. electric motor, inverter, DC/DC converter, AC/DC charger) and battery costs are forecasted up to 2030 with battery costs being calculated in two scenarios (refer to figure 14):

> Rapid advances in battery development assuming full availability of 4th generation Lithium-Ion batteries at costs of 99 EUR/kWh at battery pack level in scenario B.

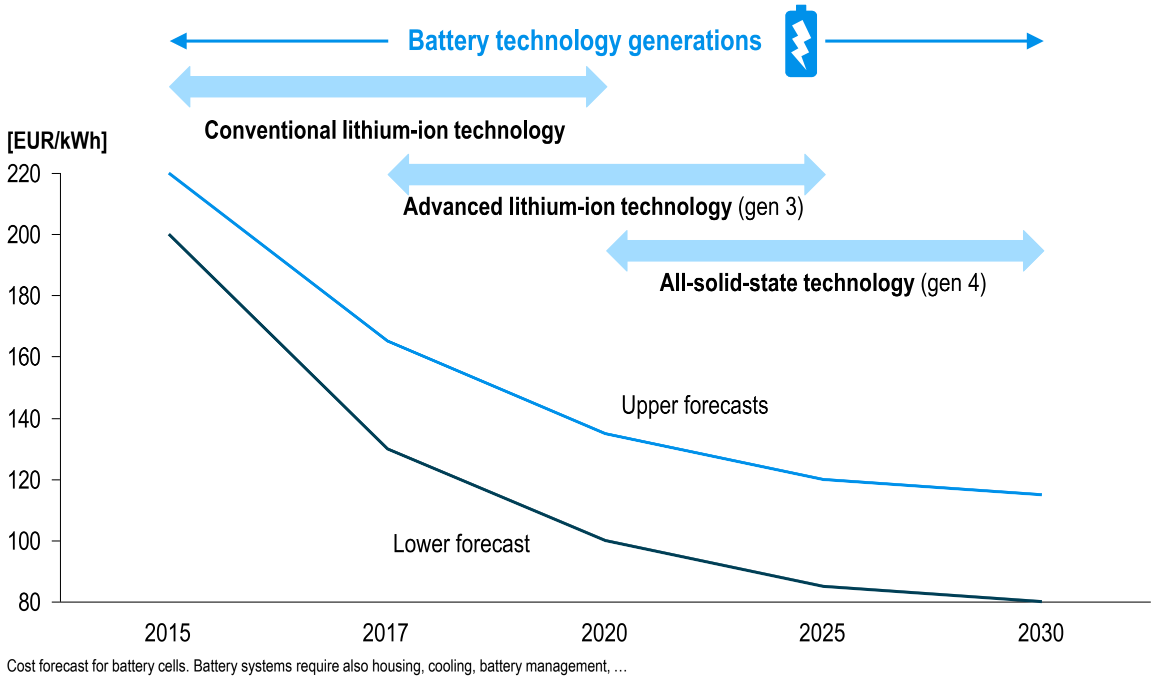
> Slower development assuming only moderate market penetration of 4th generation Lithium-Ion (up to 20%) at higher costs of 109 EUR/kWh at battery pack level in scenario A.

Furthermore battery pack costs for FH and PHEV are considered to be higher than for BEV due to the use of chemicals with lower energy density in favor of higher power density and because of a higher share of battery package and battery management system cost.

For detailed information on the powertrain cost assumption please refer to appendix 6.8

[21] Roland Berger conducts knowledge management in a systematic and strictly anonymous fashion to safeguard information about vehicle technologies, component cost and component cost developments gained during its project work. This data has been used as a basis for the model assumptions.

Figure 14: Price development of battery cells [EUR/kWh]



Source: Roland Berger

2.2.2.2 Cost and price calculations

This model differentiates between technology costs (i.e. profitable manufacturing costs for the OEM) and prices for the customer. Technology costs reflect the potential of technological progress (e.g. higher gravimetric energy density in Lithium-Ion batteries) and positive scaling effects. Customer costs include an integration factor that increases the technology cost, to reflect OEM's research, development, industrialization and marketing costs.

With the 95g CO_2 emission-level target these strategic cost-components are especially important for passenger cars up to 2021.

2.2.2.3 Customer acceptance model

While TCO is an important factor in modelling technology acceptance, this study intends to support the customers' purchase decision for vehicles with alternative powertrains with a holistic approach. For this reason, the modelling assumptions for penetration rates of alternative powertrains (BEVs and PHEVs) in new car sales are based on the results of the Customer Acceptance Model (CAM). For the CAM, future vehicle prices[22] were used as an input factor, while cost profitable manufacturing costs are the basis for the abatement cost calculation.

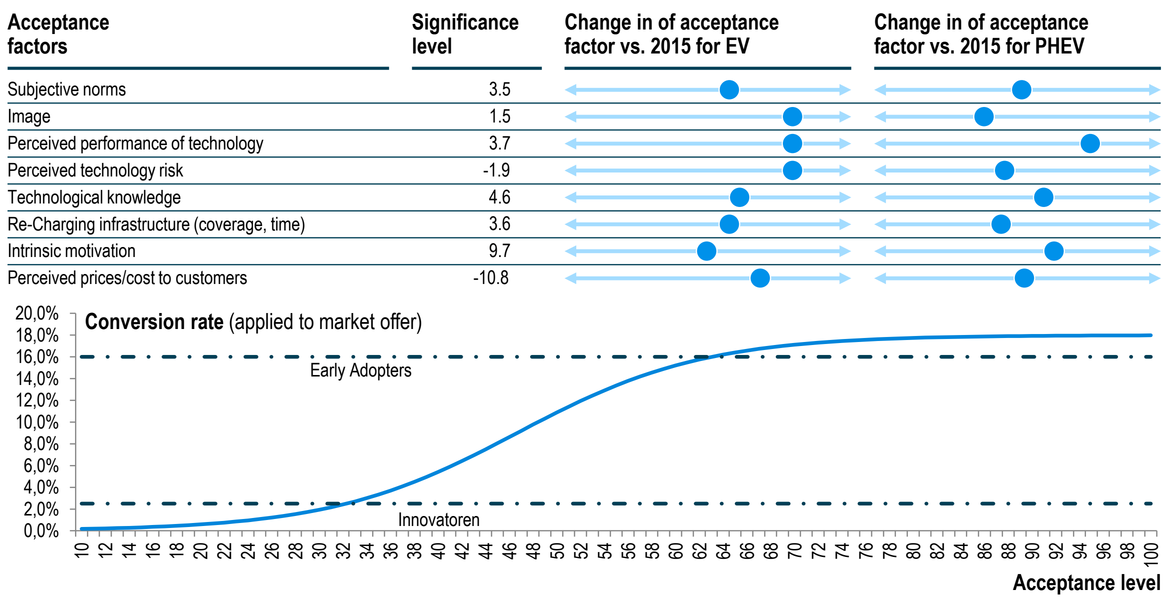
[22] Alternative CO_2 emissions compliance cost and strategic aspects are considered in OEMs' pricing decision in addition to profitable manufacturing cost.

The CAM was developed within Roland Berger, is based on Davis' Technology Acceptance Theory and has been validated both scientifically and empirically (refer to Infobox "Customer acceptance model"). This model not only considers passenger cars customers' perception of costs, but also includes a number of additional factors including the image of alternative drivetrains and the intrinsic motivation to use them, their perceived quality and technological risks, technological understanding of alternative powertrains as well as infrastructure availability and charging duration (refer to figure 15). This comprehensive methodology allows an assessment of future powertrain market penetration with all relevant parameters, not being restricted to a TCO approach (reference to acc. Infobox). Furthermore, the understanding of market penetration of alternative powertrains is based on an extended customer perspective by investigating intended use and adaptation of new technology.

End-customers perceive many hurdles when it comes to acceptance of and adaptation to electric mobility. These hurdles include the higher purchasing price and the perceived risk of use of the technologies (like burning batteries in early BEVs with Li-Ion batteries or lack of customer experience with battery lifetime), vehicle driving range limitations, limitations in infrastructure availability, or long charging times, that could reduce the convenience in using the technologies. Contrary to this, commercial customers (large companies or utility providers) and their fleet managers are really focusing on pure TCO of their vehicles and their company fleet.

The model is not restricted to TCO calculations that are of minor importance to the private customer. A comprehensive model is created instead explaining the conditions by which the customer accepts the new technology. By combining both TCO and CAM approaches, the purchase and adaptation behaviour of commercial customers can be analyzed as well as that of private customers and company car users who are influenced by factors other than TCO.

Figure 15: xEV acceptance model (example: D-segment)



Source: Roland Berger

INFOBOX – Customer acceptance model

The CAM is based on research by Dr. Ludwig Fazel ("Acceptance of e-mobility", published 2013, ISBN 978-3-658-05089-4). Dr. Fazel used the technology acceptance model (TAM) introduced by Davis in 1989 and adapted this basic research model for electric mobility. Within the TAM, two mediator variables – perceived usefulness and the perceived ease of use of the technology – are predicting the behavioural intention and actual usage of the technology. In his research, Dr. Fazel identifies nine main influencing factors that have statistically significant influence on the purchase of BEVs and motivation for electric mobility.

Within the model the following factors are seen to strongly influence the perceived usefulness of xEVs:

- subjective perception through pressure in the social environment (friends and family),
- image of xEVs that increases social status,
- quality of technological performance and
- framework conditions related to infrastructure such as availability and proximity of charging stations.
- Intrinsic motivation is positively influenced by the driving experience (low noise, instant acceleration).

Factors negatively impacting technology acceptance are perceived technology risks of electric mobility: risk of using a large battery, framework conditions regarding charging time and availability of charging stations. Perceived or required investment to use e-mobility is a very significant negative influencing factor.

The customer acceptance model evaluates all of these factors. Changes in each of these factors allow the prediction of e-mobility acceptance from an end customer point of view. The model allows us to clarify the impact of, for example changing end customer prices of BEVs or PHEVs on the acceptance of the technologies.

The model examines three customer segments: Private customers, company car buyers and commercial customers. Larger scale customers such as fleet managers, base their purchasing decisions mainly on TCO calculations. Yet vehicles in this fleet-segment account for only ~24% of new car registrations. Company car buyers and small business owners as well as private customers with higher or exclusive private use and lower annual mileages represent 55% and 21% per cent of the market respectively. For private customers, the purchase price is of high importance hence having strong concerns regarding electric powertrains. However, operating costs represent the major decision criteria for fleet buyers, while the purchase price has almost no importance.

For more information on the CAM please refer to the appendix 6.12.

2.3 GHG emissions

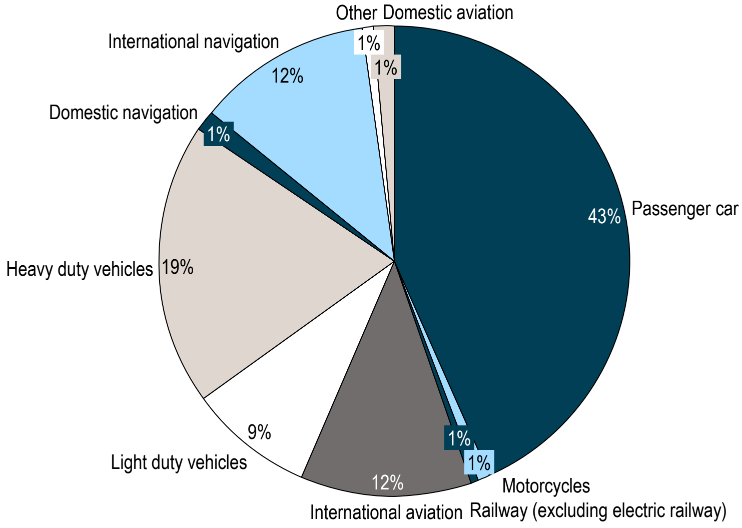
The objective of this study is to provide a holistic analysis of WTW GHG emissions of the total road transport sector. To reduce complexity and to enable a high degree of replicability, GHG emissions are modelled separately for vehicles (TTW emissions) and fuels (WTT emissions).

2.3.1 Vehicle tank-to-wheel GHG emissions

Scope of tank-to-wheel emission modelling

Tank-to-wheel (TTW) GHG emissions are modelled from 2010 to 2030 for the main road transport emitters in the EU28 countries. These emissions contributors include passenger cars (PC), light commercial, medium and heavy duty vehicles (LCV, MDT and HDT with up to 3.5, 3.5 to 16 and above 16 tons gross vehicle weight GVW) as well as buses with gross vehicle weights exceeding 3.5 tons. Two wheeled transport is excluded from this study due to its marginal contribution - motorbikes represent only one per cent of GHG emissions. (Refer to figure 16)

Figure 16: GHG emissions by transportation mode in EU28 by sector in 2013 [%]



Source: Transport emissions rising (EEA, 2015b)

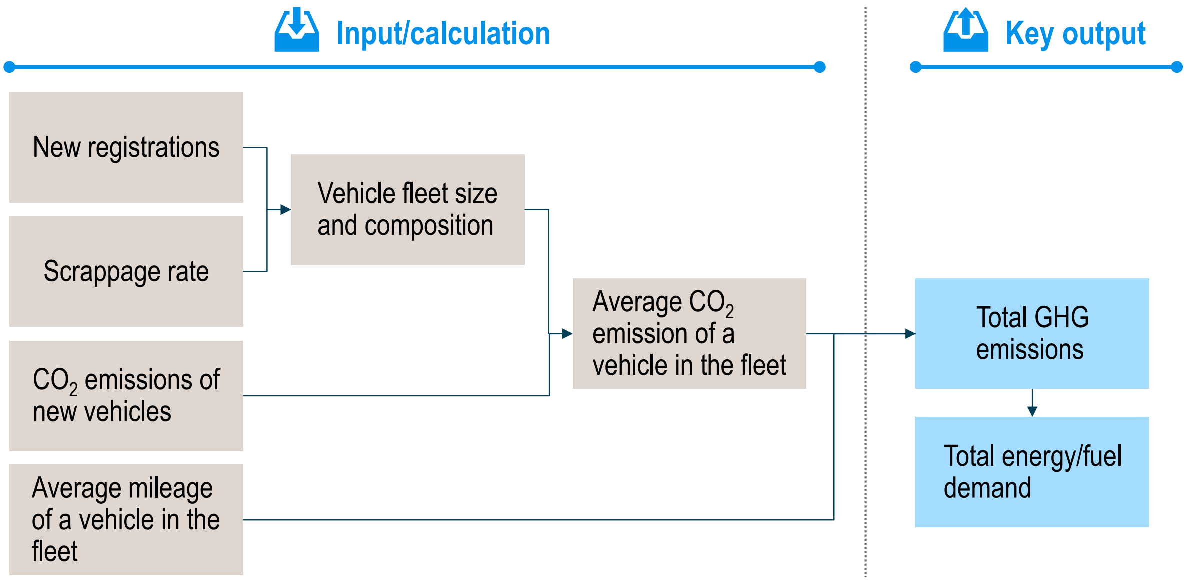
TTW GHG emissions are calculated using fleet sizes and fleet composition (new registrations minus scrappage) and average CO_2 emissions of fleet vehicles based on official test-cycle data, adjusted by a real world driving factor (refer to chapter 2), and average mileages.

Recent publications have highlighted the discrepancy between the fuel consumption of light-duty vehicles in NEDC test and real-life driving. ICCT in particular (ICCT, 2015a) has analyzed different databases and showed that the "real-world" factor varied quite significantly depending on the source, country and vehicle generation of the vehicle. For the purpose of our model, we used a "real-world" factor of 1.149 from the JEC biofuel study (JRC, 2014a). In order to match the model's resulting fuel consumption with historical fuel consumption data a vehicle's annual mileage is fine-tuned.

As shown in figure 17, the schematic calculation for total GHG emissions caused by road transport is based on the following four steps:

1. Modelling of the age structure of the vehicle fleet taking into account historical and forecasted developments of total fleet size and new vehicle sales. The scrappage rate is a function of those two input factors, similar to the approach of the study conducted under the JEC biofuels program.
2. Thereafter, information about the average GHG emissions per vehicle and manufacturing year are added onto the annual fleet structure. The average GHG emissions of each vehicle per year can be calculated as a result.
3. The next step is to multiply the average mileage with the average GHG emissions thus providing the total GHG emissions by road transport per year.
4. Based on this, the total energy demand is calculated (for conversion factors refer to appendix 6.1) to analyze related WTT GHG emissions

Figure 17: Schematic approach to calculate TTW GHG emissions of road transport



Source: Roland Berger

Tank-to-wheel data sources

The underlying data for the TTW model used in this study has been obtained from publicly available studies and databases where possible in order to satisfy the aim of keeping the analysis as holistic as possible. Where data was not publicly available, individual assumptions have been made based on exchange with experts and with existing internal Roland Berger expertise and models. Publicly available data sources include:

Eurostat: A Directorate-General of the European Commission providing statistical data including vehicle registrations and stock sizes.

EEA: The European Environmental Agency of the EU provides information and data on CO_2-emissions of new vehicles in the EU.

ICCT: The International Council on Clean Transportation is an international non-governmental organization (NGO) providing vehicle market statistics.

ACEA: The European Automobile Manufacturers Association is the official body of OEMs producing cars in the EU and as such provides data on new registrations, vehicle fleet sizes and other automotive-related topics.

TREMOVE: A database developed and published by Transport & Mobility Leuven. For this study we used the most recent TREMOVE v3.3.2 alt database covering 1995 to 2030.

JEC: JEC Biofuels Programme – EU renewable energy targets in 2020: Revised analysis of scenarios for transport fuels

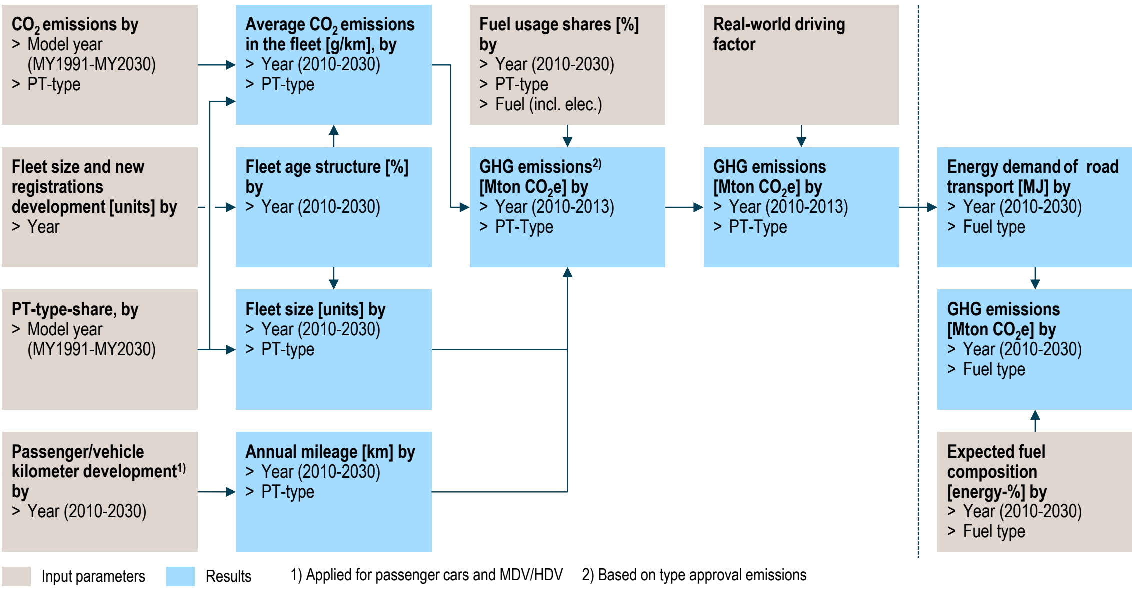
Others: Other sources include further forecast providers such as IHS Automotive, LMC Automotive, Prognos and Wood Mackenzie.

Tank-to-wheel GHG emission modelling approach

The TTW model is a spreadsheet tool simulating the EU road transport sectors direct emissions until 2030. It takes into account developments of vehicle CO_2 emissions, new vehicle sales, fleet size and powertrains to derive fuel demands and resulting GHG emissions. A schematic overview of the model structure is provided below (refer to figure 18).

Calculated energy demands of these scenarios have been input into the WTT part of the model.

Figure 18: Schematic structure of the tank-to-wheel part of the model



Source: Roland Berger

Key inputs: Passenger cars

Powertrains

With regard to passenger cars the following powertrains come under consideration: Internal combustion engines (ICE) using gasoline (including MH, FH and PHEV) and diesel with the same hybrid variants (MH, FH and PHEV). Other ICEs powered by compressed natural gas (CNG), liquefied petroleum gas (LPG) and flex-fuel vehicles (FFV) using more than one fuel type are also considered. Electric vehicles include those powered by battery (BEV) and fuel cells (FCV).

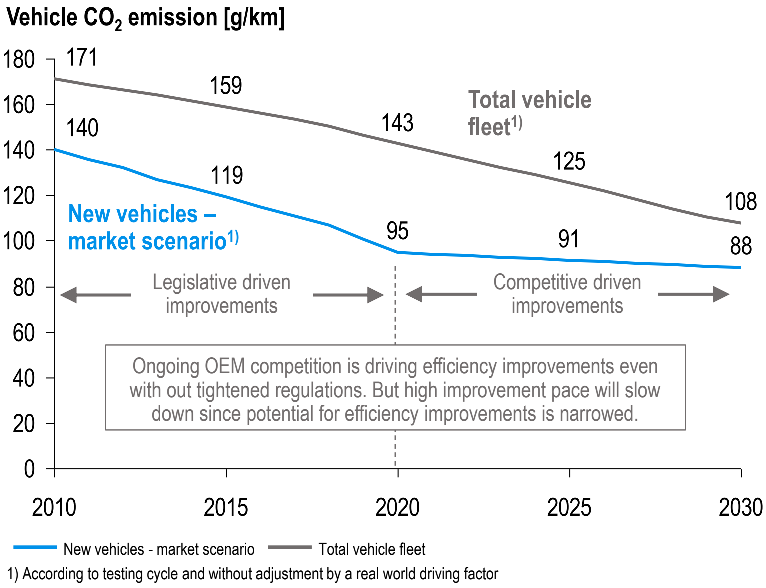
Mild-hybrid vehicles (MH) are defined as vehicles using an electric powertrain with less than 20 kW power and being able to drive electrically over short distances. Vehicles are termed as full-hybrid vehicle (FH) when they are equipped with an electric powertrain with more than 20 kW power, but are not externally rechargeable. Plug-in hybrid vehicles (PHEV) are all vehicles with an electric and conventional powertrain (ICE) and are externally rechargeable.

CO_2 emissions

Based on the assumption that manufacturers meet the 95 gCO_2/km emissions target by 2020/2021 (equal to an annual reduction 2015-2020 of approx. 4.6%) specific CO_2 emissions were derived for each of these powertrains. For the time period after 2020, on-going competition is driving efficiency improvements even without more stringent regulations beyond the 95 gCO_2/km target. As a result, there will be an improvement in efficiency, but at a slower pace than before with approx. 0.9% p.a. from 2022 till 2030 (refer to figure 19). Overall reduced CO_2 emissions of new vehicles will have a distinct impact on overall CO_2-emissions of the existing fleet resulting in an average annual reduction by approx. 2.3% from 2010 to 2030[23].

[23] The difference between cycle CO_2 emissions are real world CO_2 emissions in addresses by a correction factor of 1.149.

Figure 19: Average CO_2 emissions of new cars as measured in EU NEDC, 2010-2030 [g CO_2/km]



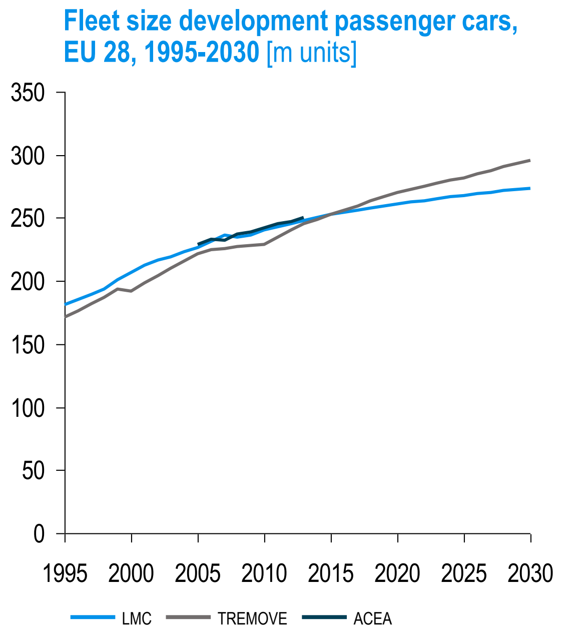
> Based on current assumptions, average CO_2 emissions of new passenger cars are expected to decrease to ~88 g/km in 2030
> Values for 2015-2030 have been forecasted based on the Roland Berger CO_2 model, assuming that OEMs meet 2015 and 2020/2021 targets of 130 and 95 g CO_2/km respectively
> Assuming that no stricter regulations will be introduced after 2020/2021, moderate annual reductions are expected for 2020-2025

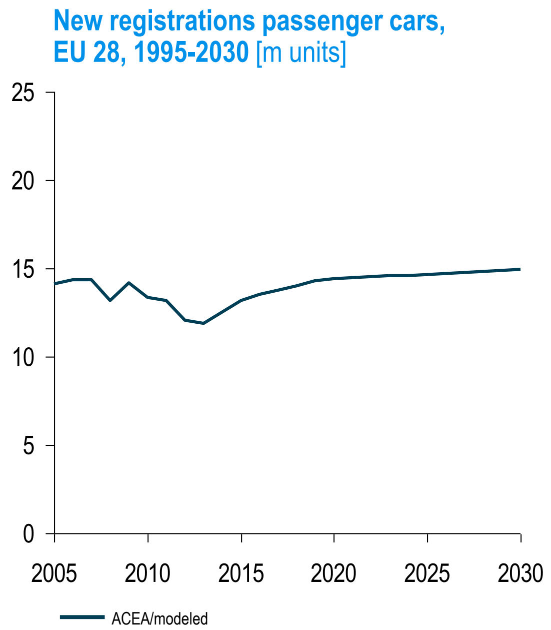
Source: EEA, Roland Berger

Fleet size

An increase in passenger car fleet size from ~250 million vehicles in 2014 to ~274 million in 2030 is to be expected (Q3/2015 forecast of LMC Automotive) which equals a growth rate of 0.6% per year. Based on ACEA actuals until 2014 and IHS growth rates new vehicle registrations are expected to rise from ~13 million in 2014 to ~15 million in 2030 (refer to figure 20).

Figure 20: Fleet size, 1995-2030 and new registrations development 2005-2030 [M units]

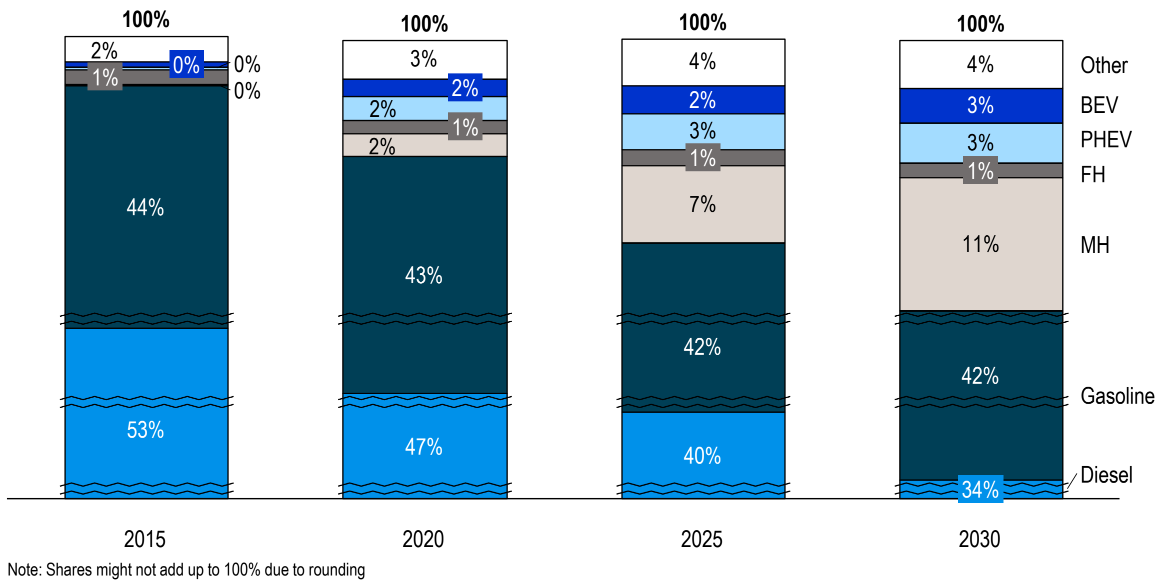




Source: LMC Automotive, TREMOVE 3.3.2 alt, ACEA, Roland Berger

For powertrain shares in new registrations two different scenarios have been modelled. Scenario A (conservative technology improvement) assumes a continuous dominance of conventional powertrains (refer to figure 21). Scenario B (progressive technology improvement) assumes a growing proportion of BEV and PHEV passenger cars (refer to appendix 6.1). These scenarios are based on the Roland Berger Customer Acceptance model addressing differing purchase decision criteria by customer groups.

Figure 21: Powertrain shares in new vehicle sales scenario A, 2015-2030 [%]

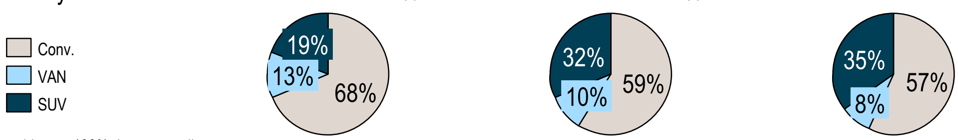


Source: Roland Berger

Moreover, both scenarios consider an equal evolution of the vehicle segmentation. From 2014 to 2030, a marginal shift to small segment vehicles is implied, while a significant shift from conventional body types such as sedan and station wagon to SUV is expected. Thereby the trend to SUV as seen in the past is continued (refer to figure 22).

Figure 22: Development of new vehicle sales by segment 2014-2030 [%]

Segment	Segment name	Segment share of new cars 2015	2022	2030
A	Mini cars	~9%	~8%	~7%
B	Small cars	~34%	~32%	~36%
C	Medium cars	~38%	~40%	~40%
D	Large cars	~13%	~14%	~10%
E	Executive cars	~5%	~7%	~7%
F	Luxury cars	<1%	<1%	<1%



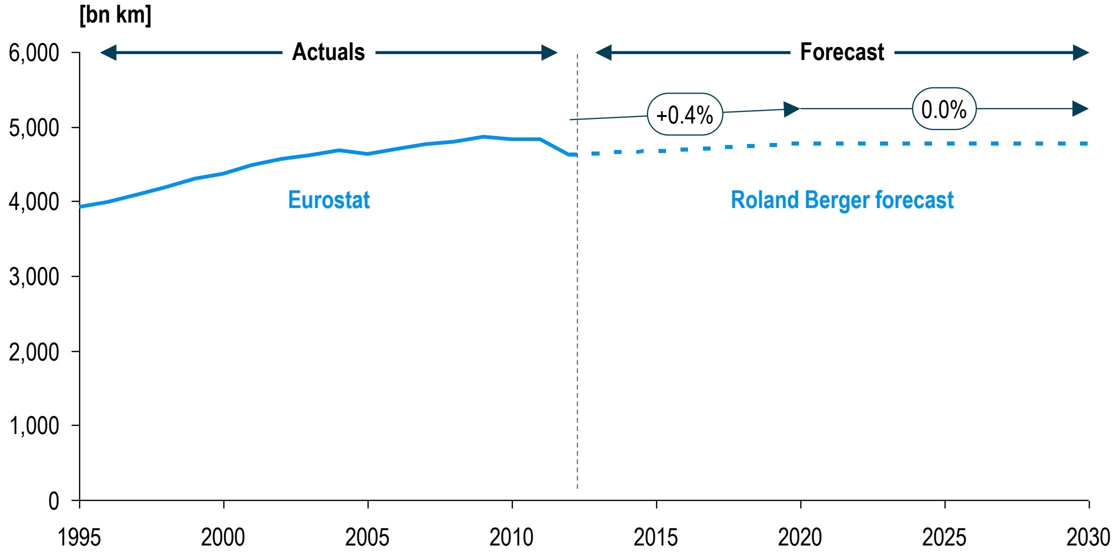
Note: Shares might not add up to 100% due to rounding

Source: European Commission, Roland Berger

The relative proportion of mileage by powertrain is derived from TREMOVE and has been defined for those powertrains that are not covered by the aforementioned data set. The reference mileage of conventional ICE (diesel and gasoline) vehicles in 2014 was determined, using actual fleet demand (Wood Mackenzie). Mileage forecast until 2030 is based on developments within the EU: passenger kilometers are expected to grow by a moderate 0.4% per year until 2020 with zero growth thereafter. This is due to slow population growth and demographic change resulting in a larger percentage of elderly with lower mobility requirements as well as a gradual modal shift towards public transport in particular in urbanized areas (refer to figure 23).

Breaking this down on an average annual mileage of vehicles, a reduction from a level of approx. 11,900 km p.a. in 2015 to a level of approx. 11,250 km p.a. in 2030 is expected. This is in line with the argumentation of a relatively constant level of passenger kilometers (refer to figure 23) and with an increasing number of vehicles and a constant number of average people per vehicle until 2030.

Figure 23: Passenger kilometer actuals 1995–2012, forecast 2012-2030 [bn km]

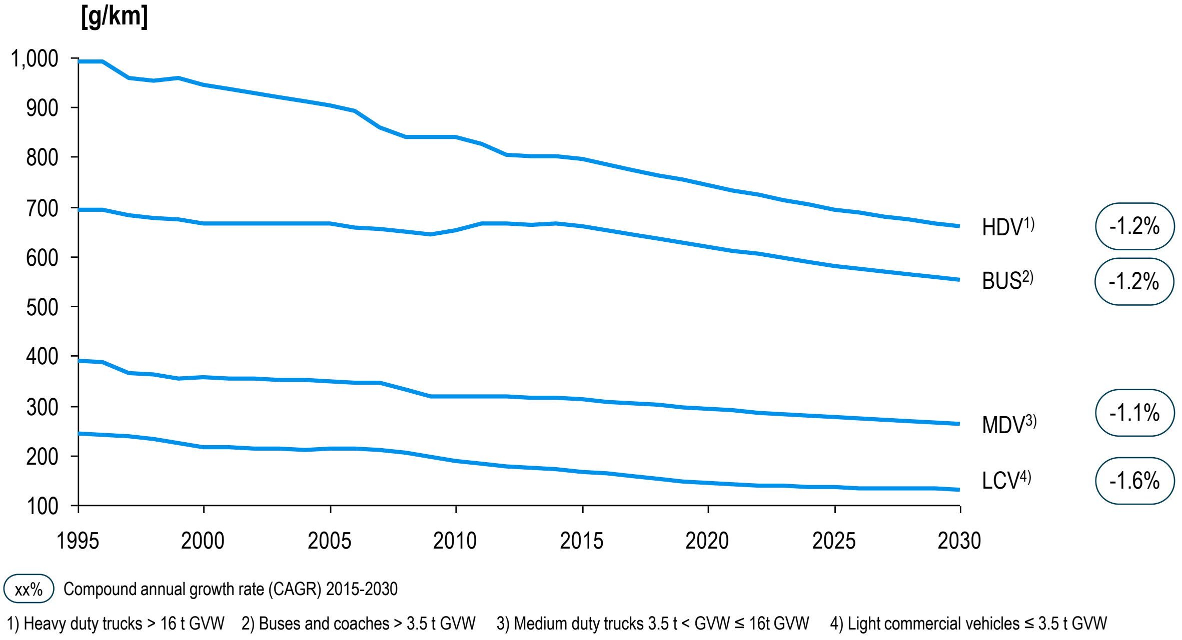


Source: Eurostat, Roland Berger

Key inputs: Commercial vehicles

The considered powertrains of LCV (up to 3.5 tons GVW) are the same as for passenger cars (see 3.4.2.1). For MDT and HDT and buses gasoline, diesel, diesel hybrid and diesel plug-in hybrid powertrains were considered as well as those powertrains that use alternative fuels (liquefied natural gas LNG, CNG, LPG) as well as electricity and hydrogen (BEV and FC). For each of these powertrains specific CO_2 emissions were forecasted until 2030 by model year. For an overview of more efficient powertrains' contribution to declining new vehicle CO_2 emission in each vehicle group refer to figure 24.

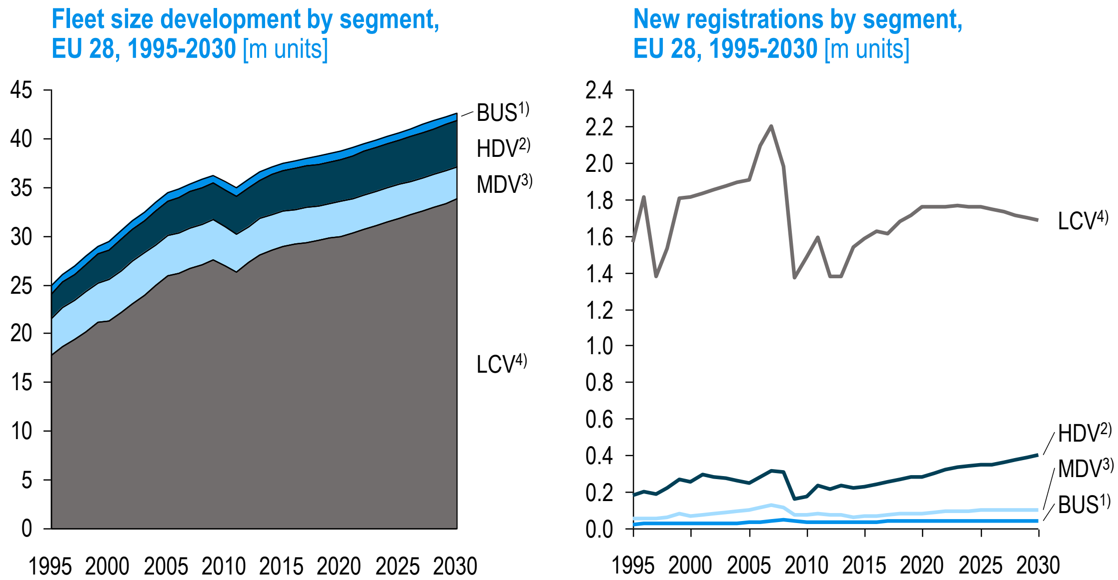
Figure 24: CO_2 emissions of new vehicles by model year and CV segment, 1995-2030 [g/km]



Source: TREMOVE, Roland Berger

The LCV segment is expected to grow from ~29 million by 2014 to ~34 million vehicles in 2030, a growth rate of 1% per year. A similar growth rate is expected for the HDT segment to ~4.7 million units in 2030 (from ~4 million in 2014). Only the MDT segment is expected to decline moderately by -0.5% per year to ~3.3 million vehicles in 2030 from ~3.6 million in 2014. This forecast is in line with the segment shift from MDT to both LCV and HDT currently being observed. The segment of buses and coaches is expected to remain stable until 2030. New registrations and forecasts are based on ACEA 2014 actuals and IHS growth rates respectively (refer to figure 25).

Figure 25: Fleet size and new registrations development by CV segment, 1995-2030 [m units]

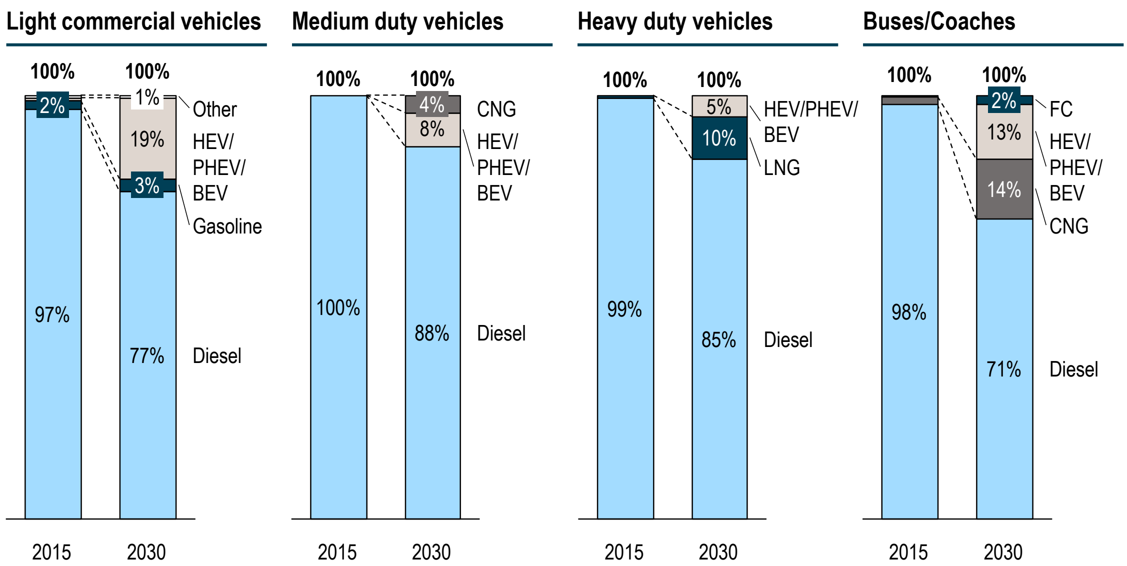


1) Buses and coaches > 3.5 t GVW 2) Heavy duty trucks > 16 t GVW 3) Medium duty trucks 3.5 t < GVW ≤ 16t 4) Light commercial vehicles ≤ 3.5 t GVW

Source: Prognos World Transport Report, Eurostat, Tremove 3.3.2 alt., Roland Berger

Based on the current market situation and Roland Berger expert assessments, an increasing share of alternative powertrains is to be expected in the commercial vehicle segment (refer to figure 26). Hybrids (mild, full and plug-in hybrids) will be the most important alternative powertrains reaching shares in new registrations of ~15% (LCV) and ~7%(MDT) by 2030. LNG will be the most important alternative powertrain in the heavy duty segment by 2030 with a share of ~10% in new registrations, followed by diesel MH with ~5%. For buses CNG and diesel HEV will be the most important alternative drivetrains by 2030 with new registration shares of ~14% and ~13% respectively. By 2030 fuel cell electric powertrains will be available, but will remain a niche application for special vehicle usage profiles (no mainstream application). Furthermore, battery electric city buses will be available, but will have a very limited impact on the overall CO_2 levels.

Figure 26: CV powertrain shares, 2015 vs. 2030 [%]



Source: Roland Berger

2.3.2 Fuel well-to-tank GHG emissions

Scope of well-to-tank emissions modelling

The well-to-tank (WTT) GHG emissions model calculates the WTT GHG emissions caused by the total energy demand in the road transport sector in the market scenario. Based on this, the changes in WTT GHG emissions until 2030 - assuming implementation of abatement measures - can be calculated.

WTT GHG emissions for the period 2014-2030 have been modelled for major road transport fuels that have considerable commercial potential until 2030. The fuels considered conventional biofuels and advanced ethanol-based blends, i.e. E5, E10, E20, E85, as well as bio based diesel blends, i.e. B7, R33 and HVO100% (hydro-treated vegetable oil including conventional and advanced biofuels), CNG (compressed natural gas), LNG (liquefied natural gas), hydrogen and electricity.

Also the importance of other biofuel blends was recognized as well as synthetically generated fuels (e.g. paraffinic fuels). These include for instance biomass to liquid (BTL), Dimethyl Ether (DME), co-processed oils, sugar-to-diesel, sugar-to-gasoline, methanol, butane and bio-SNG– but they are not specifically modelled in this study.

Well-to-Tank data sources

The underlying data for the WTT emissions model used in this study originates where possible from publicly available studies and databases. WTT emissions of transport fuels are calculated based on GHG intensities of their respective production and blending processes (refer to appendix 6.2). Publicly available data sources used include:

FQD: The pathway-equivalent GHG intensities of the FQD are used for all fuels quoted in the FQD. In case the GHG savings of pathways mentioned in the FQD do not meet the sustainability criteria, it is assumed that until 2030, they will at least meet the 50% criteria

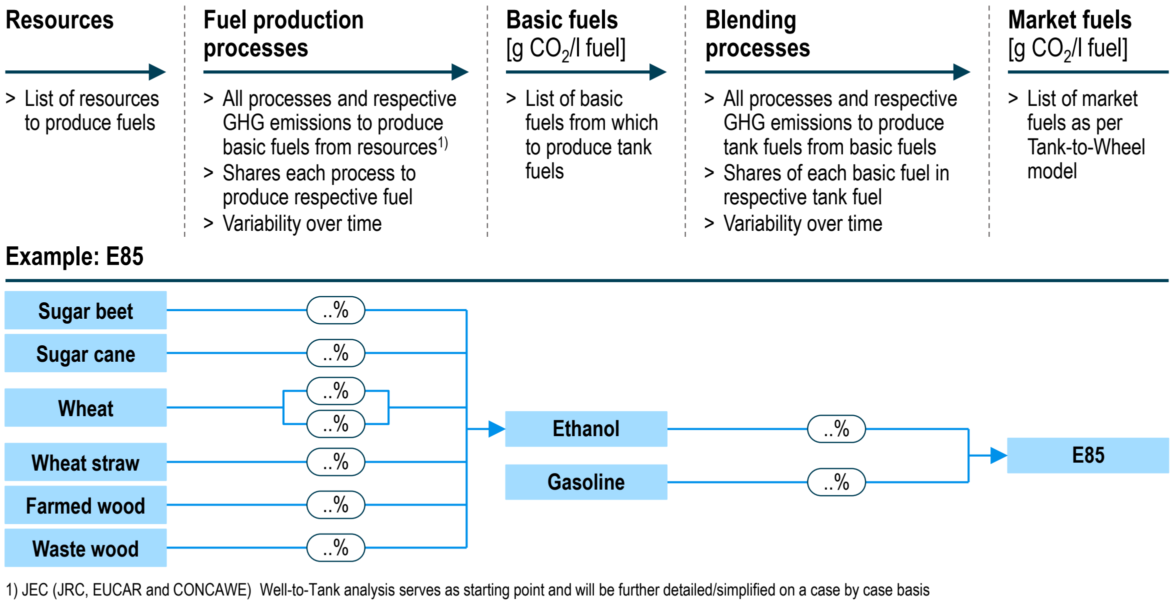
JEC: JEC Well-To-Wheels Analysis - "Well-to-Tank Report" Version 4.a
For all production pathways and fuels not included in the FQD, GHG intensities are used and calculated by JEC. EU energy mixes (e.g. electricity mix, imported natural gas mix) were updated using JEC methodology applied to the expected production/import mix in Europe in 2030. In order to be in line with the values used in the FQD, diesel and gasoline GHG intensities were updated using ICCT upstream GHG intensities for imported and processed crudes within the EU calculated by the ICCT emission[24] – which is also in line with the values used in the FQD

For the remaining production pathways (e.g. HVO from tall oil) that are neither included in the FQD nor the JEC study, public and coalition information have been used such as available historic data and assumed changes of feedstock use in the future.

Modelling of Well to-tank greenhouse gas emissions

The GHG emissions by 2030 resulting from the WTT production and blending processes of the fuels are derived from the proportion of basic fuels in market fuels and the according GHG emission intensities of basic fuels according to their production processes and base feedstock (refer to figure 27).

Figure 27: Illustration of WTT fuel intensities calculation



Source: Roland Berger

[24] ICCT upstream emissions are based on OPGEE model (EC, 2015b)

Besides the given sources as a database, the modelling of WTT GHG emissions is based on the following assumptions for modelling the reference case (refer to chapter 2.1):

> A 36% market proportion of E10 for gasoline-based fuels in 2020 (in accordance with the JEC biofuels study 2014) and thereafter
> Advanced ethanol production to rise to a level of 400M litres per year[25] until 2020 (based on JEC biofuels study 2014) and thereafter, all of which will be blended into gasoline
> Diesel blend with a proportion of 7 Vol% FAME (max. allowed limit) until 2020 and thereafter. For all diesel fuels with a larger proportion of biofuels HVO is used as a drop-in fuel for the gap
> Supply of conventional biofuels is capped by 7% of overall energy demand by road transport sector. Any additional market demand needs to be covered by advanced biofuels
> A proportion of 20% bio methane based on waste and residues in CNG used in transport (based on the JEC biofuels study 2014 and interviews with the European Biogas Association)
> 50% of hydrogen to be produced from renewable resources by 2030 in line with the target of H2M[26] Germany
> Renewable electricity to reach a proportion of 44% in overall electricity mix by 2030 (in line with the IEA World Energy Outlook 2015) is applied in both scenarios

Market fuel GHG intensities for various fuel compositions are based on this (refer to figure 28 and 29). More details on the GHG intensities of production processes and their respective sources can be found in the appendix 6.2.

[25] Equivalent of 400,000 cubic meters per year
[26] H2 MOBILITY (H2M) is a joint venture of Air Liquide, Daimler, Linde, OMV, Shell and Total with the target to build a network of 400 hydrogen fuel stations in Germany by 2023.

Figure 28: Fuel composition market fuels (gasoline)

		Base case[1)]	E5	E10	E20	E85	Source
Share of basic fuel in market fuel [energy%]	**Ethanol**	4.6%	3.3%	6.8%	14.1%	78.8%	Fuel specification
	Gasoline	95.4%	96.7%	93.2%	85.9%	21.2%	Fuel specification
WTT GHG Intensity [g CO_2e/MJ]	**Ethanol**	33.49	33.49	33.49	24.41	15.72	RB calculation
	Gasoline	19.96	19.96	19.96	19.96	19.96	JEC WTT V4a adjusted for upstream value
	Market fuel intensity	**20.58**	**20.41**	**20.88**	**20.59**	**16.62**	

1) Basecase: 36% E10 64% E5 in 2030

Figure 29: Fuel composition market fuels (diesel)

		Base case[1)]	B7	R33	HVO	Source
Share of basic fuel in market fuel [energy%]	**FAME**	6.5%	6.5%	6.5%	0%	Fuel specification
	HVO	2.0%	2,0%	25.1%	100%	Fuel specification
	Diesel	91.5%	91.5%	68.4%	0%	Fuel specification
WTT GHG Intensity [g CO_2e/MJ]	**FAME**	37.49	37.49	37.49	37.49	RB calculation
	HVO	20.06	20.06	18.61	18.94	RB calculation
	Diesel	21.68	21.68	21.68	21.68	JEC WTT V4a adjusted for upstream value
	Market fuel intensity	**22.67**	**22.67**	**21.99**	**18.94**	

1) Greenea Market Analysis 2015 - Waste-Based Biodiesel Market: Current Situation and 2020 Perspective

Source: Roland Berger

INFOBOX – Sensitivity analysis of CO_2 intensity of fuel production

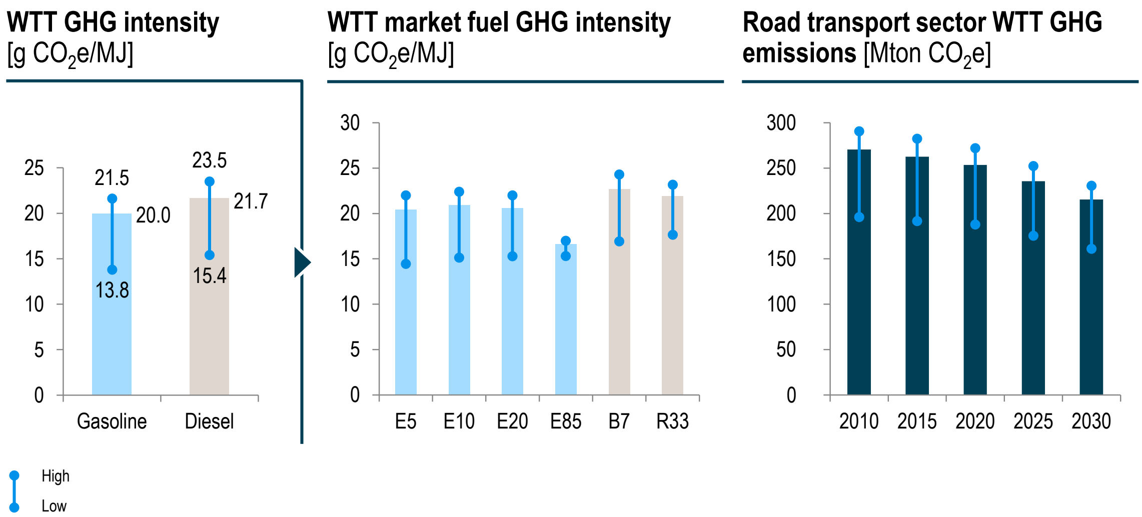
One central aspect of the discussion regarding WTW CO2 emissions in the road transport sector is the GHG emissions intensity of fuel production (WTT). This includes the GHG intensities of basic fuels as well as of blended fuels according to the specified proportion of basic fuels.

In the modelling approach, GHG emissions related to fuel production directly influence overall WTW calculations. Other studies for reference as high and low emission scenarios are included to analyze the sensitivity of assumed GHG intensities.

For conventional gasoline and diesel fuel production (i.e. not including biofuel), the basis of the calculation is 20 gCO_2/MJ (gasoline) and 21.7 gCO_2/MJ (diesel) (refer to figure 25). Looking at other studies, these values are higher than the assumptions from the JEC WTT study (2014) which assumed significantly lower figures (13.8 gCO_2/MJ(gasoline) and 15.4 gCO_2/MJ (diesel)). It reflects a higher GHG intensity of crudes processed in Europe as from ICCTs recalculation. The main drivers are an expected higher weight of complex refineries and a trend to process a wider range of crude oil. In the "high emissions scenario" (JEC adjusted with ICCT upstream values) the carbon intensity was set at 21.6 gCO_2/MJ (gasoline) and 23.5 gCO_2/MJ (diesel).

The sensitivity scenarios are varying assumptions in WTT calculations for conventional fuels, biofuel blends (E5 to E85 and B7 to R33) and resulting WTT GHG emissions in the road transport sector from 2010 to 2030 (refer to figure 30). Based on these GHG emissions, assumptions remain conservative in that they tend towards the high emission scenario, thus reducing the risk of underestimating CO_2 emissions in subsequent WTW calculations. As an illustration, the total WTT GHG emissions in the "low scenario" (JEC unadjusted) assumptions for 2030 WTW GHG emissions would be approximately 53 megatons lower than in the base-scenario. The "high emission" would add approximately 15 Megatons CO_2 over in the "base case".

Figure 30: Sensitivity of WTT GHG intensities for gasoline and diesel, 2030



High = JEC WTT 2014 adjusted for ICCT upstream value increase +20% refinery intensity resulting in +1.8 gCO_2/MJ for Diesel and +1.6 gCO_2/MJ for Gasoline based on expert interview
Base = JEC WTT 2014 adjusted for ICCT upstream value
Low = Unadjusted JEC WTT 2014

Source: Roland Berger

INFOBOX – Type of biofuels

Biofuels can be split into conventional and advanced biofuels and are defined by their process feedstock. When talking about feedstock, conventional feedstock showing a significant Indirect Land Use Change (ILUC) risk are distinguished from those with a low risk of ILUC. The rationale for this is that feedstock with a low ILUC risk is based upon biological waste or biomass processing residues. Therefore they can be classified as sustainable, as they do not encroach upon or not compete with food production. But according to the ILUC all biofuels show a different degree of risk and thereby need to be evaluated separately in detail (refer to figure 45)

Figure 31: Type of biofuels with selected examples

Process feedstock (selected examples)	**Process technology** (selected examples)		
	Conventional	**Advanced**	
Conventional (ILUC risk)	Ethanol from fermentation of wheat, maize or beet, FAME from vegetable oils	HVO from vegetable oils	Conventional biofuels
Advanced (low ILUC risk)	FAME from waste oil	LC-ethanol from straw Biomass-to-Liquid from residue; HVO from waste oil, algae, yeast	Advanced biofuels

LC – Lingo-Cellulosic , composition of carbohydrate polymers and aromatic polymers

Source: Roland Berger

3. Road transport sector's GHG emissions reduction towards 2030 under current policy framework (reference case)

The current regulatory framework for GHG emissions in EU28 is set as the reference case in this study. This section outlines the conclusions of the modelling in comparison with the EU 2030 ambition of 30% reduction in GHG emissions (vs 2005) in Non ETS Sectors. In addition to this comparison, other opportunities and risks associated with Road Transport decarbonization to 2030 are identified associated with the modelling conclusions which are also set out in Section 3. Section 4 identifies the modelling outcomes associated with further measures to achieve the 2030 ambition

3.1 Current policy framework enabling reduction of road transport GHG emissions close to EU 2030 target

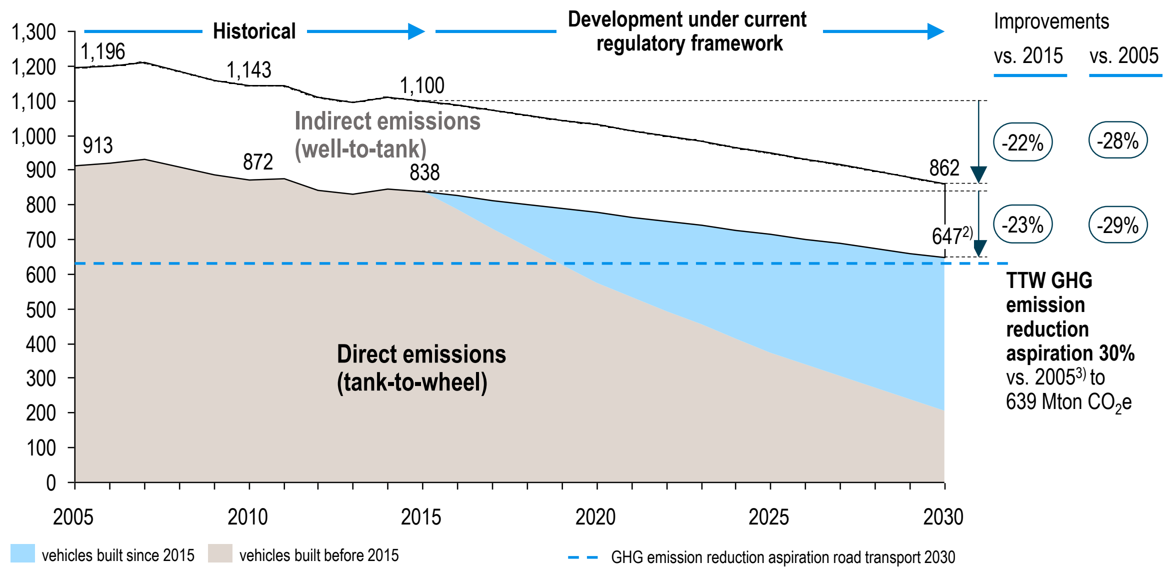
Based on the assumptions described in chapter 2 (regarding vehicle fleet development, total passenger car and truck mileage and efficiency improvements in conventional powertrains), fleet emissions of passenger cars and commercial vehicles will:

> Decrease TTW greenhouse gas emissions (-29% compared to 2005, to 647 Mton CO_2e) to the level envisaged by the European Commission Climate and Energy Framework, which suggests a 30% drop in greenhouse gas emissions from non-ETS sectors in 2030 compared to 2005 levels (TTW).

> Significantly reduce WTW greenhouse gas emissions by almost 22% from the current level of 1,100 Mton CO_2e (2015) to 862 Mton CO_2e by 2030 (refer to figure 32).

This illustrates the effectiveness of existing legislation; but road-transport legislative measures can take over 10 years to reach their full impact, as a result of the slow rate of fleet renewal.

Figure 32: EU28 Road transport sector GHG emissions[1)] [Mton CO2e] – Scenario A[2)]



1) Fleet emissions of passenger cars and commercial vehicles, excluding two-wheelers, biofuels considered TTW carbon-neutral
2) Scenario A: low oil price, high battery cost 3) Based on EU 2030 Climate & Energy Framework (2014) reduction aspiration for non-ETS sectors

Source: UNFCCC/EEA, EU 2030 Climate & Energy Framework, Roland Berger

INFOBOX – Sensitivity analysis

With the great number of input factors used in the TTW model, it is important to understand their individual contribution to the model results. Therefore all relevant input factors are varied - such as fleet size, annual passenger mileage, new car BEV share, renewable fuel shares, real world driving factors and oil-price - to derive their individual sensitivity. While each input factor is varied, all other factors remain constant.

For passenger cars, annual passenger mileage shows the greatest sensitivity to modification and thus impact on the GHG emissions model: reducing assumed “passenger-mileage ” between 2013 and 2030 by -0,35% p.a. resulted in 27 Mton fewer CO_2e emissions, while increasing passenger mileage by 0.65% p.a. was equivalent to 27 Mton more CO_2e emissions. Similar results were found by varying the renewable fuel share (for diesel from 5.2% to 17.0% biofuel proportion and for gasoline from 2.4% to 9.2%. Other sensitive parameters are the variation of “real-world factor” and “fleet size" (each varied by +-10%). (Refer to figure 33)

New car shares of BEVs were least sensitive to input variation: With no increase of their share after 2020, TTW GHG emissions would rise by only 3 Mton CO_2e.

Figure 33: Sensitivity analysis based on main input factors – Passenger cars[1)]

Input factor		Input value (low)	Input value Modeled	Input value (high)	Total TTW GHG 2030[2)] [Mton CO_2e] low	Total TTW GHG 2030[2)] [Mton CO_2e] high
1	Fleet size 2030[3)] [m units]	260 (-5%)	274	287 (+5%)	260 (-5%) 626	667 287 (+5%)
2	Annual passenger km growth 2013-2030[4)]	-0.35% (-0.5%-pt.)	+0.15%	+0.65% (+0.5%-pt.)	-0.35% (-0.5%-pt.) 620	676 +0.65% (+0.5%-pt.)
3	New car powertrain shares 2020-2030[5)]	20% BEV[6)]	~3% BEV	0% BEV	20% BEV[6)] 634	650 0% BEV
4	Renewable fuel share 2030 — Gas. / Diesel	9.2% / 17.0%	4.6% / 8.5%	2.4% / 5.2%	9.2% 17.0% 593	668 2.4% 5.2%
5	Real-world driving factor passenger cars	1.03 (-10%)	1.1499	1.26 (+10%)	1.03 (-10%) 610	680 1.26 (+10%)

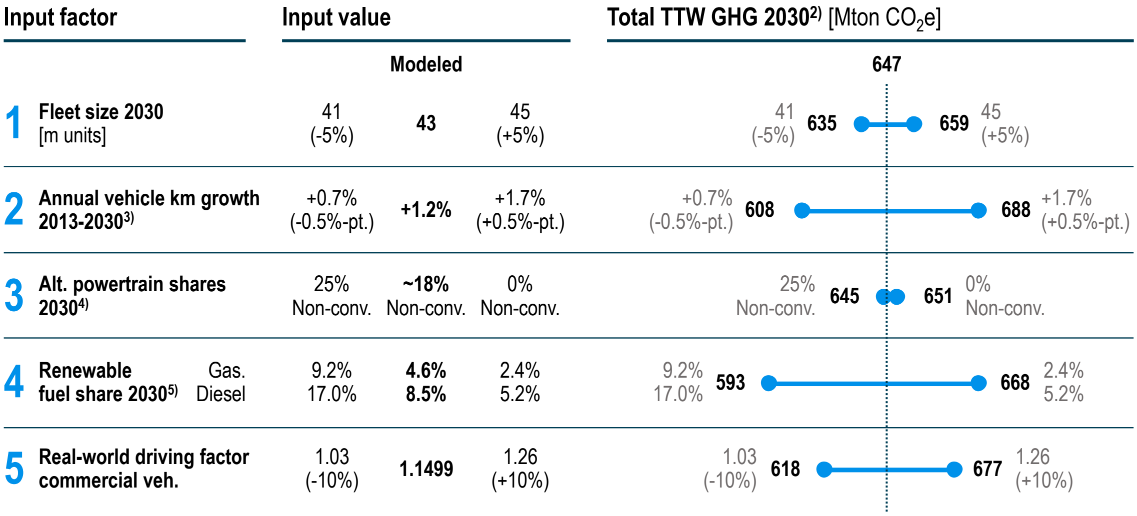
Modeled total TTW GHG 2030: 647

1) Input values for LCV/CV segments kept constant 2) Biofuels treated as carbon neutral 3) Constant vehicle mileage assumed for sensitivity analysis
4) Base assumption: 0.4% pkm growth p.a. 2013-2020; 0% pkm growth 2021-2030 (avg. = 0.15% p.a.)
5) Assumption: BEV gains shares equally from diesel and gasoline powertrains 6) Linear uptake assumed from 2020-2030

Source: Roland Berger

For commercial vehicles, annual vehicle mileage and renewable fuel share show the greatest sensitivity to modification and thus impact on the GHG emissions model: reducing assumed vehicle mileage between 2013 and 2030 from 1.2% to -0.7% results in 39 Mton less CO_2e emissions, while increasing person mileage by 1.7% is equivalent to 41 Mton more CO_2e emissions. Similar results are achieved by varying the renewable fuel share. Less sensitive to parameter variation are real-world driving factors (varied by +-10%) and fleet size (each varied by +-5%). (Refer to figure 34)

Figure 34: Sensitivity analysis based on main input factors – Commercial vehicles[1)]



1) Considering light commercial vehicles, medium/heavy duty vehicles and buses/coaches; input values for passenger cars kept constant. Input values have been varied evenly across all considered segments
2) Biofuels treated as carbon neutral
3) Fleet size development according to base scenario
4) Progressive uptake assumed from 2020-2030 in new vehicle sales
5) Combined passenger car and commercial vehicle effect

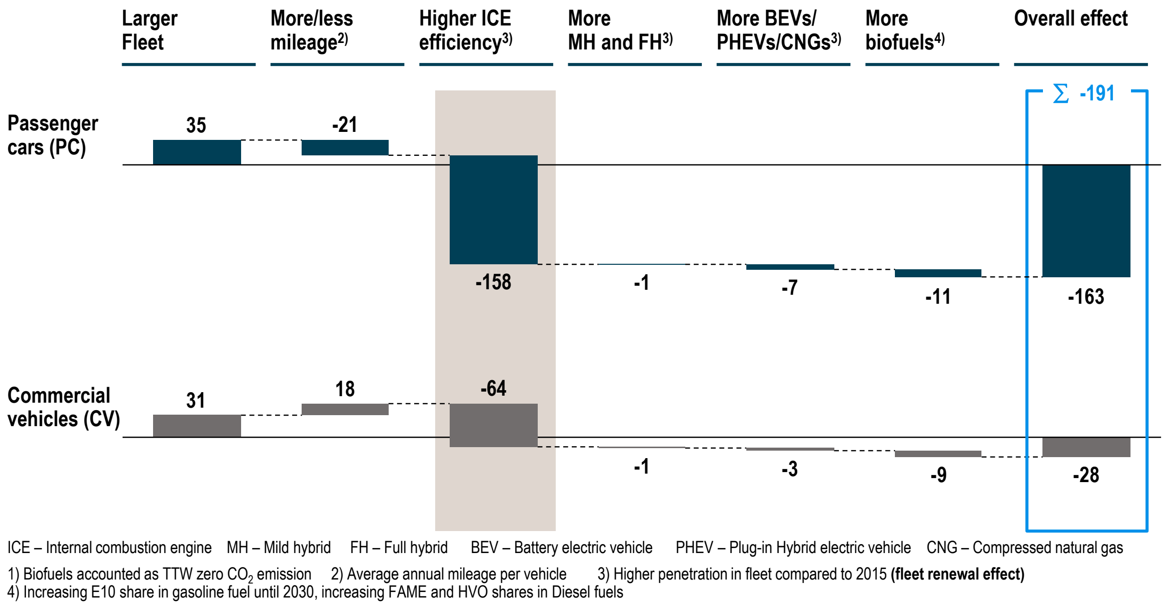
Source: Roland Berger

3.2 ICEs have highest impact on GHG emissions reduction until 2030

Although cost improvements resulting from alternative technologies such as hybrids and electric vehicles expand into the market, their proportion in overall vehicle fleet and influence on overall fleet emissions is limited without additional policy support until 2030. The modelling demonstrates that highly efficient gasoline and diesel engines (optimized Internal Combustion Engines – ICEs) are still the major contributors to the reduction of road transport GHG emissions and hence biofuels have an important role to play in in GHG emissions reduction. The development of energy-efficient powertrain-technologies and their penetration into the fleet will result in significant GHG emissions improvements by 2020 and beyond.

Furthermore, highly efficient ICEs can more than offset the effects of increased fleet size on road transport GHG emissions. Due to their large market share, highly efficient ICEs will also compensate for the increased emissions resulting from a growing vehicle fleet. This effect is also expected with commercial vehicles. Since HD Diesel powertrains are already extremely efficient (46% thermal efficiencies with a maximum potential of approx. 50% incl. hybridization and thermal recovering), most of the fuel efficiency improvement will come from tires, aerodynamics and vehicle management systems.

Figure 35: TTW GHG emissions by influencing factor 2015 vs. 20301) [Mton CO2e]



Source: Roland Berger

INFOBOX – Total Cost of Ownership (TCO)

Total cost of ownership (TCO) is a valid indicator for cost competitiveness of new technologies by estimating direct and indirect costs of owning and using a vehicle. TCO calculations include profits in manufacturing costs (vehicle costs), value depreciation over three years (assumed to be equal across all powertrain technologies), maintenance costs (lower costs for electric powertrains assumed) and retail fuel prices in 2030 (incl. average EU fuel taxation and VAT)[27]. Regardless of the powertrain technology being considered, a similar share of loss of value is assumed. Insurance costs are excluded since they are assumed to be equal for vehicles. Thus vehicle manufacturers need to proof a similar second hand value of PHEV, BEV and FCV, compared to conventional powertrains due to the unproven lifetime of battery packs or fuel cell stacks. For details on powertrain technologies and oil price scenarios, please refer to the appendix 6.5.

Nevertheless, TCO remains a valid indicator of the cost competitiveness of new technologies. However, as there is no single “average customer”, a single TCO-figure will not be appropriate for evaluating vehicle costs without reflecting driving profiles: A beneficial TCO is highly dependent on how the vehicle is actually used. Therefore analyzing existing driving profiles expands the standard TCO calculations significantly. Individual TCOs are calculated for various customer driving profiles based on varying annual mileage and individual share of urban traffic.

[27] Assumption for retail fuel prices: Gasoline high oil price = 1.581 EUR/l; Gasoline low oil price = 1.341 EUR/l; Diesel high oil price = 1.552 EUR/l; Diesel low oil price = 1.285 EUR/l

The individual proportion of urban and city traffic reflects possible TCO advantages of electrified powertrains: The higher the proportion of urban use (with shorter distances and high degree of stop-and-go traffic), the higher the expected cost saving through recuperation (MH and FH) and electric driving (PHEV, BEV). Yet a "heat-map" of existing driving profiles shows that the majority of drivers experience low annual mileages with a limited share of urban traffic (shown by the concentration in the top left of the chart (refer to figure 40). The degree of overlap between heat map (use) and green boxes (TCO) provides an estimate of how many customers could expect a favorable TCO for alternative powertrains.

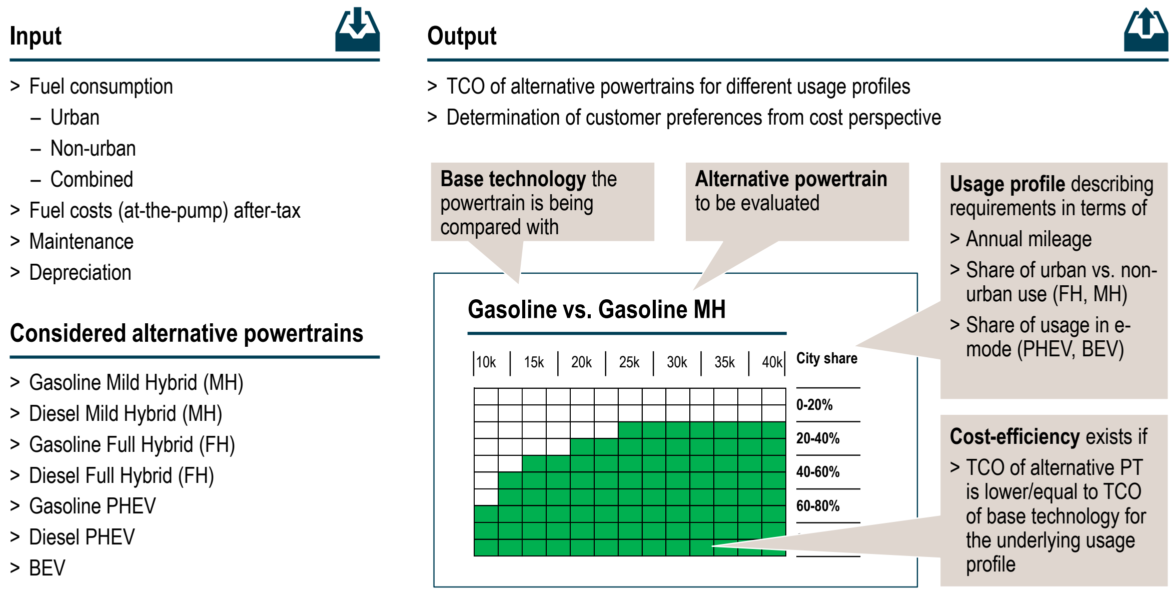
Existing and future infrastructure and battery capacity sets a practical limit of about 30 km of electric driving per day. Therefore driving profiles with higher annual mileages and higher share of city traffic cannot be performed by electric driving modes of PHEVs and hence generate favorable TCO.

The charts (figure 37, 38 and 39 and appendix 6.5) reveal favorable TCO for vehicles in two aspects: Annual mileages in 5,000 km intervals versus city-traffic as a share of total mileage. The TCO advantages of alternative powertrains increase with annual mileage and a greater share of city and urban traffic.

Reference powertrain technologies (gasoline and diesel) were compared with MH, FH and PHEV (each in gasoline and diesel configuration) for different vehicle segments (B, C and D, plus for PHEVs) for both high and low oil price scenarios. Green boxes mark profiles where the alternative technology has equal or better TCO compared with the reference technology. The general conclusion is that MH and PHEV only have favorable TCO for small customer groups. Examples of alternative powertrains with beneficial TCO are

- Gasoline MH versus diesel with low mileage and versus gasoline vehicles with high city-share and
- Gasoline FH with high mileages with high share of city traffic.

Figure 36: TCO calculation methodology overview



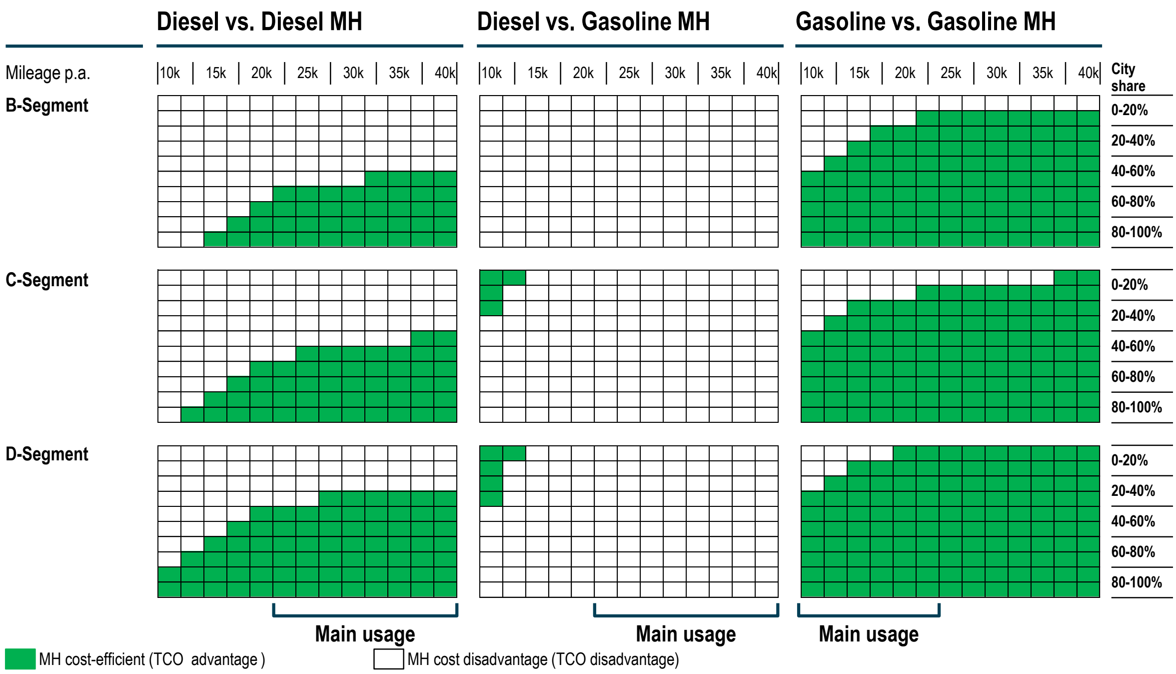
Source: Roland Berger

3.3 Alternative powertrains are a lever in OEMs GHG emissions compliance strategy despite lacking TCO competitiveness

Many alternative powertrain technologies for passenger cars need to be pushed by OEMs to achieve compliance with 2021's 95 gCO_2/km mandate; however the modelling demonstrates that even in 2030 they will continue to remain uncompetitive in relative terms.

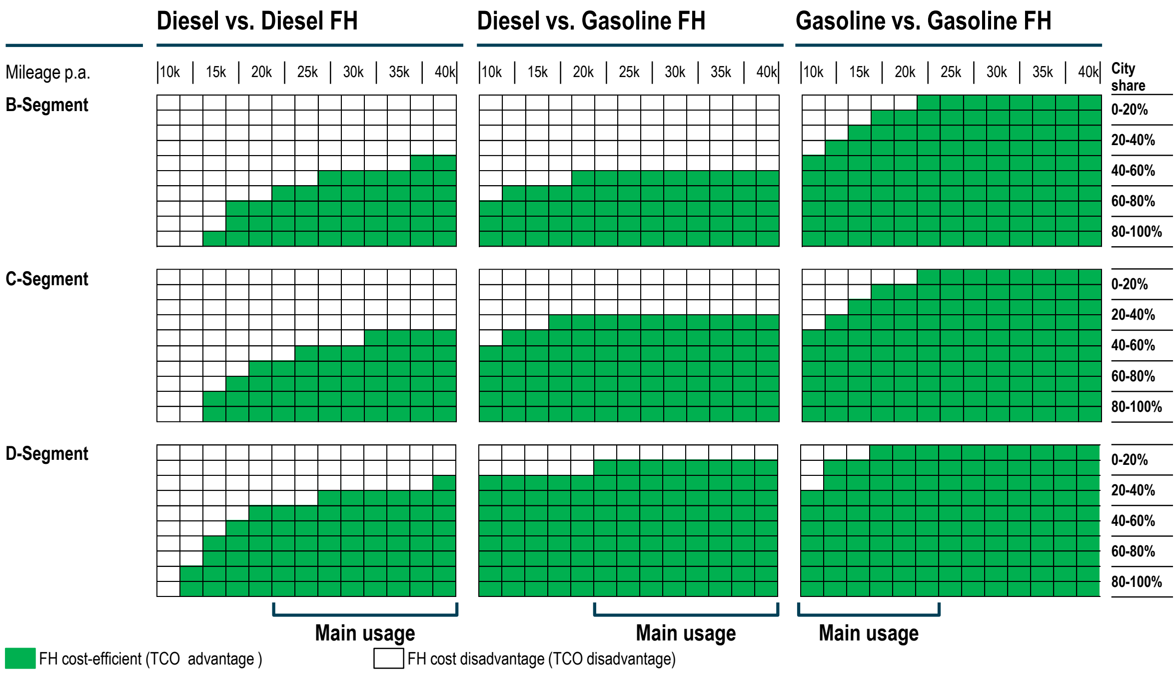
The study demonstrates the lack of competitiveness of a number of alternative powertrains such as BEV and PHEV from the customer perspective by applying the economic concept of total cost of ownership (TCO) to all powertrain technologies being considered. Thereby these low carbon powertrain technologies are compared to either a gasoline or diesel reference vehicle with respect to customer purchasing fuel and maintenance costs (refer to Infobox – TCO). PHEVs from a TCO perspective only make sense for a relative limited number of driving profiles even when considering a high oil price scenario of 113 USD/bbl (refer to figure 39). In contrast, diesel and gasoline MH/FH offer customers a TCO advantage at an oil price level of 113 USD/bbl (refer to figure 37 and 38). A stronger customer pull (by a more favorable TCO) is highly recommended to ensure increased technology penetration and help alternative technologies make a greater contribution to reducing GHG emissions.

Figure 37: Relative competitiveness of driving profiles from a TCO perspective for a MH at an oil price of 113 USD/bbl



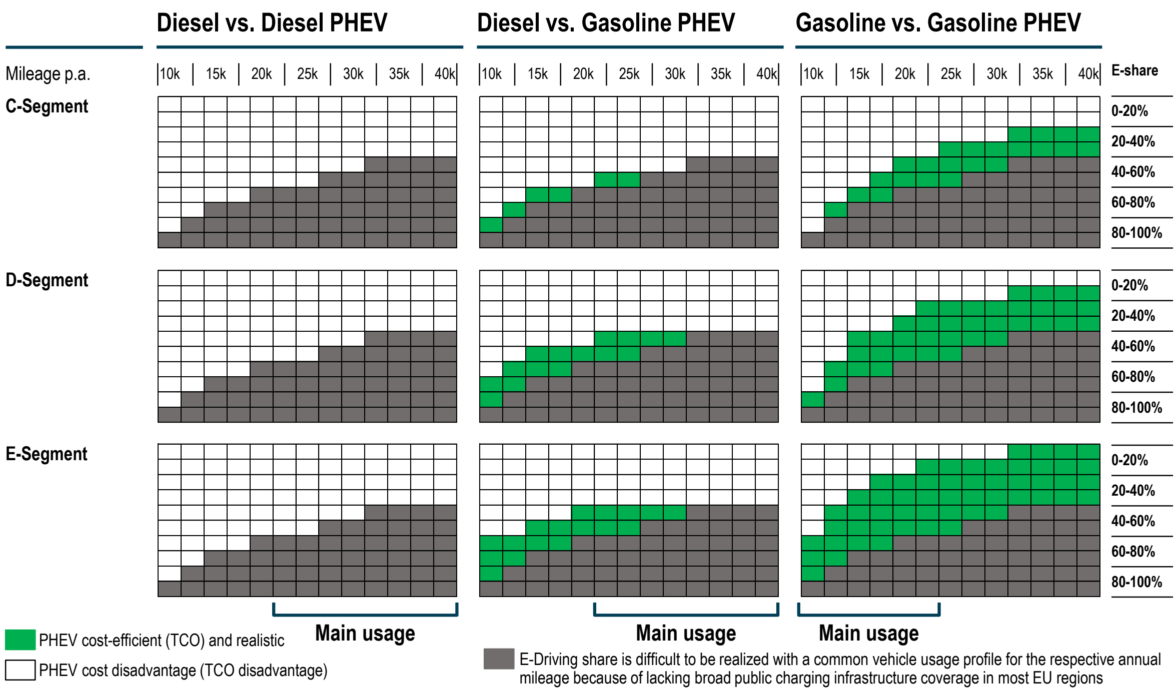
Source: Roland Berger

Figure 38: Relative competitiveness of driving profiles from a TCO perspective for a FH at an oil price of 113 USD/bbl



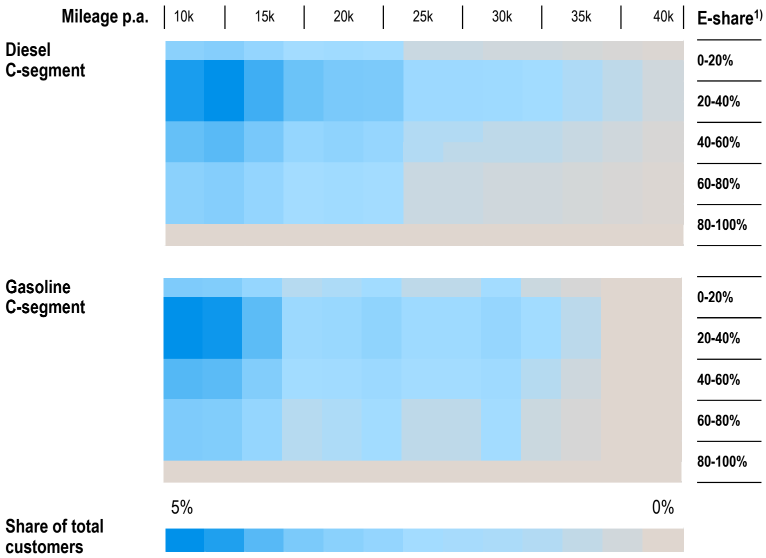
Source: Roland Berger

Figure 39: Relative competitiveness of driving profiles from a TCO perspective for a cost-efficient PHEV at an oil price of 113 USD/bbl



Source: Roland Berger

Figure 40: Distribution of driving profiles for reference powertrains in C-segment (examples Germany)



1) E-share refers to proportion of pure electric driving within a single driving cycle

> There is no "average customer" with an average driving profile, but there are many individual TCO cases of customers
> TCO benefit of high efficiency PT technologies need to address wide array of driving profiles to make TCO attractive for many customers
> Majority of high-mileage customers does not have a very high city driving share

Source: ADAC, Roland Berger analysis

3.4 Current policy framework results in significant GHG abatement costs

Providing the consumer with optimized ICEs and alternative technologies represents a significant challenge for passenger car manufacturer and fuel supplier. For passenger cars it is estimated to account for EUR 380-390bn of cumulated incremental powertrain costs between 2010 and 2030. Achieving the 95gCO_2/km target requires a EUR 216bn investment leading to incremental average powertrain costs of approximately 1,700 EUR per passenger car.

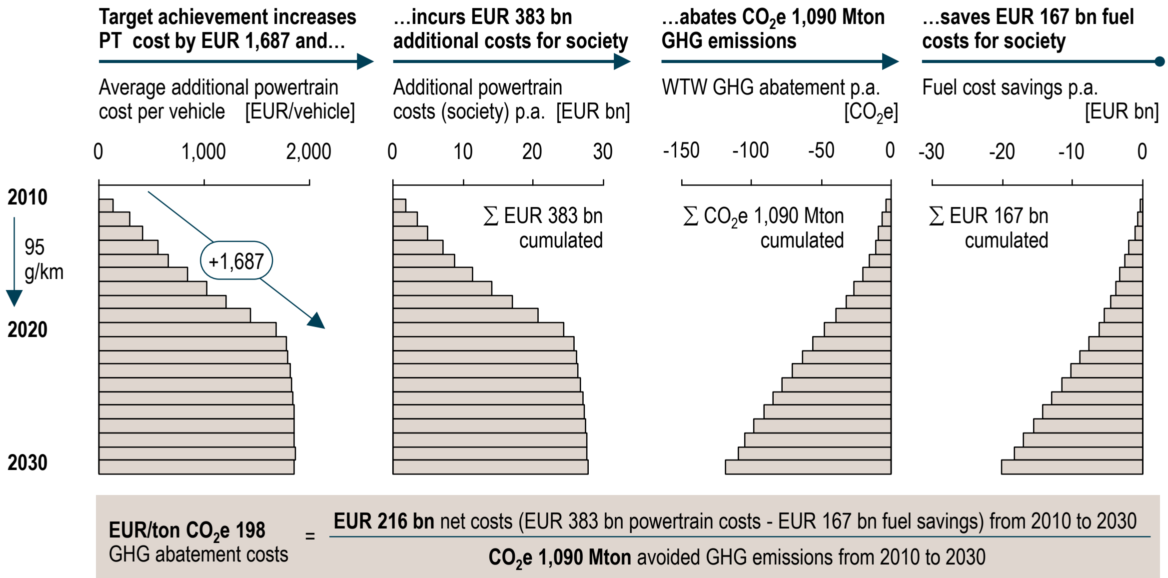
The benefits of these investments are a reduction in GHG emissions and cost savings for society as a whole. These benefits are to be expected primarily over the longer term until 2030:

> GHG abatement of approximately 1,090 Mton CO_2 over the same period

> Fuel cost savings between EUR 170bn (scenario A) and EUR 220bn (scenario B) (refer to figure 41 appendix 6.7)

The study reveals that the average abatement cost in the auto industry will be approximately 200 EUR/ton CO_2 in scenario A and approximately 150 EUR/ton CO_2 in scenario B[28] until 2030.

Figure 41: Effect of current regulatory framework (95 gCO_2/km target) for GHG abatement until 2030 (Low oil price)



Source: Roland Berger

3.5 Highly efficient powertrain technologies have significant impact on tax revenues

The reduction in fuel consumption brought about by energy efficient powertrain technology will result in a drop in EU28 fuel excise and value added tax revenue (VAT) of EUR 192-200bn per annum[29].

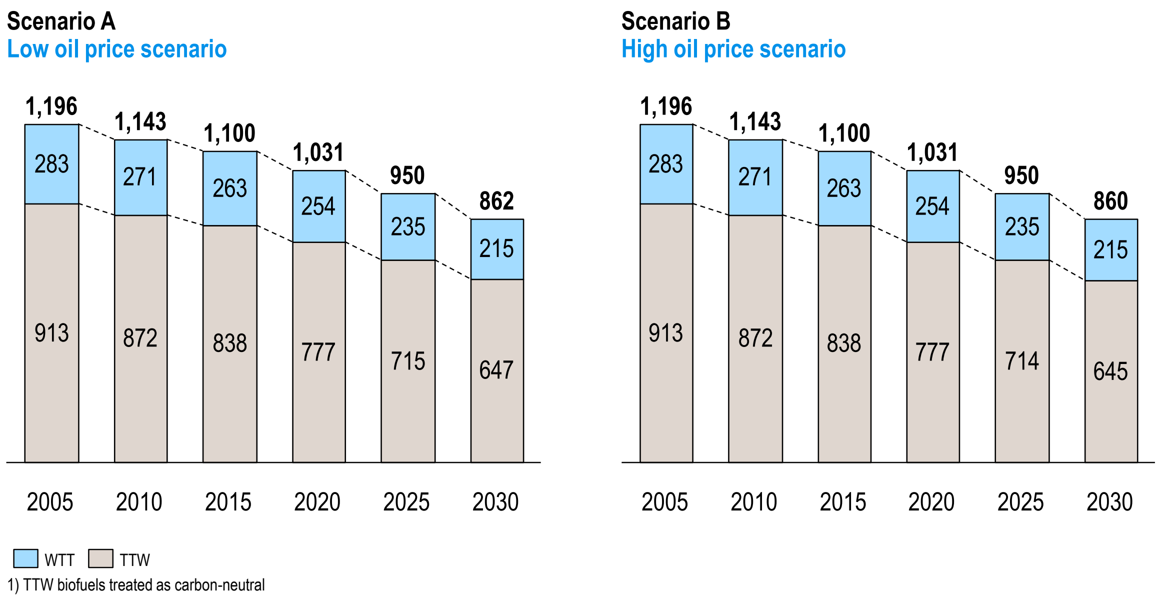
[28] refer to appendix 6.7 figure 92

This important side effect of more energy efficient powertrain technology will require compensating actions by EU member states to balance fiscal budgets. 1). The attrition of fiscal revenue comes at odds with the need to support alternative (and more costly) powertrains. This requires that a new system of road transport fiscal measures may be needed.

3.6 Limited impact of oil price on customers' acceptance of alternative powertrains

High oil prices excluding fiscal effects, will have limited impact on passenger car customers' acceptance of highly efficient alternative powertrains. Similarly, because of the time required to penetrate fleets and influence demand, the influence of high oil prices on overall emissions is equally limited by 2030.

Figure 42: EU 28 WTW emissions[30] road transport, 2005-2030 [Mton CO_2e]



Source: Roland Berger

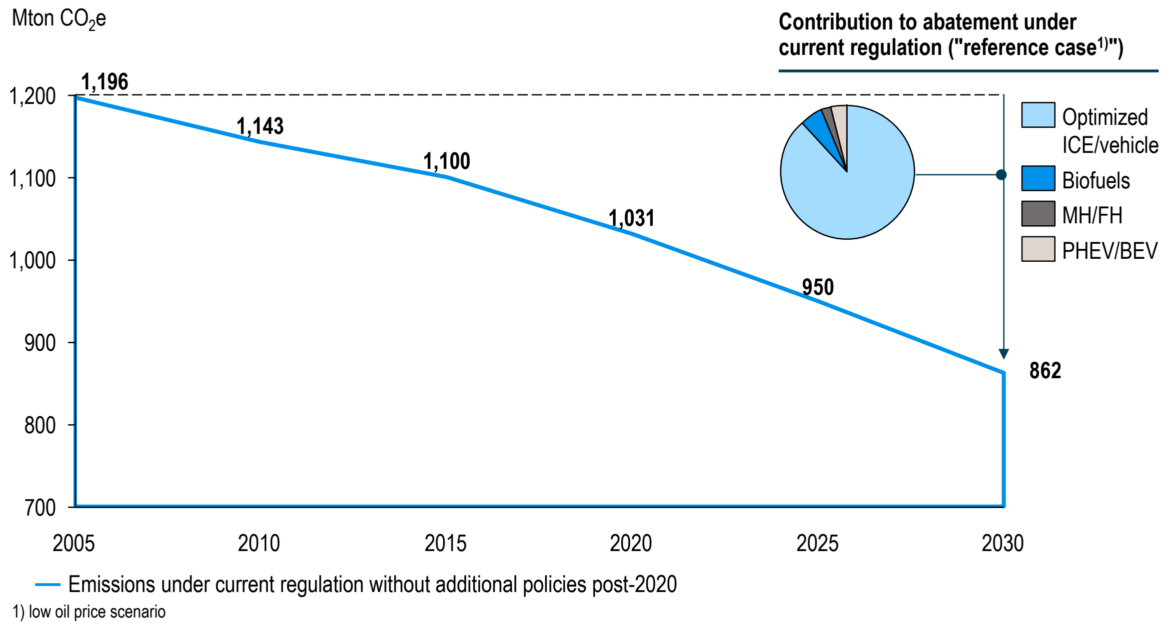
[29] Refer to chapter 3.2 for information about fuel taxation assumptions

[30] TTW biofuels treated as carbon-neutral

4. Additional potential for GHG abatement: 2030 and beyond

To meet the 2030 reduction target for the road transport sector (-30% compared to 2005), a number of further potential measures can reduce GHG emissions until 2030, in addition to those actions already contributing to GHG reductions in the current regulatory framework. Those additional abatement levers need to ensure the expected GHG emissions reduction until 2030 in a resilient way, so that efforts to reduce GHG emissions the by companies active in this sector are successful even if framework conditions change from today's expectations within the next 15 years.

Figure 43: WTW emissions from road transport sector 2005-2030, EU 28 [Mton CO_2e]



Source: Roland Berger

Low GHG abatement cost for society is the primary reason for prioritizing the potential measures, assuming that technology is available and general social acceptance present. Therefore GHG abatement costs of defined vehicle technologies and proportion of biofuel usage are compared for each powertrain type and vehicle segment and assessed individually.

4.1 Biofuels, mild and full hybrids for passenger car and new truck concepts offer an additional, cost-efficient reduction in GHG emissions until 2030

4.1.1 Passenger cars: Biofuels, mild and full hybrids offer cost-efficient GHG emissions abatement potential

Biofuel usage and hybrid vehicles (mild hybrids and gasoline full hybrids) have been identified as the most cost-efficient abatement measures for passenger vehicle available to society. These costs diminish with higher energy prices in both low- and high oil price scenarios. Highly efficient ICEs (Gasoline E5 and Diesel B7) served as the cost reference for the calculations.

Cost-efficiencies of GHG abatement powertrain technologies are calculated assuming a 250,000 km lifetime mileage for all technologies. Without statistically significant experience for technologies such as BEVs and FCVs for such lifetime mileage, this assumed lifetime mileage is positioned at the upper-end of the scenarios discussed and needs to be proven by OEMs. Consequently, low carbon emission powertrains with higher investment costs are given some benefits compared to conventional powertrain technologies with lower costs. Cost calculations are based on profited manufacturing costs as defined in section 3.2 and do not necessarily reflect consumer-prices.

In the accompanying diagram (figure 44, 45, 46), bars of varying length represent variable costs from a range of oil-price scenarios (the bottom side representing minimum costs with high oil prices and vice versa) with fuel costs reflecting production, distribution and retailing costs, excluding taxes. From a technological perspective, FHs and PHEVs are analyzed twice, optimized once for low CO_2 emissions at lowest cost and once with performance-oriented specifications. BEVs designed for short range applications[31] are differentiated from those with higher battery capacities[32] that could be used as a longer-range alternative to conventionally powered vehicles.

An uptake of higher ethanol blends for gasoline (E10 to E20) and HVO for diesel are very competitive with costs under 200 EUR per ton CO_2e abated. Mild hybrids (MH) with gasoline are even more cost-efficient with GHG abatement costs ranging from 10 EUR to 70 EUR per ton CO_2e for a C-segment vehicle.

Gasoline full hybrids (FHs) and diesel MHs are the 2nd most cost-competitive abatement alternatives on the vehicle side with FHs generating most interest primarily in high oil price scenarios. Diesel-based FHs are not cost-efficient with GHG abatement costs of more than 210 EUR per ton CO_2e because of their lower potential for efficiency improvement and fuel consumption costs.

At zero emission electric vehicles (BEVs and FCVs), only BEVs equipped with small batteries suitable for short range driving profiles represent a cost-efficient solution to further reduce greenhouse gas emissions until 2030: GHG abatement costs for short-range BEV[31] vary between 215 EUR and 350 EUR per ton CO_2e), while those costs for long-range BEV[32] range from 475 EUR to 750 EUR per ton CO_2e. (Refer to figure 44 and to appendix 6.8) BEV lifetime mileage of 250,000 km is bearing some risks regarding an equivalent battery lifetime hence the risks of higher abatement costs if a change of battery is needed during BEV lifetime.

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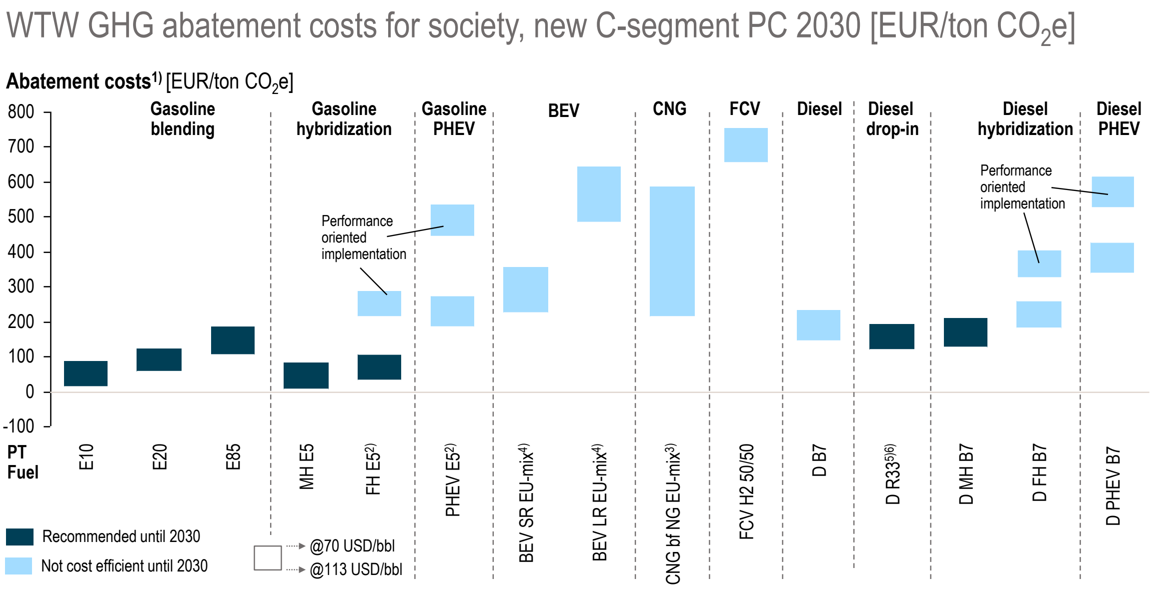
[31] Short-range BEV offer > 200 km driving range resulting in a gross battery capacity of 35 kWh.

[32] Long-range BEV offer approx. 400 km driving range resulting in a gross battery capacity of 65 kWh.

Figure 44: GHG abatement costs C-segment passenger car 2030 (WTW) [EUR/ton CO_2e]



1) Compared to optimized Gasoline powertrain 2030 using E5, all technologies with 250,000 km lifetime mileage 2) 30% e-driving, higher e-driving share reduces abatement costs
3) Large range between scenarios driven by decoupling effect of natural gas price 4) Risk of higher abatement costs due to need of second battery over lifetime,
SR – short range with 35 kWh battery capacity, LR – long range with 65 kWh battery capacity, both using 2030 EU mix electricity, 5) Diesel fuel with 7% FAME and 26% HVO
6) Abatement cost in existing vehicle: -67 EUR/ton CO_2 (high oil price), 7 EUR/ton CO_2 (low oil price)

Source: Roland Berger

4.1.2 Commercial vehicles: Biofuels and new truck concepts offer cost-efficient GHG emissions abatement potential

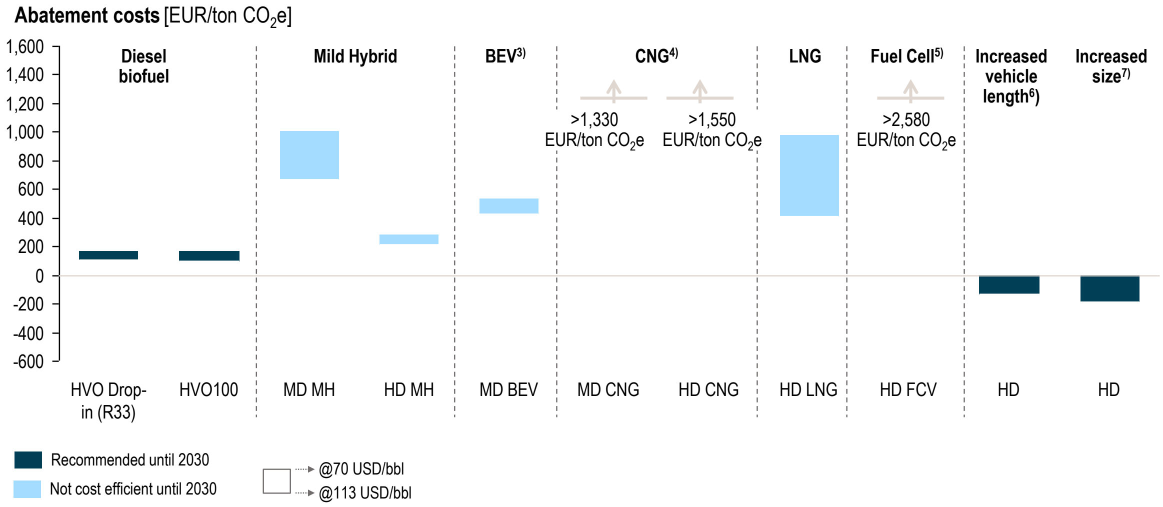
In the reference case for commercial vehicles (LCV, MD and HD) cost efficient GHG reduction via powertrain technology is already leveraged by high annual mileages in a large share of use cases for these vehicles.

Further highly cost-efficient GHG abatement in CV segments is possible through higher uptake of drop-in advanced biofuels for diesel with cost for society remaining in a similar range as for passenger cars.

Additional potential for further GHG abatement is offered by new highly efficient truck concepts that also reduce transport costs: Heavy-duty truck concepts could leverage the efficiency advantages of higher payloads by larger gross vehicle weight and aerodynamic efficiency advantages of greater maximum vehicle length.

By contrast, alternative powertrain technologies - such as hybridization - would cause high abatement costs for society: Compared to similar measures in the passenger vehicle segment, hybridization comes with high adaptation costs redeemed by a relatively small number of CVs produced. This also applies to fuel cell vehicles in CV segments in the time frame until 2030. As long as these cost issues are not resolved, the additional challenges of fuel cell technologies (e.g. lower system energy density) are less relevant. LNG is the next cost effective option for HD, though the higher abatement costs (400-900 EUR/ton CO2) could only be justified thanks to the Air Quality benefits of LNG. (Refer to figure 45 and 46).

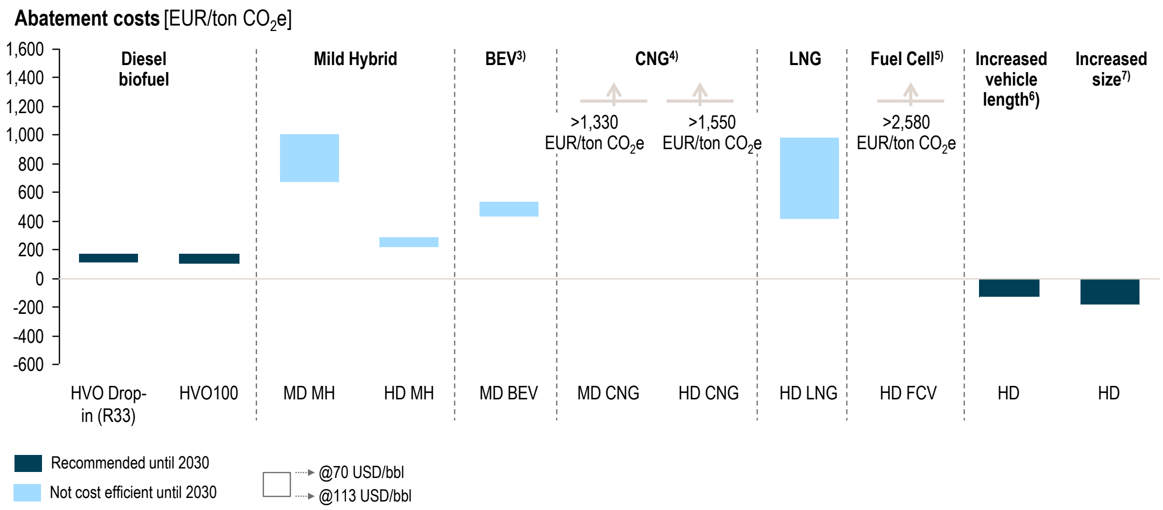
Figure 45: GHG abatement costs of light-commercial vehicles 2030 [EUR/ton CO_2e]



1) Medium duty 2) Heavy duty 3) Exclusion of HD BEV due to incompatibility of BEV range with long haul requirements 4) High CO_2 abatement costs for CNG and LNG within MD/HD/City Bus s result from low quantities of vehicles (missing economies of scale) and CO_2 abatement potential compared to Diesel is small (<5% savings/km) 5) High system cost and low lifetime mileage in medium duty trucks causes very high abatement cost , therefore incompatibility 6) Increased efficiency due to aerodynamic measures to reduce drag 7) Length and gross vehicle weight increase, increased transport efficiency by 10%

Source: Roland Berger, Expert interviews, IKA CO_2 study

Figure 46: WTW GHG abatement costs of MD and HD commercial vehicle 2030 [EUR/ton CO2e]



1) Medium duty 2) Heavy duty 3) Exclusion of HD BEV due to incompatibility of BEV range with long haul requirements 4) High CO_2 abatement costs for CNG and LNG within MD/HD/City Bus s result from low quantities of vehicles (missing economies of scale) and CO_2 abatement potential compared to Diesel is small (<5% savings/km) 5) High system cost and low lifetime mileage in medium duty trucks causes very high abatement cost , therefore incompatibility 6) Increased efficiency due to aerodynamic measures to reduce drag 7) Length and gross vehicle weight increase, increased transport efficiency by 10%

Source: Roland Berger, Expert interviews, IKA CO_2 study

In summary: Cost-efficiencies of GHG abatement fuel technologies and powertrain technologies are calculated for passenger cars and commercial vehicles based on two oil price scenarios as well as different implementation and application scenarios for FHs, PHEVs and BEVs as well as FCV.

Gasoline MH and higher ethanol blends (gasoline) and HVO (diesel) are observed to be the most cost competitive technologies for passenger cars, followed by gasoline full hybrids (FHs) and diesel MHs. PHEVs, BEVs and FCVs do not represent cost-efficient solutions until 2030, except for short range use cases (with smaller battery packages). Higher uptake of drop-in advanced biofuels for diesel and increased payloads could facilitate additional cost-efficient GHG abatement in the commercial vehicle segment.

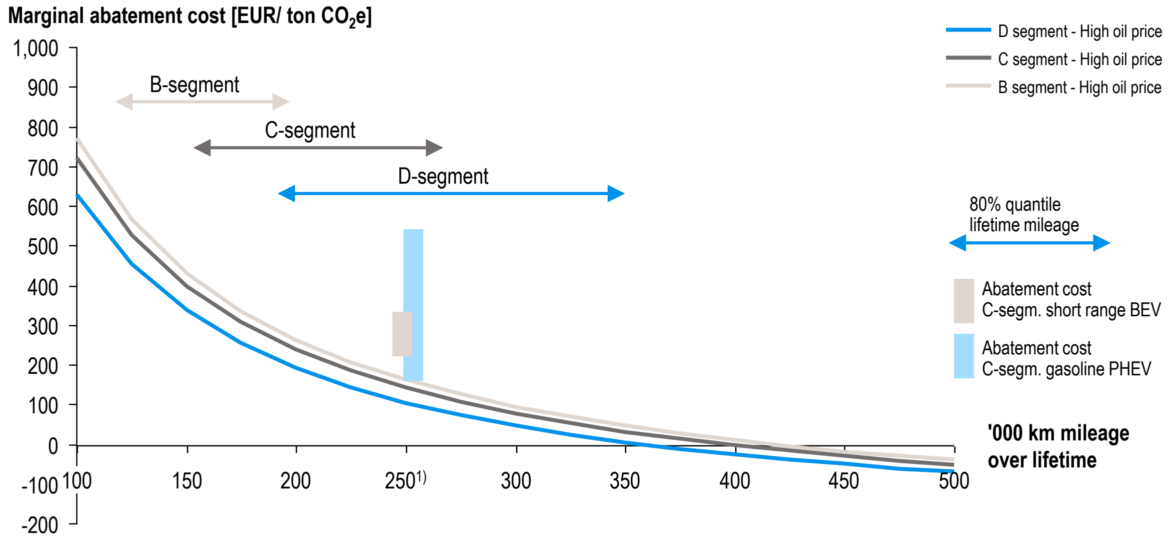
Applying the principle of lowest abatement cost for society, future regulatory frameworks need to be introduced to support these technologies until 2030. Such a framework also has to ensure a path to low and zero carbon emission technologies at lowest possible costs for society beyond 2030.

4.2 Leveraging potential of improved diesel powertrains until 2030

Improved high-pressure injection systems, variable valve trains and other technologies contributing to better diesel combustion will ensure diesel engines' efficiency and CO_2 emission advantages until 2030. This makes optimized diesel powertrains in upper vehicle segments (D segment and above) with high mileages (more than 250,000 km lifetime mileage is common) a cost-efficient GHG abatement technology (refer to figure 47). But in the upper vehicle segments, cost-efficient additional potential is limited due to the already high levels of diesel penetration.

Emissions from diesel vehicles have been the subject of recent regulatory investigations. While the non-GHG vehicle emissions have been decreasing, the rate of decrease has been slower than desired due to the time required for vehicle turnover to Euro 6 vehicles. More stringent criteria for pollutant emissions regulations (beyond measures resulting from Euro 6 and future RDE compliance) however, would result in even higher vehicle costs. Also a significant reduction of the price-advantage of diesel fuels compared to gasoline or introduction of city access limitations for diesels could reduce their customer appeal. This would result in a reduced proportion, both of new diesels coming into the market and those over time in the fleet.

Figure 47: GHG abatement costs of diesel passenger cars 2030 [EUR/ton CO_2e



1) Assumptions for previous abatement costs calculation
High oil price scenario: 113 USD/bbl

Source: Roland Berger

4.3 Beyond 2030: the 2050 GHG emissions reduction challenge

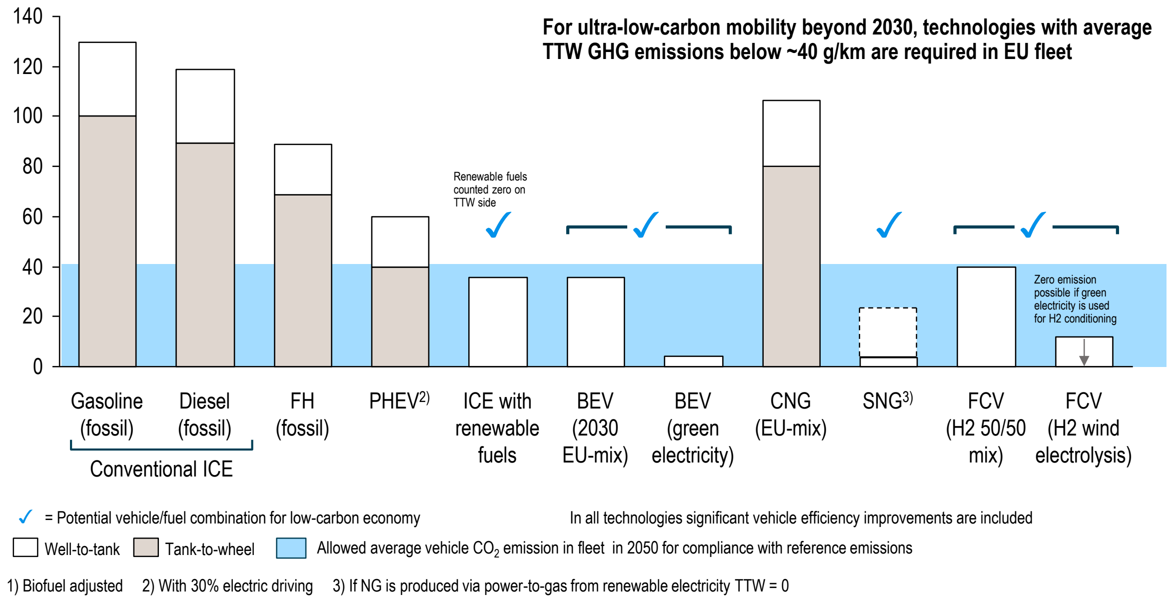
For a “low-carbon economy” beyond 2030, GHG emissions below ~40 gCO_2/km are considered for passenger cars as the defining threshold. Calculation is based on a 2050 road transport sectors target of a 60% reduction of 1990's CO_2 emission announced in the 2011 EC White Paper as well as the assumed fleet size and annual mileage introduced in chapter 2.3.

The analysis of well-to-wheel efficiencies of various technologies demonstrates the limits of the conventional ICE in contributing to a low-carbon economy. Only technology and fuel combinations based on renewables[33] will facilitate the development of "ultra-low-carbon” mobility and “zero-carbon emission” vehicles. These are:

1. Highly-efficient ICEs fuelled with advanced biofuels and bio-gases
2. PHEVs fuelled with advanced biofuels and renewable electricity
3. BEVs powered by expected 2030 EU energy mix (44% renewable energy) or renewable electricity
4. FCVs fuelled with hydrogen from 50/50 mix or with 100% renewable hydrogen

[33] Other GHG emissions free energy sources are also conceivable like nuclear, fossil with CCS, hydrogen via NG SMR and CCS. For a summary of vehicle technology and fuel combination please refer to the appendix (refer to appendix 6.6)

Figure 48: WTW GHG efficiencies by technology[1], average C-segment vehicle 2030 [g/km]



Source: JEC, Roland Berger

Commercial vehicles will likely rely on liquid or compressed fuels (including CNG, LNG and more biofuels) in the long-term even with further efficiency improvements. Additionally fuel cell powertrains are also a long-term powertrain option for long-haul, which would require significant technological and cost improvements however. CVs require sufficient range and payloads that are impacted negatively by battery components and benefit from the high energy density of hydrocarbon-based fuels. Locally deployed, shorter range, commercial vehicles (for delivery services or in communal use) rely on these fuels to a lesser degree.

5. Regulatory framework and policy recommendation

5.1 Regulatory framework – Integrating biofuels and hybrids

Approaching 2030 GHG reduction challenge with existing policy measures

The reference scenario model (refer to figure 49) has shown that continuing existing vehicle efficiency targets (passenger car and light commercial vehicles) and the transport RED targets with no additional changes as well as the provisions within DAFI/AFID will deliver a 25% reduction of total road transport GHG emissions of 862 Mton CO_2e by 2030 (refer to figure 49). In this reference case, the overall GHG emissions reduction corresponds to a 29% reduction in WTW emissions in 2030 compared to 2005 levels. This includes a reduction of 26% in TTW as well as a 30% in WTT emissions.

On the vehicle side, the current regulatory framework accelerates the implementation of fuel-saving measures thus optimizing conventional ICE powertrains (gasoline and diesel) along with road load reduction measures in the vehicle (i.e. weight reduction, improved aerodynamics, low rolling resistance tires). Optimizing conventional combustion engine technologies and systems will include start/stop, thermal management, as well as downsizing or selective cylinder shut-off in order to reduce friction loses. Additionally, efficiency-optimized transmissions with a greater number of gears and wider gear ratios that are at the same time efficiency optimized will become standard. These measures squeeze out the remaining efficiency improvement potential in conventional ICE powertrains at a reasonable incremental cost. They account for a ~90 % of the annual GHG reduction that totals ~300 Mton CO_2e (2010 to 2030).

Further potential for cost efficient GHG abatement until 2030 exists, but depends on adjusted policy frameworks since the reference case already includes expected changes in technology, energy and fuel prices as well as customer behavior.

Compliance with aspired GHG emission reduction until 2030 with additional policy support

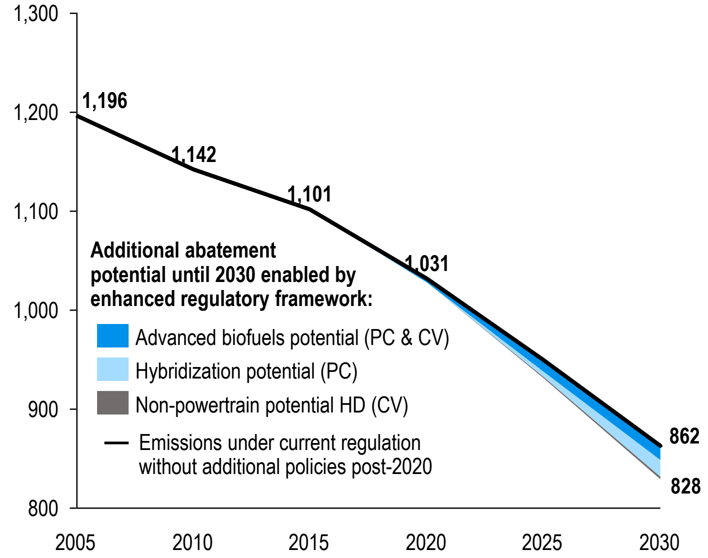
The cost abatement analysis (refer to figure 47) identified the existence of further potential for cost efficient GHG abatement until 2030. This could potentially enable achievement of the GHG emissions reduction ambition. However it will require adjusting policy frameworks and thereby cause changes in technology, energy and fuel prices as well as customer behavior.

Figure 49 demonstrates the greater market penetration of MHs and gasoline FHs (18 Mton CO_2e) as well as the usage of fuels containing a high proportion of advanced biofuels (15 Mton CO_2e) (refer to Infobox). Commercial vehicles can provide additional GHG abatement through increasing gross vehicle weights (increased payloads) and aerodynamically more efficient trucks. These technologies provide society as a whole with cost-efficient GHG abatement.

Efforts to push these technologies by vehicle manufacturers and fuel suppliers need to be complemented by a stronger customers' market-pull. However, the existing regulatory framework is not capable of achieving the full market potential of these technologies.

The GHG emissions reduction aspiration can only be achieved if there is a strong and long-term customer's market-pull to complement investments and the push of these technologies by vehicle manufacturers and fuel suppliers. The existing regulatory framework is not capable of achieving the full market potential of these technologies as it does not address vehicles, fuel and customers in an integrated manner.

Figure 49: WTW emission from road transport sector with integrated roadmap implemented 2005-2030, EU 28 [Mton CO_2e]



> Under **current regulation**, the transport sector will significantly reduce GHG emissions to 862 Mton CO_2e
> Additional measures (biofuels, HEVs, new truck concepts) allow **additional reduction** to 828 Mton CO_2e
> **Advanced biofuel measures**
  – **Full** coverage of **E10**[1)]
  – Introduce **E20** on fuel and vehicle[2)]
  – Increase **HVO drop-in** share[3)]
> **Hybridization**
  – Increase **MH** uptake in new passenger car sales (assuming **~40%** sales share in new car sales 2030)
  – Increase **FH** uptake in new passenger car sales (assuming **~20%** sales share in new car sales 2030)
> **Non-powertrain measures for HD CV**
  – increased vehicle length/weight (assuming 5% share in new truck sales 2030)

1) In reference case a 36% E10 coverage is assumed 2) Assuming full E20 compatibility from MY 2025 onwards, 7% cap for conventional biofuel remains
3) In reference case full B7 coverage is assumed, assumed feedstock restriction 4% advanced HVO drop in ("R11")

Source: Roland Berger

A major contribution from technologies that are part of the solutions for the required GHG emission abatement beyond 2030 (i.e. BEVs and FCV) is not expected. But vehicle manufacturer and fuel suppliers need to drive performance improvements and cost reduction ensuring competitiveness and customer acceptance beyond 2030.

5.2 Regulatory framework - Integrating supply and demand to address obstacles of pathway technologies

Additional policies as part of the future EU regulatory framework need to address obstacles standing in the way of cost efficient GHG abatement technologies to allow further penetration of the market. This can be achieved best by integrated demand and supply-side policy measures at EU level and by proposals to member states.

These integrated policies are required in addition to the existing policies, which are addressing both CO_2 emission targets for newly registered vehicles and conventional biofuel mandates. A further strengthening of those targets based on the current regulatory framework would generate high costs for society. These would result by pushing technologies to market before they are cost-efficient with respect to GHG abatement or by not ensuring the leverage of the full potential of a technology. For example:

> PHEV are a cost-efficient option compared to penalties in OEMs' compliance strategies for new vehicle CO_2 emission targets leading to an increase of the proportion of PHEV in new car sales. However, as seen previously (refer to figure 44) an increasing penetration of PHEV among new car sales will not lead to cost-efficient GHG abatement until 2030.

> The reinforcement mechanism for current biofuel blending mandates, e.g. penalties for non-compliance in RED and FQD, does not ensure full leverage of biofuel abatement as the GHG abatement potential depends on the manner in which member states transpose EU directives into national legislation and defines the required reinforcement mechanisms.

The key obstacles that need to be addressed to allow greater penetration of biofuels and hybrids are summarized in Figure 50. Policies are needed to address obstacles to cost-efficient GHG abatement technologies in order to secure their increased acceptance and uptake of identified pathway technologies. The pathway technologies identified as part of the Integrated Roadmap to 2030 include:

> More advanced biofuels

> More hybrid vehicles (MH and FH)

> More highly efficient trucks with higher gross vehicle weight allowing for increased payload and better aerodynamics from an extended vehicle length[34]

The obstacles to each of these pathway technologies are discussed below:

5.2.1 Higher proportion of advanced biofuels in market fuels

One of the main obstacles preventing a higher proportion of advanced biofuels in the future is the lack of pricing-signal and demand-stability enabling industry to justify the high capital required investments with long-term amortization. A second obstacle is the lack of cost competitiveness for biofuels from first-of-a-kind plants compared to conventional fuels and conventional biofuels. This cost disadvantage for biofuels from new technology plants needs to be removed so that they are competitive along the entire value chain from production to customer. Current technology hurdles will also need to be overcome. Furthermore incompatibility of vehicles to fuels with a higher proportion of biofuels due to a lack of standards is another obstacle to be addressed by regulations to guarantee market acceptance in the future. Finally, the customer needs to be educated about the advantages of using advanced biofuels regarding GHG emissions.

5.2.2 Hybrid vehicles (MH/FH)

The second pathway technology reducing GHG emissions is vehicle powertrain hybridisation. Although already available in many markets, the following have been identified as major obstacles hampering increased customer acceptance of hybrid vehicles:

Increased customer awareness and knowledge (i.e. cost implications) are required for the acceptance of MH and FH technologies and their benefits. An even greater obstacle to this acceptance is the lack of cost competitiveness (TCO) of MH or FH vehicles in particular when the price of oil is low. As petrol-engined vehicles usually have a lower annual mileage, cost competitiveness for MH or FH is challenging due to the low total lifetime fuel consumption. However, customers with a high annual mileage tend to choose diesel-engined vehicles leaving MHs and FHs having to compete with very high combustion efficiencies and diesel fuel price advantages. Hence, making additional efforts to reduce GHG emissions further by using more highly efficient technologies in combination with a base of addressable operation costs, which is already limited, is in general, a challenge for all highly efficient, conventional powertrains. Thereof an acceptable payback time for consumers is often not provided, especially under all oil price scenarios

[34] All cost-efficient potentials for conventional powertrain are leveraged in the reference case.

5.2.3 Enhanced efficiency in commercial vehicle operations

Highly efficient trucks and improved commercial vehicle operations have been identified as the third pathway technology for future GHG abatement:

By increasing vehicle length and payloads as well as improving aerodynamics, highly efficient commercial vehicles could lower GHG abatement costs and in some cases even generate negative GHG abatement costs. Nevertheless, the lack of a regulatory framework for such heavier and longer trucks is a major obstacle preventing achievement of their potential to reduce GHG emissions in the transport sector. Also, the lack of any regulatory framework for highly automated, autonomously driving trucks and of TCO benefits from higher registration costs, poses an obstacle to furthering their efficiency.

Figure 50: Overview of key obstacles of pathway technologies: high biofuels share fuels, MHs/FHs and new truck concepts

Fuel with high advanced biofuel share	MHs and FHs for passenger vehicle	Highly efficient truck concepts
Remaining uncertainty regarding **sustainable demand** (price and volume)	**High purchasing cost**[1] for customers and lack of **TCO benefits**	
Cost competitiveness vs. conventional fuels (in all scenarios)		
Technology hurdles for advanced generation		
Uncertain **vehicle compatibility/lack of fuel standards**		Regulatory limitation of **vehicle length and weight**
Lack of customer **technology awareness and knowledge**	Lack of customer **technology awareness and knowledge**	

1) incl. other registration cost (e.g. purchasing taxes)

Source: Roland Berger

5.3 Recommended policies – To meet the 2030 GHG emissions reduction challenge

For the period 2021-2030, it is assumed that the 2020 regulatory framework will (for the most part) still be in place as it will continue to act as a point of reference regarding GHG emissions reductions until 2030. In particular for vehicles, this includes continuing the new vehicle 95 gCO_2/km target (147gCO_2/km target for LCV). For fuels, the 10% RED requirement should be continued as it has yet to demonstrate its full abatement potential related to biofuels. FQD7a should be discontinued as biofuel benefits can be achieved through RED targets alone.

The structure of this integrated roadmap including corresponding technologies and policy framework is shown in figure 51.

Figure 51: Approach for development of integrated roadmap – Illustrative

	Main contributing technologies (= Pathway technologies)	Enabling policy framework
GHG abatement in reference case until 2030	> **Optimized ICE/vehicle** > Biofuels > Hybrids > PHEV/BEVs	Current policy framework prolonged until 2030
Additional cost efficient GHG abatement unit 2030 (ensuring compliance with reference value)	Cost efficient abatement technologies: > Biofuels > Hybridization > Efficient trucks	Additional **policies addressing obstacles** of cost efficient technologies
Prepare readiness of ultra low carbon emission technologies for GHG abatement beyond 2030	> ICEs with **advanced biofuels** > PHEVs **advanced biofuels and renewable electricity** > **BEVs** > **FCVs**	Support of technologies in R&D and market ramp-up

Integrated roadmap

Source: Roland Berger

However, to address the obstacles discussed in Section 5.2, new policies are also recommended to support a higher proportion of advanced biofuels, the increasing penetration of MHs and gasoline FHs, as well as highly efficient trucks. These policies, summarized in figure 52, include:

> Financial instruments

> Regulations

> Customer education

Financial instruments should provide taxation benefits for fuel with a high proportion of advanced biofuels and also encompass the introduction of CO_2 based vehicle taxation (e.g. registration taxes and/or annual taxes) as recommendations to EU member states. While keeping in mind that a common European taxation system is rather difficult to implement, the recommendation's advantages of an equal EU wide taxation with respect to increasing harmonization of fuel taxation favours implementation.

Regulation and liabilities for future policies should address fuel and vehicle compatibility (e.g. with E20) and ensure that biofuel TTW CO_2 emissions are not accounted for in total TTW CO_2 emissions. For highly efficient trucks, future regulations should be adjusted for heavy-duty commercial vehicles with greater length and higher gross vehicle weights thus allowing increased payloads. Furthermore, while new operating concepts such as platooning or optimized logistic concepts have considerable abatement potential, they remain as yet unqualified in this study.

Customer awareness of the benefits being offered by biofuels and MH/FH needs to be raised. Customer education could be achieved by the introduction of CO_2 labelling for fuels and more transparent fuel taxation at the point of sale (e.g. gas stations). Member states should also introduce transparent cost- and TCO-labelling of vehicles, highlighting the advantages of hybrid vehicles.

Figure 52: Policy recommendation to member states until 2030

	Fuel with high biofuel share	MHs/FHs power-trains for PC	Highly efficient trucks
	Existing supportive policies at fuel supply side (e.g. transport RED targets, provision within DAFI/AFID) and vehicle side **kept unaltered**		
Additional financial instruments	> Introduce **additional fuel taxation components** enabling a price advantage for fuels with high advanced biofuel share, e.g. – Biofuel bonus/malus + CO_2 component – Biofuel tax exemption + CO_2 component > Support the use the Innovation Fund for invest-ments in innovations in low carbon technologies	> **Change existing vehicle taxation towards a CO_2 based taxation**, e.g. – CO_2 based vehicle registration tax – CO_2 based annual vehicle tax – CO_2 based vehicle usage tax	
Additional regulation/ liabilities	> Set **tailpipe emission to zero** for the renewable part of the fuel that the vehicle is compatible with, above 2020 levels – define reference fuels accordingly		> Adjustments in truck **length and weight regulation**
Additional other policies	> Introduce **CO_2 labeling for fuels** > Offer/support "**customer education**" for biofuels > Make fuel **taxation transparent** to customer (e.g. at gas station)	> Introduce **cost/TCO labeling** for vehicles	

Taxation as powerful financial instrument is in responsibility of member states, additional regulation and liabilities can be introduced on EU level

Source: Roland Berger

5.3.1 Recommended policies for biofuels – Integrated approach providing incentives for customers, vehicle manufacturers and fuel suppliers

Policies enabling increasing usage of new market fuels with a higher advanced biofuel proportion need to address the obstacles of fuel suppliers, vehicle manufacturers and end-customers in an integrated approach (refer to figure 48). Furthermore, these policies also need to implement current regulation objectives for biofuel usage in road transport fuels on an extended basis as current policies do not leverage biofuels' full abatement potential.

Vehicle manufacturers

Based on the roadmap developed, vehicle manufacturers can contribute to GHG abatement by ensuring vehicle compatibility with higher advanced biofuels blended fuels for as long as specific requirements concerning specifications for engines and powertrains exist.

To further encourage OEMs to increase vehicle compatibility to biofuels it may be possible to set tailpipe emission to zero for the renewable part of the fuel that the vehicle is compatible with, above 2020 levels. In addition, reference fuels need to be defined accordingly.

Fuel suppliers

Low-Carbon fuel producers and suppliers require long term stable market conditions in terms of volume demand as well as prices to enable long term investment certainty to develop alternative fuels. Attractive pricing and dependable demand are the pre-requisites for significant long-term investment in additional production capacity for advanced biofuels.

To accelerate the ramp-up of production and availability of advanced biofuels and blending, additional investment and research support would allow fuel suppliers to resolve the remaining technical hurdles in a timeframe, which is even shorter. Another factor to be considered is the existing taxation regime of diesel fuels, sustainability criteria for biofuels and support of blends as opposed to pure biofuels, enabling a faster and strong market penetration of biofuels. Therefore, support for use of the Innovation Fund for investments in innovations in low carbon technologies. The Innovation Fund should be used to fund capex and opex for initial advanced biofuel plants (fuel supplier/biofuel producers).

Customers

For the end-customer, a distinct pricing signal is required to support their choice of biofuels (such as E20 or R33) at the point of sale, the gas station. Increased customer acceptance for market fuels with higher biofuel shares would not only allow new car buyers to contribute to lowering GHG emissions, but also car owners in general.

Hence, a long-term strategy for defining new fuel grades (standards, certification of fuels, etc.) is the central issue thus guaranteeing planning security for all stakeholders – vehicle manufacturers, fuel suppliers and customers.

Due to the relatively low GHG abatement costs of diesel (refer to figure 47), the taxation system should ensure that the relative price advantage of diesel versus gasoline fuel (which is the case in most member states,) is not changed significantly. If this advantage were to be eliminated, it is highly likely that in addition to the assumed shift in the reference case, even more customers would favour gasoline engines. To achieve equivalent GHG emissions reductions under this framework conditions would require other technologies to compensate for this. Based on the abatement cost calculations made for the study, these technologies would come at a much higher cost for the society.

Different policy options have been assessed with regard to both quantitative and qualitative criteria. To quantitatively compare the effect of the policies, the market fuels E5, B7 were assessed on price and taxation vis à vis E20 and R33 in the major European countries (Germany, France, United Kingdom, Spain and Italy) thereby covering a significant proportion of the European transport fuel market. (Refer to appendix 6.9)

As a result and aiming for EU-wide execution, the study concludes that the recommendation to integrate an additional taxation component as an "add-on" to existing fuel taxation is the preferred option. Thereby member states do not need to implement a completely new fuel taxation system, but need, at the same time, to send a single, strong price signal for end customers to buy low carbon fuels, (fuel with a higher proportion of advanced biofuels) without harming diesel sales. After considering all the possibilities for additional taxation components, two options were shortlisted for recommendation:

> A combination of a bonus/malus system depending on the biofuel share and CO_2-based taxation component for fuels or
> A combination of a tax exemption instrument for biofuel and a CO_2-based taxation component

Both combinations of taxation components have the advantage of compensating weaknesses present when introduced individually. These combinations are fully compatible with the long-term vision of the stronger application of market mechanisms on abatement of road transport GHG emissions to ensure that the fundamental principle of this study of lowest abatement costs to society is achieved.

INFOBOX – Taxation components

Bonus/Malus tax component – introduction of a taxation component that provides tax incentives for high biofuel proportions above a defined threshold and tax penalties for biofuel shares below the defined threshold

CO_2**-based tax component** – introduction of a taxation component within the fuel taxation system that is based on TTW CO_2 emissions in combination with reduced charges for 1st and advanced biofuels up to a cap

Biofuel tax exemption – exemption of taxation for advanced biofuels, up to a drop-in/blending limit

5.3.2 Recommended policies for hybrids - improving cost position and supporting customer awareness

Better acceptance and therefore a higher penetration of these pathway technologies (hybrid) among new vehicles could be achieved by two complementary measures:

> Recommending EU member states to employ a vehicle taxation system based on an intensified focus on CO_2 emission that is

> Accompanied by an expansion of current CO_2 labelling to include information about cost benefits and savings.

In this way and as with high biofuel content fuels, MHs' and gasoline FHs' main obstacles, namely the lack of cost competitiveness and customer knowledge, will be overcome.

MHs and gasoline FHs are at a disadvantage due to a higher purchase price compared to optimised gasoline- and diesel-engined vehicles. Most customers do not recoup these higher investments over the intended period of use (Total Cost of Ownership (TCO)). The TCO gap does not materially reduce over time because of declining system costs and the fact that ICE efficiency improvements are also lowering the addressable fuel cost base. Therefore, it is important to reduce the purchase price gap to ICE powertrains with help of a vehicle taxation system (incl. vehicle registration taxes and annual vehicle taxes) that reflects vehicle CO_2 emissions and, as such, provides cost benefits for highly efficient technologies as MHs and FHs. Raising fuel taxes for fuels with high carbon content can support this.

Additionally, the operating cost savings made possible by MHs and FHs need to be made very transparent to end-customers. One method would be to extend current vehicle efficiency labelling with additional information regarding cost savings compared to a defined reference vehicle over the vehicle's life-time or in relation to the overall purchasing costs. By so doing, the customer no longer focuses solely on the purchase price; rather they are encouraged to consider the overall costs and potential savings being offered by a highly efficient powertrain.

5.3.3 Recommended policies for commercial vehicles – enhancing efficiency

In order to leverage efficiency potentials of conventional trucks with higher payloads and better aerodynamic efficiency, regulatory adjustments will be required regarding maximum overall vehicle length and maximum gross vehicle weight.

5.3.4 Supporting transition to Alternative Energies – continuing existing regulatory framework to further promote low-emitting vehicles and zero-emitting vehicles

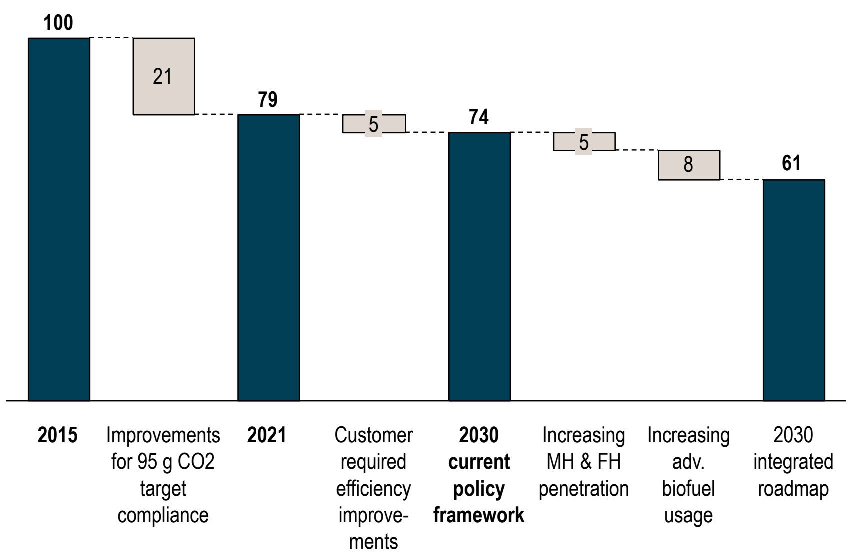
The effect of the current regulatory framework (FQD (excluding FQD7a), RED transport target of 10% energy, vehicle efficiency standards at 95 gCO_2/km and DAFI/AFID implemented) leading to the introduction of low-emitting vehicles and zero-emitting vehicles (PHEV, BEV, FCV) should be maintained in future policy considerations as these form one of the routes to zero carbon emission pathways.

5.3.5 Extended polices will provide for CO_2 emissions improvements in new vehicles

As shown in figure 53 the current regulatory framework to 2030 will result a CO_2 emission reduction of approx. 21% compared to 2015 level (approx. 120 gCO_2/km indexed as 100%) to be compliant with the 95 gCO_2/km target in 2021. The proposed policies - addressing obstacles to cost efficient abatement technologies via an integrated approach - together with existing policies will set conditions to reduce average CO_2 emissions of new vehicles by an additional 18% compared to 2015. The driving forces for this reduction are strong competition among vehicle manufacturers driving vehicle efficiency innovations and a stronger customer pull for low carbon emitting conventional powertrains (approx. 5% by 2030), MHs and FHs (approx. 5% by 2030)and low WTW carbon emitting fuels (approx. 8% by 2030).

This could be equivalent to GHG emissions of 72 gCO_2/km of new vehicles, but only if all measures become effective and if TTW GHG emissions of biofuels are discounted. Therefore new vehicles need to be compatible with higher biofuel-blends (e.g. full E20 compatibility). The required usage of biofuel is ensured by the integrated approach providing the necessary price signal to the customer, guaranteed vehicle compatibility and stable market support in the long term.

Figure 53: Average CO_2 emissions of new passenger cars with additional policies supporting biofuels and MH/FHs, EU 28, 2010-2030 [g/km]



- Integrated roadmap with higher MH and FH in new vehicle sales would reduce average new passenger cars CO_2 emissions by 31% until 2030 (**82 g/km**)
- A carbon-neutral consideration of biofuels in the tank-to-wheel emission from 2020 onwards would lead equivalent CO_2 emissions of 72 g CO_2/km in 2030, assuming full E20 compatibility for gasoline vehicles built in 2025 and beyond

Source: Roland Berger

5.4 Recommended policies – Transitioning to meet the 2050 GHG emissions reduction challenge

The way towards ultra-low carbon mobility requires an integrated approach to significantly improve vehicle efficiency and to drive the decarbonization of transport fuels including electricity and hydrogen. Policy frameworks that allow these developments should rely more heavily on market mechanisms, in order to allow low GHG abatement costs for society.

5.4.1 Decarbonization of road transport sector requires efforts by fuel/energy, vehicles, infrastructure and the customer

Electrified powertrain and electric-vehicle technologies are, together with biofuels, solutions for the long-term requirement of a decarbonized road transport sector. Furthermore Power-to-X and paraffinic fuels show distinct potential to further decarbonize fuel production (refer to appendix 6.6). To achieve a higher market penetration of xEV vehicles and a broader usage of biofuels, broad customer acceptance of these powertrain technologies and fuel types is required. Therefore three key criteria need to be fulfilled: Firstly, xEV should not be put at a significant disadvantage in terms of TCO or purchasing price compared to conventional powertrains for the majority of customers and their individual driving profiles. Secondly, customers need to perceive the technological advantages and thirdly, logistical infrastructure such as fuel supply or charging stations need to be established.

To enable the decarbonization of that sector, a future regulatory framework would need to aim for a higher penetration of zero carbon emission powertrains by

> Simultaneously improving the cost-competitiveness of ultra-low carbon fuels together with vehicle technologies

> Reducing investment risks for alternative fuel infrastructure including e-charging, hydrogen infrastructure, etc.

> Making alternative fuels (including electricity and hydrogen) GHG emission free

As future policies also need to address the promotion of higher shares of renewable energy and other GHG emission free energy sources, this recommendation reaches beyond the road transport sector. It would require efforts to integrate other sectors relevant for overall GHG emissions (e.g. energy).

5.4.2 Cost-effective decarbonization through stronger usage of market based mechanisms

In line with the long-term EU vision of a low-carbon society, it is necessary to develop instruments that drive progress towards cost-effective ultra-low-carbon mobility. It is widely agreed among economists, that the increasing usage of market based mechanisms is an effective long-term instrument to reduce GHG emissions at lowest possible GHG abatement costs.

Market based mechanisms could be used e.g. a cap and trade mechanism. A maximum is set on the total GHG emissions that can be emitted by all participants covered by the cap. The "permission" to emit GHG is then sold, via an auction or allocated for free. To ensure GHG abatement is achieved at lowest societal cost among all participants, the GHG emission rights can then be traded. Participants with emissions exceeding that permitted by their allowances must purchase GHG emissions rights from others. Conversely, a participant reducing GHG emissions can sell their leftover allowances; the overall level of emissions remains equal to the supply of allowances on the market. All participants must report their GHG emissions, ensuring they submit enough emissions allowances to the authorities.

Among the different implementation strategies available by customers, vehicle manufacturers (OEM) and fuel suppliers, levying the obligation on the fuel suppliers is the simplest administratively and the most cost-effective approach and therefore the most favorable alternative (refer to figure 54). Fuel suppliers would purchase emissions allowances for government auctions based on the CO_2-intensity of the fuel. The road transport market, like the power market, is not trade exposed and therefore does not face competitiveness issues, as a result fuel suppliers will be able to pass the CO2 costs to the consumer.

Alternative implementation strategies would have significant drawbacks. An implementation at the part of vehicle manufacturers would require the OEM to buy emissions allowances for each car based on individual CO_2-emissions – making it complex and exact emissions cannot be accounted for (only an average). Furthermore, customer behavior towards fuel consumption and fuel type would not be affected. Customer based implementation would see the consumer purchasing emissions rights, based on individual vehicle, mileage and resulting CO_2-emissions, creating extreme administrative overheads.

Figure 54: Overview implementation strategy for market based mechanisms

Regulated entity	Consumer	Car manufacturer	Fuel supplier
Billing	Reports annual mileage and purchases for allowances	Purchases allowances for sold vehicle units (assuming an average lifetime millage per vehicle and emissions)	Purchases allowances for fuel sold (passed on to consumer)
	EUR/p.a.	EUR/vehicle sold	EUR/liter sold
Implemen-tation difficulty	High	High	Low

Example for upstream implementation of market based mechanisms

ETS Filling Station
Main Street 111, 12345 New Town
Station no.: 000000000xyz
Station tax no.: 13/456/xyzxyz
Company tax no.: 01 234 56789
Receipt no. 1234/005/00001 03.03.2021 9:22
Card payment

Super 65.13 EUR A #
Pump 03 43.45 l 1.499 EUR/l #

EU ETS carbon credits 3.04 EUR C #*
* 43.45 l x 2.33 kg CO_2/l = 101.24 kg CO_2
* x 30.00 EUR/credit for 1,000 kg CO_2

Total 68.17 EUR

Type	Net	VAT	Gross
A: 19.00%	54.73	10.40	65.13
C: 0.00%	3.04	0.00	3.04

Thank you for your visit. Have a safe trip!

Source: European Commission, ZEW, ICCT, IW Köln, Roland Berger

To achieve the target of a cost-effective and transparent reduction in GHG emissions, the following design principles are recommended:

> Fuels suppliers should be the obligated party.
> All emissions allowances need to be purchased via government auction and can be traded.
> Only CO_2 emissions from the combustion of fuels should be included in the cap and based on average TTW emissions (CO_2/unit volume for gasoline and diesel).
> Biofuels should be accounted for as zero CO_2 TTW emissions and only those that meet agreed sustainability criteria be allowed for compliance.
> Funds from auctioning allowances for fuels should be used to provide time limited support for both the additional policies for advanced biofuels, hybrids or ultralow carbon technologies as well as R&D into these technologies.

Following these principles and implementing a cap and trade system would enable secondary market and a forward price curve to develop for the emissions permits. The forward curve provides a price signal for operators against which they can hedge their exposure for any given compliance year. Furthermore, a secondary market provides flexibility to business over when they can purchase compliance units depending on their cash flow, i.e credits can be purchased now for compliance at some point in the future. To fully achieve the full potential of these market based mechanisms, degree of market liquidity is required. Allowing third parties to access the compliance market provides cash flow and liquidity and improves the efficiency of the compliance instrument. Liquidity is an important feature of any functioning market; the greater the number of eligible buyers and sellers, the greater the ability of the market to accurately reflect the cost of complying with the emission target. Open participation also minimizes the risk that any one large entity will corner or otherwise manipulate the market.

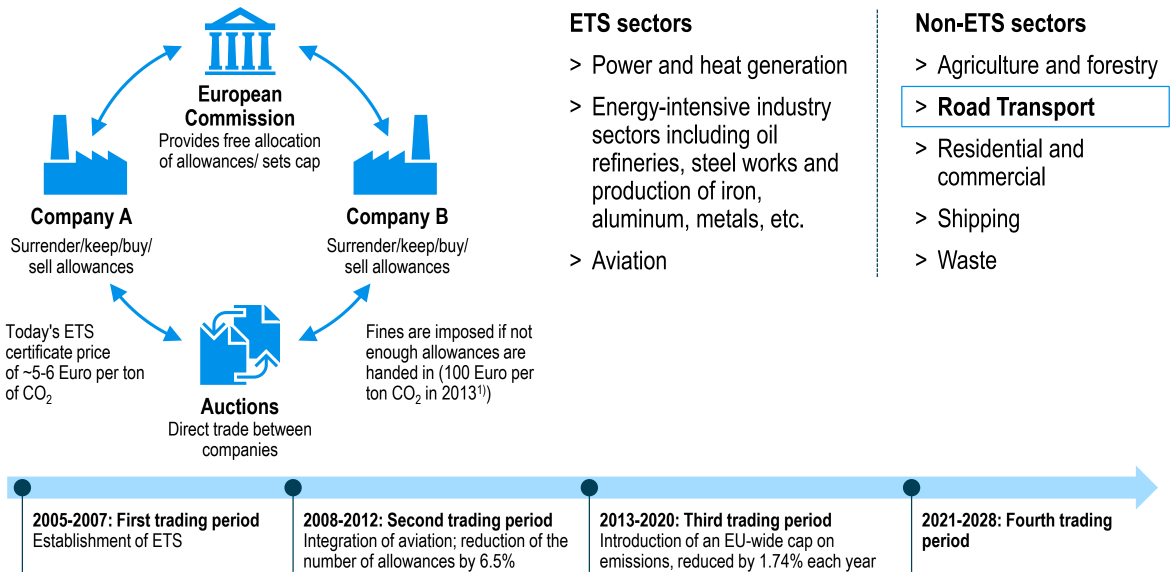
Complementary measures should be transitional in nature as society moves to increasing usage of market-based mechanisms on an economy-wide basis across Europe but ideally on a global basis.

INFOBOX – Emissions Trading System in the European Union

Certain sectors in the European Union have obligations under Emissions Trading System (ETS) which is a market based approach for reducing GHG emissions resulting in cost-effective abatement. It is the biggest international system for trading greenhouse gas emissions allowances and covers power stations, industrial plants and airlines in 31 countries. Sectors not covered by the ETS include agriculture and forestry, waste and road transport. The ETS works as a cap-and-trade system, where a limit (cap), is set on the total amount of greenhouse gases that can be emitted. Within the cap, companies receive or buy emissions allowances, which they can trade with one another as needed. If a company reduces its emissions, it can sell these carbon credits to participants that are short of credits. By putting a price on carbon – and thereby giving a financial value to each tons of emissions saved - ETS is a highly cost-efficient market-based system to reduce GHG emissions.

Economists agree that such market-based approaches to GHG emissions reduction are not only efficient, but also reduce administrative overheads. By coupling GHG emissions targets with monetary incentives, ETS stimulates participants into developing the most effective technologies at the lowest possible cost.

Figure 55: Example for usage of market based mechanisms in the European Union



1) The fine is adjusted according to inflation in the Euro zone

Source: European Commission, ZEW, Roland Berger

6. Appendix

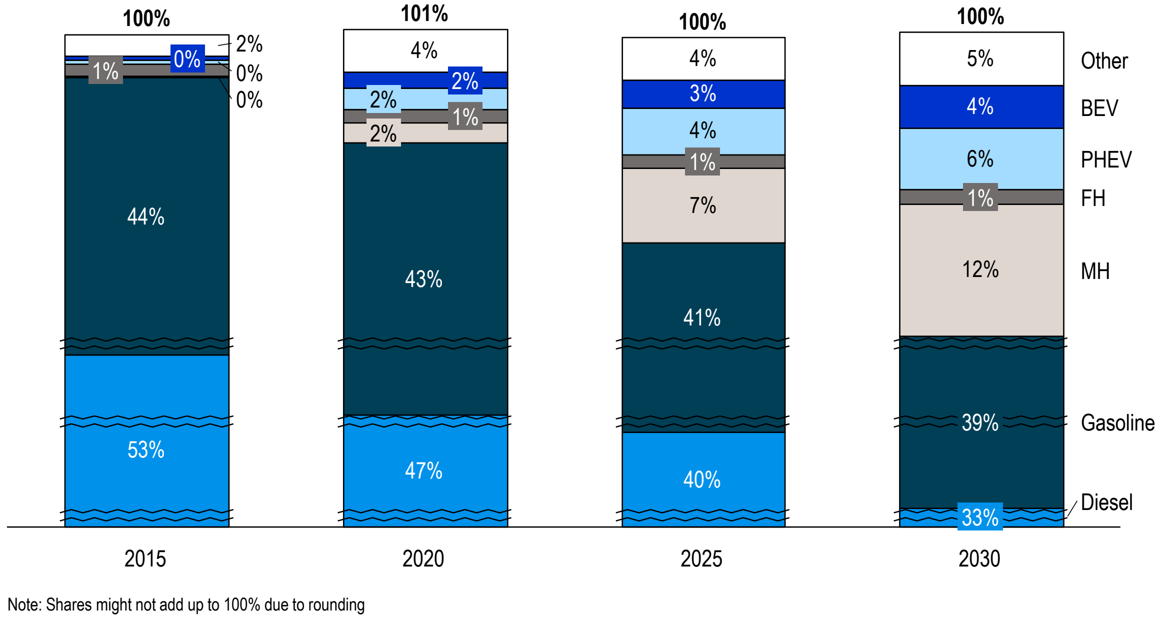
6.1 Tank-to-wheel GHG emission intensities

Figure 56: CO2 intensities fuels [g CO_2 per l/kg]

Conversion factors	
1l Gasoline	2.353 g CO2
1l Diesel	2.622 g CO2
1 kg CNG	2.750 g CO2
1l LPG	1.629 g CO2

Source: EMISIA SA, 2013 (Traccs study 2013)

Figure 57: Powertrain shares in new vehicle sales scenario B, 2015-2030 [%]



Source: Roland Berger

6.2 Well-to-tank GHG emission intensities

Well-to-tank greenhouse gas intensities and respective source according to figure 58, 59 and 60

Figure 58: WTT intensities used for major production processes [g CO_2e/MJ]

Basic fuel name	Resource	WTT GHG intensity	Source
Gasoline	Crude oil	20.0	JEC WTT 2014 (COG1) adjusted for ICCT upstream value
Diesel	Crude oil	21.7	JEC WTT 2014 (COD1) adjusted for ICCT upstream value
CNG	NG - EU-mix 2030	18.9	JEC methodology based on updated NG import mix in 2030 (WoodMacKenzie)
SNG	Wind + blue/green CO_2	3.3	Not included in JEC and FQD, therefore based on JEC data and logic
SNG	Wind + flue gas	3.3	FQD-Art7a implementing directive
CBG	Municipal waste	16.8	FQD Annex 4: Rules for calculating the life cycle greenhouse gas emissions from biofuels
CBG	Maize/Barley	40.8	JEC WTT V4a (OWCG4), as no value in FQD
LPG	LPG (remote)	8.0	JEC WTT V4a (LRLP1)
LPG	LPG from refinery	13.6	LBST Study "CNG und LPG – Potenziale dieser Energieträger auf dem Weg zu einer nachhaltigeren Energieversorgung d. Straßenverkehrs"
LNG in vehicles	NG (remote)	19.4	JEC WTT V4a (GRLG1)
Compressed H2	Coal (EU mix)	234.0	FQD-Art7a implementing directive
Compressed H2	NG (EU mix)	104.3	FQD-Art7a implementing directive
Compressed H2	Waste Wood (gasification)	14.1	JEC WTT V4a (WWCH1)
Compressed H2	Electricity from Wind	13.0	JEC WTT V4a (WDEL1/CH2)
Compressed H2	Electricity (grid, EU mix 2030)	95.7	Based on updated electricity mix (IEA WEO 2015) using JEC methodology
Ethanol	Sugar beet	32.7	FQD Annex 4: Rules for calculating the life cycle greenhouse gas emissions from biofuels
Ethanol	Wheat (process fuel not specified)	41.9	FQD Annex 4: Rules for calculating the life cycle greenhouse gas emissions from biofuels, assuming that 50% sustainability criteria is met

Source: Roland Berger

Figure 59: WTT intensities used for major production processes [g CO_2e/MJ]

Basic fuel name	Resource	WTT GHG intensity	Source
Ethanol	Sugar cane	24.3	FQD Annex 4: Rules for calculating the life cycle greenhouse gas emissions from biofuels
Ethanol	Wheat straw	10.9	FQD Annex 4: Rules for calculating the life cycle greenhouse gas emissions from biofuels
Ethanol	Waste Wood	16.8	FQD Annex 4: Rules for calculating the life cycle greenhouse gas emissions from biofuels
Ethanol	Barley/Rye	36.9	Assumed that same as maize, as not included in FQD and JEC value is not expected to meet sustainability criteria
Ethanol	Maize	36.9	FQD Annex 4: Rules for calculating the life cycle greenhouse gas emissions from biofuels
MTBE	NG (remote) + field butane	15.7	JEC WTT V4a (GRMB1)
MTBE	LPG + NG	15.7	Assumed same as above, as no alternative data available
ETBE	LPG	29.9	JEC WTT V4a (LREB1)
Biodiesel	Rapeseed	41.9	FQD Annex 4: Rules for calculating the life cycle greenhouse gas emissions from biofuels, assuming that 50% sustainability criteria is met
Biodiesel	Sunflower	35.2	FQD Annex 4: Rules for calculating the life cycle greenhouse gas emissions from biofuels
Biodiesel	Soy beans	41.9	FQD Annex 4: Rules for calculating the life cycle greenhouse gas emissions from biofuels, assuming that 50% sustainability criteria is met
Biodiesel	Palm oil (process not specified)	41.9	FQD Annex 4: Rules for calculating the life cycle greenhouse gas emissions from biofuels, assuming that 50% sustainability criteria is met
Biodiesel	Tallow oil	10.1	FQD Annex 4: Rules for calculating the life cycle greenhouse gas emissions from biofuels
Biodiesel	Waste cooking oil	10.1	FQD Annex 4: Rules for calculating the life cycle greenhouse gas emissions from biofuels
HVO	Rapeseed	41.1	FQD Annex 4: Rules for calculating the life cycle greenhouse gas emissions from biofuels
HVO	Sunflower	29. 3	FQD Annex 4: Rules for calculating the life cycle greenhouse gas emissions from biofuels
HVO	Palm oil	41.9	FQD Annex 4: Rules for calculating the life cycle greenhouse gas emissions from biofuels, assuming that 50% sustainability criteria is met
HVO	Tallow oil	24.5	JEC WTT V4a as not defined in FQD (TOHY1a)

Source: Roland Berger

Figure 60: WTT intensities used for major production processes [g CO_2e/MJ]

Basic fuel name	Resource	WTT GHG intensity	Source
HVO	Waste cooking oil	8.1	JEC WTT V4a as not defined in FQD (WOFA3)
HVO	Tall[1)]	9.0	Data from Neste based on JEC 2014
HVO	FAD	12.0	Data from Neste based on JEC 2014
Electricity	NG	136.4	Based on updated import mix (Source: WoodMacKenzie) into Europe in 2030 using JEC methodology, assuming GTCC
Electricity	Biogas (municipal waste)	23.7	JEC WTT V4a adjusted by exclusion of biomethane-credit in biogas (for consistency reasons with FQD)
Electricity	Biogas (liquid manure)	24.0	JEC WTT V4a adjusted by exclusion of biomethane-credit in biogas (for consistency reasons with FQD)
Electricity	Biogas (dry manure)	93.9	JEC WTT V4a adjusted by exclusion of biomethane-credit in biogas (for consistency reasons with FQD)
Electricity	Heavy fuel oil	237.8	JEC WTT V4a (FOEL1)
Electricity	Coal (EU mix)	292.4	JEC WTT V4a (KOEL1)
Electricity	Coal (EU mix)	262.4	JEC WTT V4a (KOEL2)
Electricity	Nuclear	5.0	JEC WTT V4a (NUEL)
Electricity	Wind	-	JEC WTT V4a (WDEL1)
Electricity	Hydro	-	RB assumption based on JEC logic – JEC assumes zero emissions for wind – this is also applied for other renewables
Electricity	Solar	-	RB assumption based on JEC logic – JEC assumes zero emissions for wind – this is also applied for other renewables
Electricity	Geothermal	-	RB assumption based on JEC logic – JEC assumes zero emissions for wind – this is also applied for other renewables
Electricity	Marine	-	RB assumption based on JEC logic – JEC assumes zero emissions for wind – this is also applied for other renewables
Additives for ED95		29.9	Assumption that same as ETBE, as no other data available (ETBE is ~half of additives volume in 2030)

1) Tall is a residual product of the pulp and paper industry

Source: Roland Berger

Additionally the following adjustments to fuels GHG emission intensities were applied:

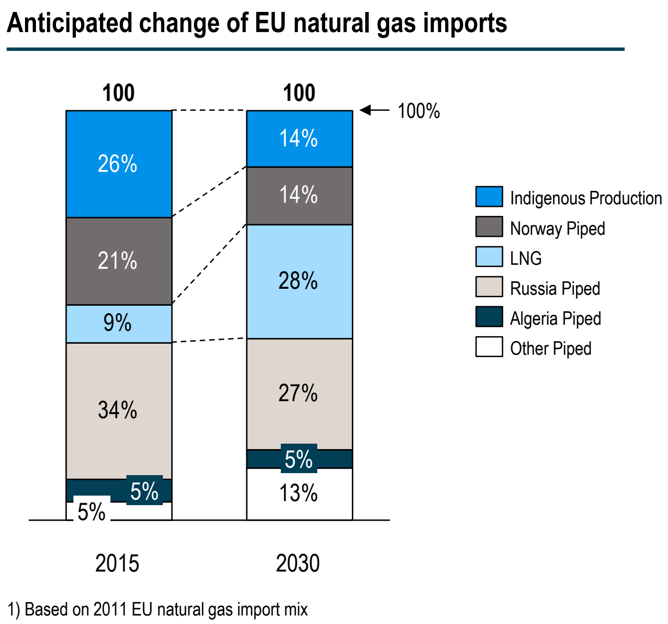
Gasoline and diesel

For gasoline and diesel production processes the JEC WTT GHG intensity were used as basis updated for the upstream share of the figure calculate by the ICCT in 2014. ICCT suggests a GHG intensity of 10 gCO_2e/MJ for crude coming into the EU. This approach is in line with the intensities used in the FQD.

Natural gas

- Given the expected change in the EU import mix of natural gas that is foreseen by Wood MacKenzie, the NG WTT GHG intensity was updated– based on the JEC WTT 2014 methodology
- Previous JEC WTT Natural gas EU-mix GHG intensity: **13 gCO_2e/MJ**[1)]
- Updated GHG intensity based on 2030 natural gas import mix: **18.9 gCO_2e/MJ**

Figure 61: Natural gas WTT GHG intensity in 2030



Source: Wood MacKenzie; Roland Berger

Electricity

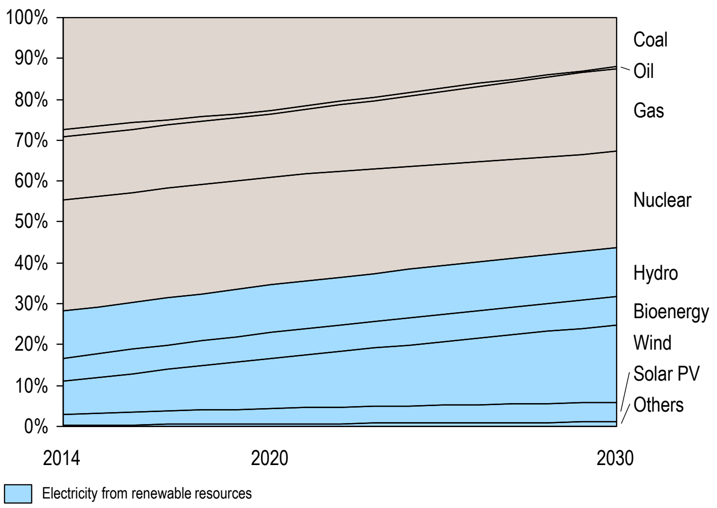
> For consistency reasons with the electricity price, this study uses the electricity generation mix of the IEA WEO 2015 New Policies Scenario

> It indicates an increase of the renewables share from 28% in 2014 to 44% in 2030

> The EU-mix electricity production process was updated based on JEC production processes for each "electricity type" leading to **67 g CO_2e/MJ** in 2030

> For this update, it is assumed that the GHG intensity for wind, hydro, solar, geothermal, marine is 0 gCO_2/MJ. It should be noted however, that there are other studies that imply that there is a higher intensity due to the base load of fossil fuels electricity that needs to be available in the grid

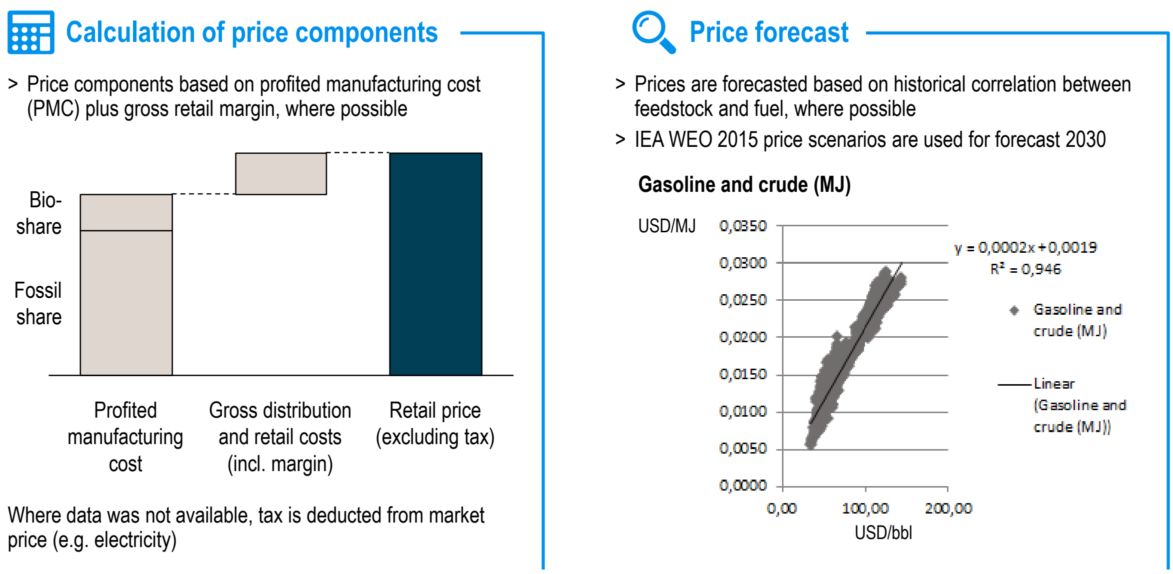
Figure 62: EU electricity generation in IEA WEO 2015, new policies scenario [%]



Source: IEA World Energy Outlook 2015, Roland Berger

6.3 Fuel price calculation

Figure 63: Fuel price calculation – illustrative for gasoline



Source: Roland Berger

Please refer to chapter 6.4.2 for additional information on distribution cost

6.4 Modeling of the fuel price and the infrastructure price uplift

6.4.1 Basic fuel prices

Figure 64: Methodology to calculate gasoline wholesale price 2030

> Linear regression between European gasoline wholesale price and brent price (R^2 = 0.95) provides a linear regression equation. This equation is used to derive gasoline wholesale price 2030
  – Gasoline wholesale price 2030 = a*crude price 2030 + b
> IEA 2030 crude price used in equation to derive 2030 value of gasoline wholesale price

2030 gasoline wholesale prices

IEA low oil price scenario

EUR/MJ	EUR/liter
0,0145	0,463

IEA new policies scenario

EUR/MJ	EUR/liter
0,0223	0,7127

Source: Bloomberg, Roland Berger

Figure 65: Methodology to calculate diesel wholesale price 2030

> Linear regression between diesel wholesale price and brent price (R^2 = 0.97) provides a linear regression equation. This equation is used to derive diesel wholesale price 2030
  – Diesel wholesale price 2030 = a*crude price 2030 + b
> IEA 2030 crude price used in equation to derive 2030 value of diesel wholesale price

2030 diesel wholesale prices

IEA low oil price scenario

EUR/MJ	EUR/liter
0,0136	0,4909

IEA new policies scenario

EUR/MJ	EUR/liter
0,0215	0,7724

Source: Bloomberg, Roland Berger

Figure 66: Methodology to calculate ethanol wholesale price 2030

Ethanol wholesale price

- > Linear regression between ethanol T2 and maize provides a linear regression equation (gasoline correlation with ethanol is not significant)
  - Ethanol wholesale price 2030 = a*maize wholesale price 2030 + b
  - R^2 = 0.66, highly negative p-values, and high F-value
- > To account for biofuel subsidies, addition of 0.15 EURct per liter[1)] on top of forecasted ethanol wholesale price
- > For ethanol 2G profited manufacturing cost/wholesale price in 2030, different studies as well as coalition member input were reviewed[2)]
  - Prices ranged between 0.54 and 0.75 EUR/liter
  - Given that over time costs decreases as part of the learning curve will be achieved, a conservative assumption of 0.64 EUR/liter seems realistic in 2030

Maize wholesale price

- > Based on FAO Agricultural Outlook 2015-2024 p.50, the real price is slightly decreasing from ~170 EUR/ton to 160 EUR/ton in 2024. Thereafter, we kept it flat until 2030

2030 ethanol wholesale prices

IEA low oil price scenario		
	EUR/MJ	EUR/liter
Ethanol 1G	0.0218	0.4579
Ethanol 2G	0.0305	0.64
	EUR/ton	
Maize	160	

IEA new policies scenario		
	EUR/MJ	EUR/liter
Ethanol 1G	0.0218	0.4579
Ethanol 2G	0.0305	0.64
	EUR/ton	
Maize	160	

1) Source: GSI and iisd 2013: Biofuels—At What Cost? A review of costs and benefits of EU biofuel policies, p. 35 2) Studies included are: IEA Energy technology perspectives 2012, IEA Energy Technology Essentials 2006 and 2007, "Techno-economic analysis of lignocellulosic ethanol: A review", Edgard Gnansounou, Arnaud Dauriat in 2010 as well as coalition member data

Source: Bloomberg and MATIF data retrieved from AHDB Cereals & Oilseeds Market Data Centre, Roland Berger

Figure 67: Methodology to calculate FAME wholesale price 2030

FAME wholesale price

- > Linear regression between diesel, rape and FAME[1)] wholesale prices to derive linear regression equation:
  - FAME wholesale price 2030 = a*diesel wholesale price 2030 + b*rape wholesale price 2030 + c
  - R^2 = 0.67, highly negative p-values, and high F-value
- > To account for biofuel subsidies, addition of 0.32 EURct per liter[2)] on top of forecasted wholesale price

Rape wholesale price

- > Assumed on same level as in 2014 (*real* prices)

2030 FAME wholesale prices

IEA low oil price scenario		
	EUR/MJ	EUR/liter
FAME[3)]	0,0317	1,0446
	EUR/ton	
Rape	352	

IEA new policies scenario		
	EUR/MJ	EUR/liter
FAME[3)]	0,0337	1,1112
	EUR/ton	
Rape	352	

1) Fame at -10 degrees 2) Source: GSI and iisd 2013: Biofuels—At What Cost? A review of costs and benefits of EU biofuel policies, p. 35 3)Including adjustment for subsidies

Source: Bloomberg, Roland Berger

Figure 68: Methodology to calculate NG and CBG wholesale price 2030

NG wholesale price
> IEA WEO 2015 EU NG import price scenarios serve as EU NG prices in 2030

CBG wholesale price
> CBG wholesale price = CBG production price
– Production price consists of production cost, injection cost and upgrading cost[1)]
– Share of production processes[2)]: 90% from waste (4.6ct/kWh), 10% from maize silage (6.5ct/kWh)
– Production cost assumed flat until 2030
– No margin assumed, as biogas is currently still subsidized

Sources
> NG price: IEA WEO 2015
> CBG wholesale price: IEA Bioenergy study 2014, EBA, Ministry for agriculture Germany

1) Source: IEA Bioenergy study 2014: Biomethane – status and factors affecting market, as recommended to use during interview with EBA
2) Source: Ministry for Agriculture Germany; Evaluation and Experience report 2013

2030 NG/CBG wholesale prices

IEA low oil price scenario

	EUR/MJ	EUR/kg
NG	0,00767	0,3458
CBG	0,0239	1,0774

IEA new policies scenario

	EUR/MJ	EUR/kg
NG	0,00956	0,4313
CBG	0,0239	1,0774

Source: Roland Berger

Figure 69: Methodology to calculate HVO wholesale price 2030

> Assumption that HVO has same production cost as FAME on a **per ton** basis[1)]
> Therefore, conversion of HVO wholesale price per ton (=FAME wholesale price per ton incl. subsidy) into EUR/MJ and EUR/liter
– FAME wholesale price used is adjusted for subsidies (additional 0.32 EURct/liter) – therefore HVO as well
> HVO wholesale price development until 2030 assumed the same as FAME wholesale price development

1) Source: Coalition member

2030 HVO wholesale prices

IEA low oil price scenario

	EUR/MJ	EUR/liter
HVO	0,0268	0,9100

IEA new policies scenario

	EUR/MJ	EUR/liter
HVO	0,0285	0,9680

Source: Roland Berger

6.4.2 Market fuel prices

Figure 70: Methodology to calculate gasoline retail prices (excl. taxes) [2030]

Retail price calculation logic	Example
2030 retail price (excl. taxes) =	E5 retail price (excl. taxes)
XX%[1)] of 2030 gasoline wholesale price	95%-vol of 2030 gasoline wholesale price (EUR/l)
+ XX%[2)] of 2030 ethanol T2 wholesale price (adjusted for subsidies) and ethanol 2G price	+ 5%-vol of 2030 ethanol (EUR/l) wholesale price (adjusted for subsidies) and 2G content
+ Average historic retail margin	+ Average historic retail margin (EUR/liter)

2030 prices used in model

IEA low oil price scenario

	EUR/MJ	EUR/liter
E5	0,0179	0,571
E10	0,0180	0,571
E20	0,0192	0,588
E85	0,0296	0,707

IEA new policies scenario

	EUR/MJ	EUR/liter
E5	0,0254	0,808
E10	0,0254	0,796
E20[2)]	0,0259	0,788
E85[2)]	0,0312	0,745

1) Exact shares depend on the respective fuel, e.g. E5, E10, etc. 2) Includes cap of 1G ethanol at 7%, rest 2G ethanol price

Source: Roland Berger

Figure 71: Methodology to calculate diesel retail prices (excl. taxes) [2030]

Retail price calculation logic	Example
2030 retail price (excl. taxes) =	B7 retail price (excl. taxes)
XX%[1)] of 2030 diesel wholesale price	93%-vol of 2030 diesel wholesale price (EUR/l)
+ XX%[1)] of 2030 FAME wholesale price (adjusted for subsidies)	+ 7%-vol of 2030 FAME (EUR/l) wholesale price (adjusted for subsidies)
+ Average historic retail margin	+ Average historic retail margin (EUR/liter)
(+ For R33[2)]: 26% of 2030 HVO wholesale price)	

2030 prices used in model

IEA low oil price scenario

	EUR/MJ	EUR/liter
B7	0,0184	0,659
R33	0,0215	0,759

IEA new policies scenario

	EUR/MJ	EUR/liter
B7	0,0258	0,921
R33	0,0274	0,968

1) Exact shares depend on the respective fuel at the retail station, e.g. B7 2) R33 = 7% FAME, 26% HVO, 67% diesel

Source: Roland Berger

Figure 72: Methodology to calculate average historical retail margins of gasoline and diesel

Gasoline

> Historic average difference between European gasoline retail prices (excl. taxes) and gasoline wholesale prices
> Historic data ranges from 2005-2015

> Source retail price: EC Weekly Oil Bulletin

Margin used in model
> EUR/MJ: 0,0031
> EUR/liter: 0,1076

Diesel

> Historic average difference between European diesel retail prices (excl. taxes) and diesel wholesale prices
> Historic data ranges from 2007-2015

> Source retail price: EC Weekly Oil Bulletin

Margin used in model
> EUR/MJ: 0,0034
> EUR/liter: 0,1208

Source: Roland Berger

Figure 73: Methodology to calculate HVO retail price (excl. taxes) [2030]

> HVO (100%) retail price 2030 = HVO wholesale price + HVO retail margin
> Assumption that HVO retail margin is the same as diesel retail margin in EUR/MJ[1)]

2030 prices used in model

IEA low oil price scenario

	EUR/MJ	EUR/liter
HVO	0,0301	1,0243

IEA new policies scenario

	EUR/MJ	EUR/liter
HVO	0,0318	1,082

1) Source: Coalition member

Source: Roland Berger

Figure 74: Methodology to calculate CNG market fuel retail price (excl. taxes) [2030]

Retail price calculation logic (see also illustration on next page)

CNG market fuel retail price =
CNG market fuel wholesale price + Average historic CNG retail margin

> CNG market fuel wholesale price 2030 consists of 80% NG and 20% CBG[1] – assumption taken from interview with European Biogas Association – they validated with NGVA
> Therefore, CNG price at the pump consists of same components:
  – 80% NG price 2030
  – 20% CBG price 2030

> German retail margin taken as a proxy for European retail margin (excl. taxes) due to lack of data on European level
> Retail margin calculation logic:
  – Difference between German retail price (excl. taxes) and German border NG wholesale price (Source: Bloomberg, EID)
  – Taxes excluded: 19% VAT, 13.9 EURct/MWh energy tax
  – 2030 margin: 0.0088 EUR/MJ, 0.395 EUR/kg

2030 prices used in model

IEA low oil price scenario

	EUR/MJ	EUR/kg
CNG market fuel	0,0197	0,887

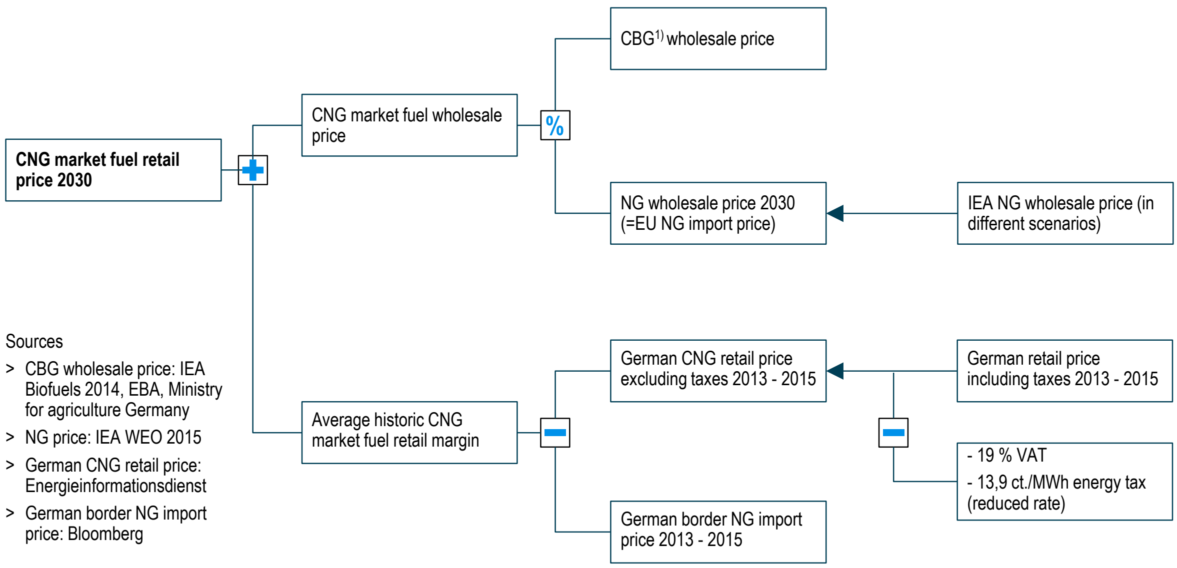
IEA new policies scenario

	EUR/MJ	EUR/kg
CNG market fuel	0,0212	0,955

1) CBG = Compressed biogas, bio-methane

Source: Roland Berger

Figure 75: Methodology to calculate CNG market fuel retail price (excl. taxes) [2030]



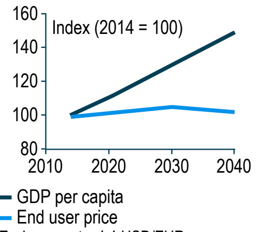
1) CBG = Compressed biogas, biomethane

Source: Roland Berger

Figure 76: Methodology to calculate electricity price (excl. taxes) [2030]

> IEA WEO 2015 electricity price scenario (new policies) is taken as basis for price development until 2030
  – Index (see graph below) used to calculate 2030 household price (incl. taxes) based on 2014 price (260 USD/MWh)
> To calculate price excluding taxes, European average VAT as well as other non refundable taxes & levies were deducted
  – Historical average EU28 VAT: 14% of household price (based on Eurostat data, nrg_pc_204)
  – Historical average EU28 other taxes & levies: 19% of household price (based on Eurostat, nrg_pc_204))

EU residential electricity prices and GDP per capita in IEA New Policies Scenario



	2014	2020	2030
Index	100	102.5	105
%-change		2.5%	2.4%
Average level [USD/MWh][1]	260	266.5	273

1) Exchange rate: 1.1 USD/EUR

2030 household electricity price

IEA low oil price scenario

> No information provided in IEA WEO 2015 – they only give information for new policies scenario
> Assumption that it is similar to new policies scenario

IEA new policies scenario

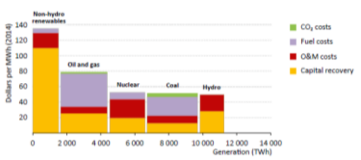
EUR/MJ	EUR/kWh
0,0468	0,168

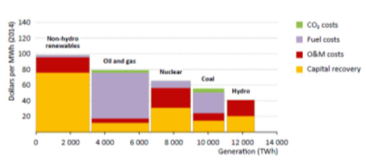
Source: IEA WEO 2015, Roland Berger

Figure 77: Methodology to calculate green electricity price (excl. taxes) [2030]

> Electricity price calculated for EU-mix based on IEA WEO 2015 is basis for calculation of renewable electricity price
> Addition of production cost difference between EU-mix electricity and renewable electricity based on IEA WEO 2015
  – Calculation of EU-mix electricity production cost and renewable electricity production cost in 2030 based on extrapolation of data from IEA WEO 2015 in 2020 and 2040
  – Addition of difference between both 2030 production cost to the forecasted EU-mix household electricity price

Total power generation costs for different sources of electricity


2020


2040

1) Exchange rate: 1.1 USD/EUR

2030 household electricity price

IEA low oil price scenario

> No information provided in IEA WEO 2015 – they only give information for new policies scenario
> Assumption that it is similar to new policies scenario

IEA new policies scenario

EUR/MJ	EUR/kWh
0,0584	0,210

Source: IEA WEO 2015, Roland Berger

Figure 78: Methodology to calculate LNG retail price (excl. taxes) [2030]

- Historic LNG retail prices from The Netherlands serve as basis for price calculation (2012-2015) – Source: LNG24
- Deduction of Dutch VAT as well as excise duties from retail price at the pump
  - Dutch VAT: 21%
  - Excise duty in NL: 0,18 EUR/kg
- Forecast of LNG price based on IEA WEO 2015 scenarios on US NG import price
  - Application of year-on-year growth rate on Dutch LNG retail price to forecast 2030 retail price

2030 LNG retail price

IEA low oil price scenario

	EUR/MJ	EUR/kg
LNG market fuel	0,0256	1,152

IEA new policies scenario

	EUR/MJ	EUR/kg
LNG market fuel	0,0256	1,152

Source: IEA WEO 2015, Roland Berger

Figure 79: Methodology to calculate Hydrogen retail price (excl. taxes) [2030]

	IEA low oil price scenario		**IEA new policies scenario**	
2030 Diesel price (excl. taxes) at pump	**EUR / MJ**	**0.01816**	**EUR / MJ**	**0.02561**
		x		x
2030 Fuel consumption conventional diesel ICE	MJ / km	1.035	MJ / km	1.035
		=		=
2030 Fuel cost for 100km (assumed to be equal for diesel/ gasoline and Hydrogen)	**EUR / 100km**	**0.0188**	**EUR / 100km**	**0.0265**
		/		/
2030 Fuel consumption FCEV	MJ / km	0.78	MJ / km	0.78
		=		=
2030 hydrogen parity price (excl. taxes) at pump	**EUR / MJ**	**0.0241**	**EUR / MJ**	**0.03398**
		=		=
2030 hydrogen parity price (excl. taxes) at pump	EUR / kg	2.89	EUR / kg	4.07

1) Based diesel since diesel parity is lower than gasoline parity price

Source: Roland Berger

Figure 80: Methodology to calculate ED95 retail price (excl. taxes) [2030]

- ED95 wholesale price 2030 = 95% of ethanol wholesale price + 5% additives price[1)] (assumed at 1500 EUR/cbm in 2030 based on coalition data)
- 1G Ethanol price is used for 7% (1G cap), the remainder is 2G ethanol price
- Assumption that ED95 retail margin is the same as diesel retail margin in EUR/MJ

2030 prices used in model

IEA low oil price scenario

	EUR/MJ	EUR/liter
ED95	0.0348	0.742

IEA new policies scenario

	EUR/MJ	EUR/liter
ED95	0.0348	0.742

1) Respective energy shares are: Ethanol: 93.7%; Additives (assumed at same density as ETBE): 6.3%

Source: Roland Berger

6.4.3 Infrastructure price uplift

Figure 81: Infrastructure cost allocation to fuel price

Fuel	**Price uplift for new retail & production infrastructure** [EUR/MJ]
Gasoline (incl. different bioshares)	Included in price
Diesel (incl. different bioshares)	Included in price
CNG	Included in price: Assumption that current retail price includes cost for retail & distribution. Current retail infrastructure is scalable at same marginal costs as existing infrastructure.
LNG	Price uplift for LNG retail station calculated
H2	High uncertainty about expected production cost in 2030 (different studies come to different results). Therefore, no explicit calculation of retail price uplift
Electricity	Price uplift for charging infrastructure calculated, as household electricity price does not cover investments in charging posts, etc. – for methodology see next slide
HVO (100%)	In case of HVO (100%) introduction at pump, assumption that no investment in additional dispenser at existing retail station is required; rather, existing dispenser would be re-purposed for HVO. Same argument for distribution; Production cost covered by retail price; Therefore, no price uplift required;
ED95	See same argument as HVO (100%); no price uplift required

Source: Roland Berger

Figure 82: EV charging infrastructure cost allocation – Based on EV project

EV infrastructure cost uplift
> 8.01 EURct/kWh
> 0,0223 EUR/MJ

Assumptions

Share of charging type[1]			Investment cost [EUR]	[source]	[cost decrease]	O&M cost [%]	Lifetime [years]	Utilization[1] [%]
83%	**Private**	**EURct/kwh 2.47**	520	DAFI[2]	0.3% p.a.	12	10	8
3%	**Semi-private** (e.g. companies)	**EURct/kwh 15.8**	2,500	VDA[3]	0.3% p.a.	12	10	6
10%	**Public**	**EURct/kwh 31.9**	5,280	DAFI[2]	0.3% p.a.	12	10	2
4%	**DC Fast**	**EURct/kwh 65.1**	41,000	JRC[4]	0.3% p.a.	5	10	3

1) Based on actual data from the 'EV Project'; in line with DAFI that ~10% of infrastructure should be public
2) EU Directive: Deployment of alternative fuel infrastructure 3) VDA: Ladestationen für Elektroautos 2015 4) Plug-in Hybrid and Battery Electric Vehicles 2010

Source: Roland Berger, DAFI, VDA, JRC, EV Project, coalition feedback

Figure 83: LNG infrastructure cost allocation – Based on LNG blue corridors

Assumptions for LNG retail station

> Investment cost in 2015 — EUR 1.0 m — Interview NGVA
> Specific capacity: — 3,200 kg/h[1] — Rolande
> Progress ratio: — 95.5% — Interview NGVA
> Annual operating hours: — 8,640 hours — RB assumption
> Technical lifetime: — 20 years — RB assumption
> Operation & maintenance: — 2.7% — same as H2
> Interest Rate: — 4% — Cost-to-Society

0.90 m EUR
Annual cost per station

Total annual dispensed LNG

> Daily average number of tank fillings — 10 — RB assumption
> Average amount of LNG per tank filling — 525 kg — IVECO
> Annual days of operation — 360 — RB assumption

1,890 t
Annual dispensed LNG

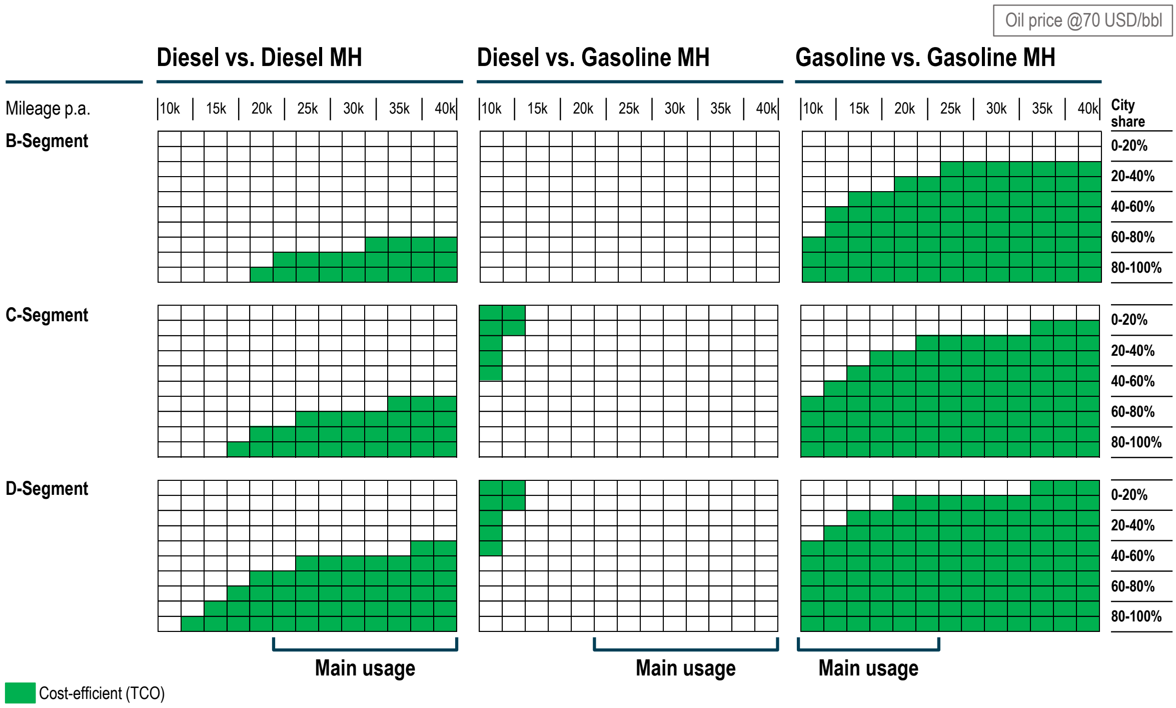
LNG infrastructure cost uplift
> 2.66 EURct/kg
> 0.0006 EURct/MJ

1) Assuming 200 HDV fillings per day

Source: Roland Berger

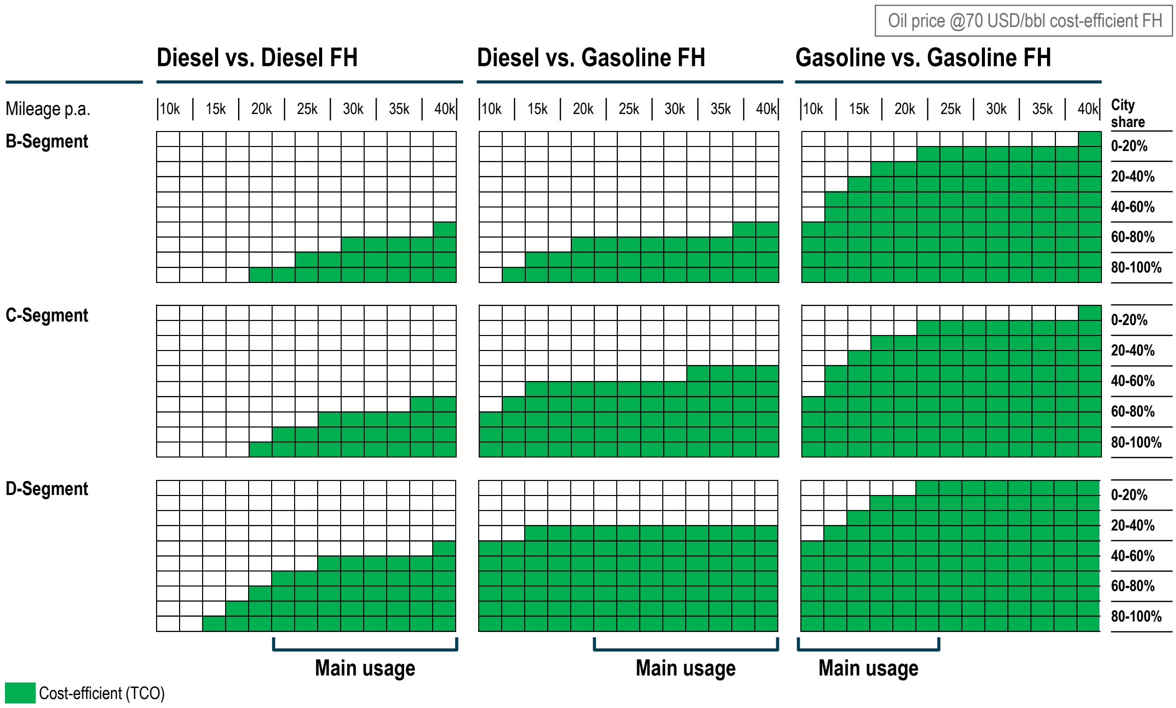
6.5 Results of TCO calculations

Figure 84: Relative competitiveness of driving profiles from a TCO perspective for a MH at an oil price of 70 USD/bbl



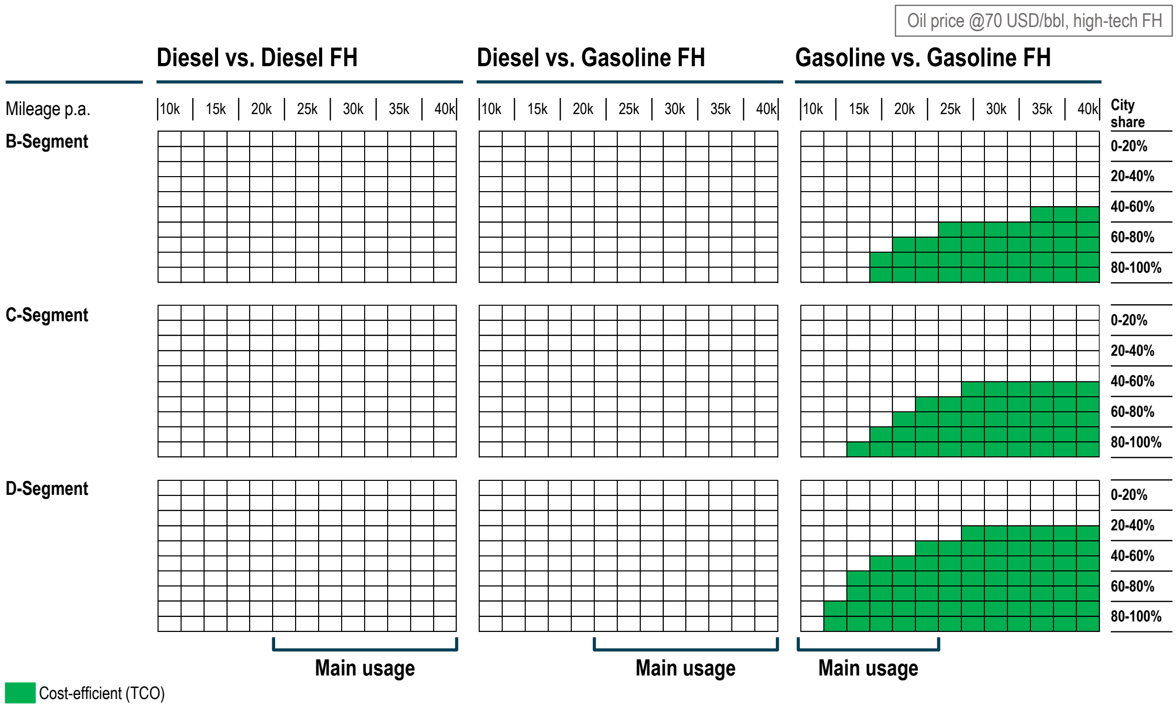
Source: Roland Berger

Figure 85: Relative competitiveness of driving profiles from a TCO perspective for a FH at an oil price of 70 USD/bbl



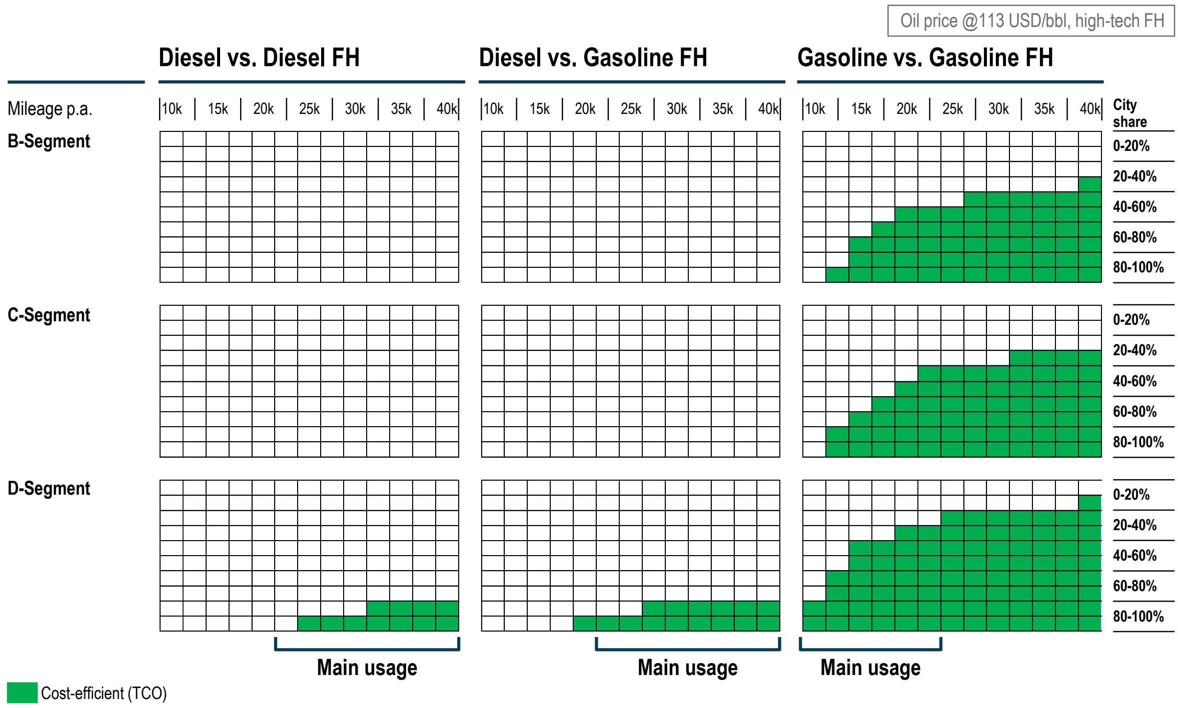
Source: Roland Berger

Figure 86: Relative competitiveness of driving profiles from a TCO perspective for an expensive FH at an oil price of 70 USD/bbl



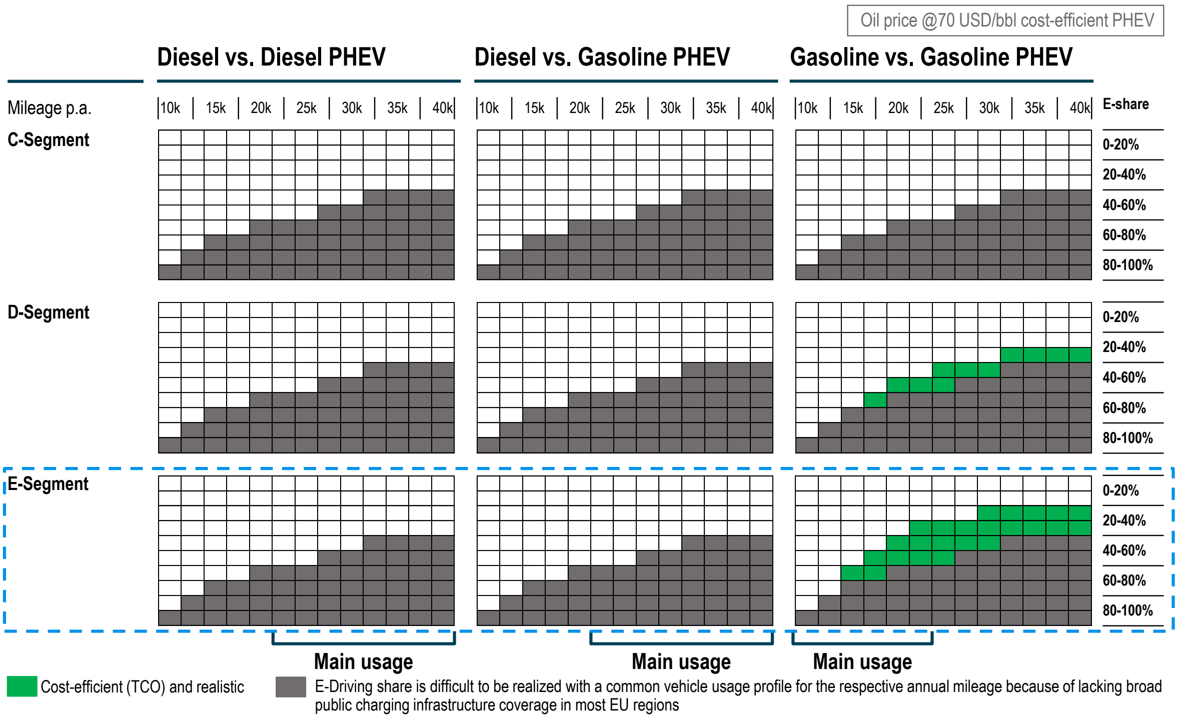
Source: Roland Berger

Figure 87: Relative competitiveness of driving profiles from a TCO perspective for an expensive FH at an oil price of 113 USD/bbl



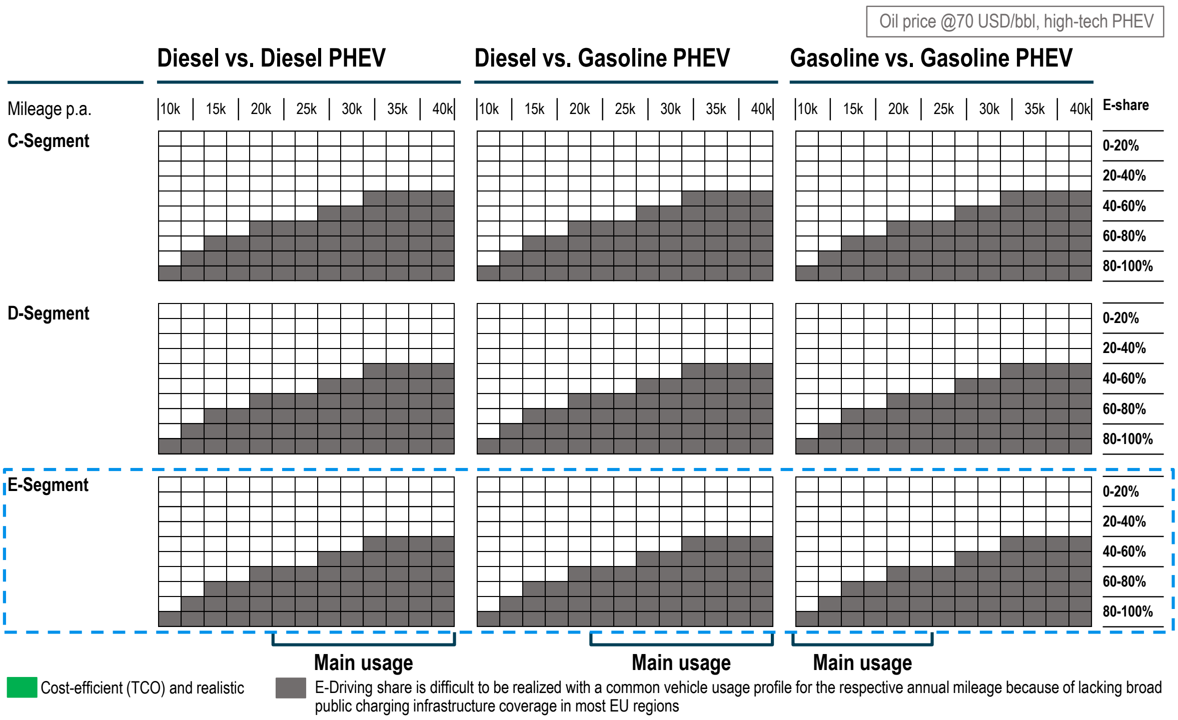
Source: Roland Berger

Figure 88: Relative competitiveness of driving profiles from a TCO perspective for a cost-efficient PHEV at an oil price of 70 USD/bbl



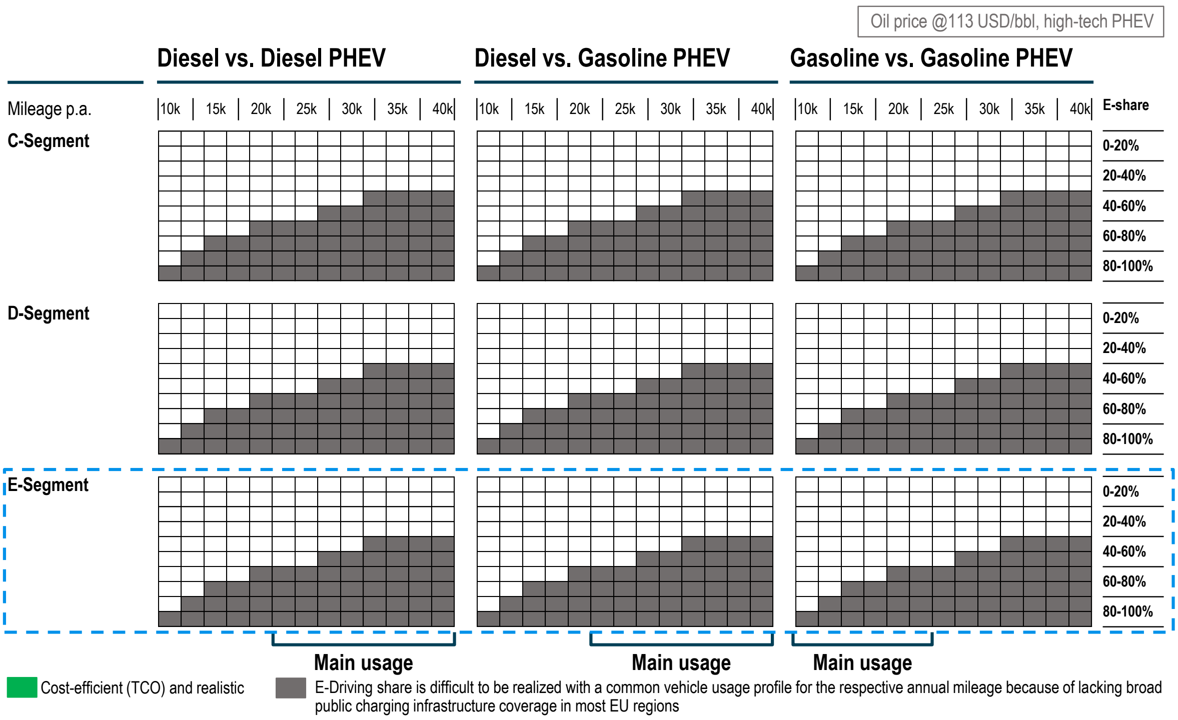
Source: Roland Berger

Figure 89: Relative competitiveness of driving profiles from a TCO perspective for a high-tech PHEV at an oil price of 70 USD/bbl



Source: Roland Berger

Figure 90: Relative competitiveness of driving profiles from a TCO perspective for a high-tech PHEV at an oil price of 113 USD/bbl

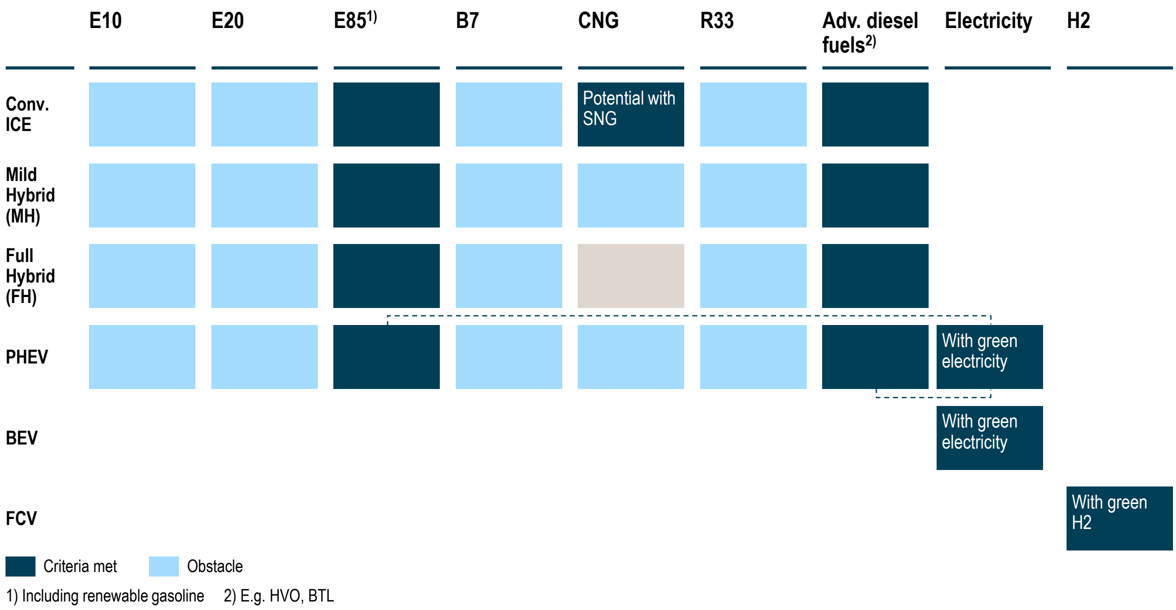


Source: Roland Berger

6.6 Solution beyond 2030

In this study, different fuel/vehicle technology combinations have been examined in order to assess their suitability for an optimal pathway beyond 2030. On the fuel side, several technologies can contribute to a further reduction of road transport emissions and ultimately zero-carbon emission.

Figure 91: Evaluation of paths/technologies PC for optimal pathway beyond 2030



Source: Roland Berger

Besides already considered solutions like HVO and higher Ethanol blends, other fuel-related solutions can also provide zero-carbon emission in the long-term. Examples are Power-to-X, where surplus renewable electricity is used to produce renewable transport fuels, pure ethanol, electricity from renewable sources and paraffinic fuels. Paraffinic fuels are a synthetic substitute for conventional, mineral oil based diesel transport fuels and cover Gas-to-Liquid (GTL), Coal-to-Liquid (CTL), Biomass-to-Liquid, (BTL) and HVO. Since HVO has already been considered in the pathway to 2030 and GTL as well as CTL are produced from fossil feedstock, BTL is the remaining opportunity for zero-carbon emission from the range of paraffinic fuels.

6.6.1 Excursus Power-to-X

Power-to-X uses surplus renewable electricity to produce renewable transport fuels. These fuels are either synthetic natural gas (Power-to-Gas) or synthetic gasoline and diesel (Power-to-Liquid).

Power-to-X production processes are based on electrolytic production of hydrogen from renewable and ideally surplus electricity production. The hydrogen can be used directly to power FCVs (with its infrastructure requirements for distribution and retail) or it can be used for synthetic fuel production with the established Fischer-Tropsch method. These synthetic diesel and gasoline has much better properties compared to conventional fossil fuels. They lack neither aromatics nor sulphur, allowing for much leaner, more cost-effective exhaust gas treatment in vehicles. Alternatively, synthetic gas is produced by methanation - the reverse reaction of the well-known steam methane reforming process. Both methods need CO_2 as a carbon source that can be provided by biogas plants, ethanol fermentation, but can also use atmospheric CO_2, resulting in a negative CO_2 footprint of the fuels produced.

Advantages of Power-to-X:

> Can be used to store surplus renewable electricity[35]
> Fuel production does not compete with feedstock and therefore complies with the definition of sustainable renewable fuel
> Relevant vehicles powertrains technologies are available
> Partly leverage of existing infrastructure for distribution and retail, so investment can be focused on production capacity
> Carbon source CO_2 can be extracted from atmosphere

Currently cost remains a challenge for power-to-gas applications.

6.6.2 Excursus paraffinic fuels

Paraffinic fuels are synthetic substitutes for conventional diesel fuel and can be used in existing diesel engines without technical changes[36]. Compared to conventional fuels, direct emissions can be reduced significantly. Paraffinic fuels can contribute to an increased supply of non-mineral oil based fuels and/or fuels from renewable sources.

Paraffinic fuels are synthetic fuels produced from natural gas (Gas-to-Liquid, GTL), coal (Coal-to-Liquid, CTL), biomass (Biomass-to-Liquid, BTL) or vegetable oil (Hydrotreated Vegetable Oil, HVO). In the case of BTL and HVO, these fuels are produced from renewable feedstock and can contribute to a decarbonisation of transport fuels. GTL fuels are produced from natural gas using the Fischer Tropsch method. BTL fuels are also produced based on the Fischer Tropsch method, however, biomass such as woodchips is used as feedstock. HVO is a renewable fuel using a refinery-based process converting vegetable oils to paraffins. Animal fats are also suitable for HVO production.

Paraffinic fuels are totally fungible and can be used as drop-in blending components for conventional diesel fuels.

Advantages of paraffinic fuels:

> Opportunity to increase the share non-mineral oil based fuels
> Positive impact on particulate matter and NOx emissions compared to conventional diesel fuels
> Compatibility with existing conventional diesel engines
> CO2 emission reduction is possible without technical adaptions on vehicles

Technology maturity to ensure cost competitiveness compared to conventional fuels is a current challenge for paraffinic fuels, in particular for BTL.

6.7 Effect of current regulatory framework for GHG abatement until 2030

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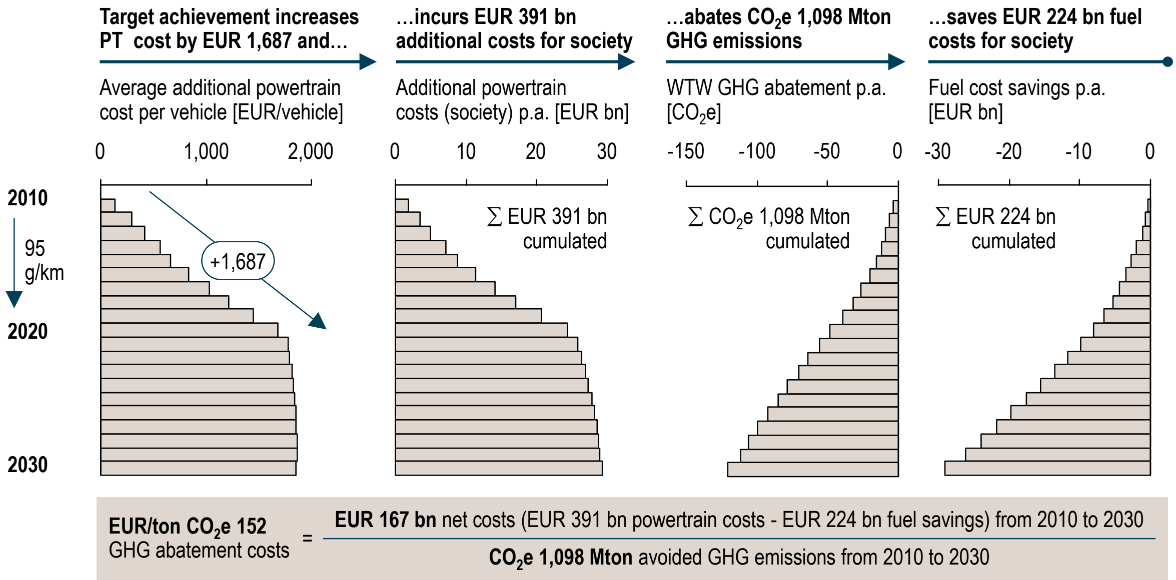
[35] Current storage technologies in Germany such (e.g. pumped-storage power plants and batteries or BEV fleet) are able to store 0.04 to 0.45 TWh_{el} respectively, which equates to 6 hours of renewable electric power production in Germany. By using the natural gas grid in Germany for storage, power-to-gas has a capacity of 130 TWhel. That is equivalent to two months of renewable electric power production.

[36] Specific calibrations can be necessary in order to enable highest possible emission reduction

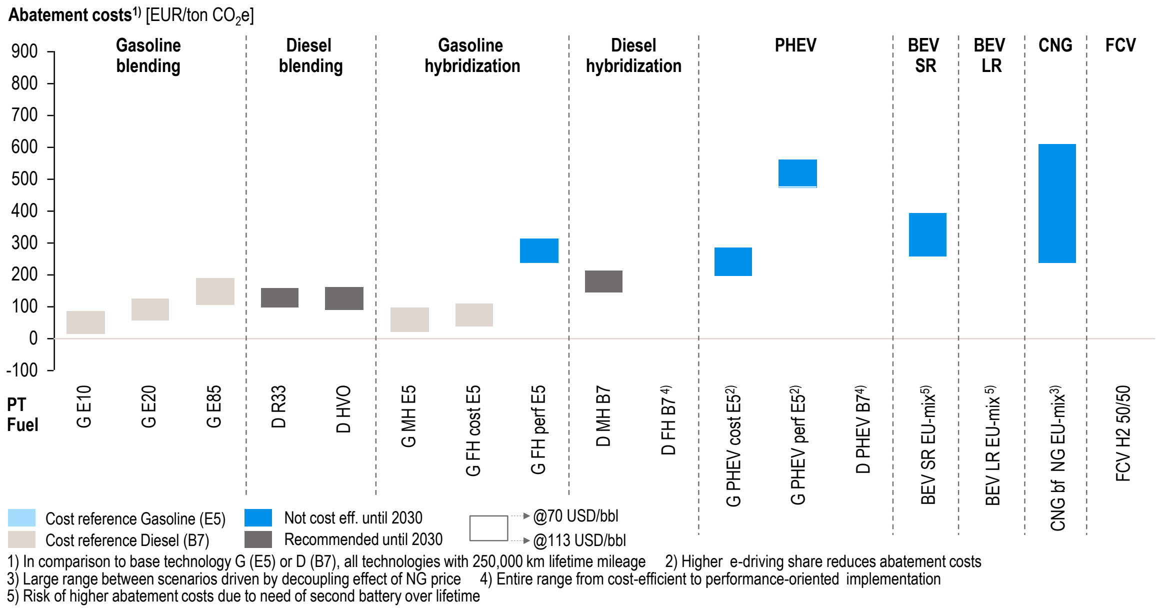
Figure 92: Effect of current regulatory framework (95 gCO_2/km target) for GHG abatement until 2030 (Oil price @ 113°USD/bbl – Scenario B)



Source: Roland Berger

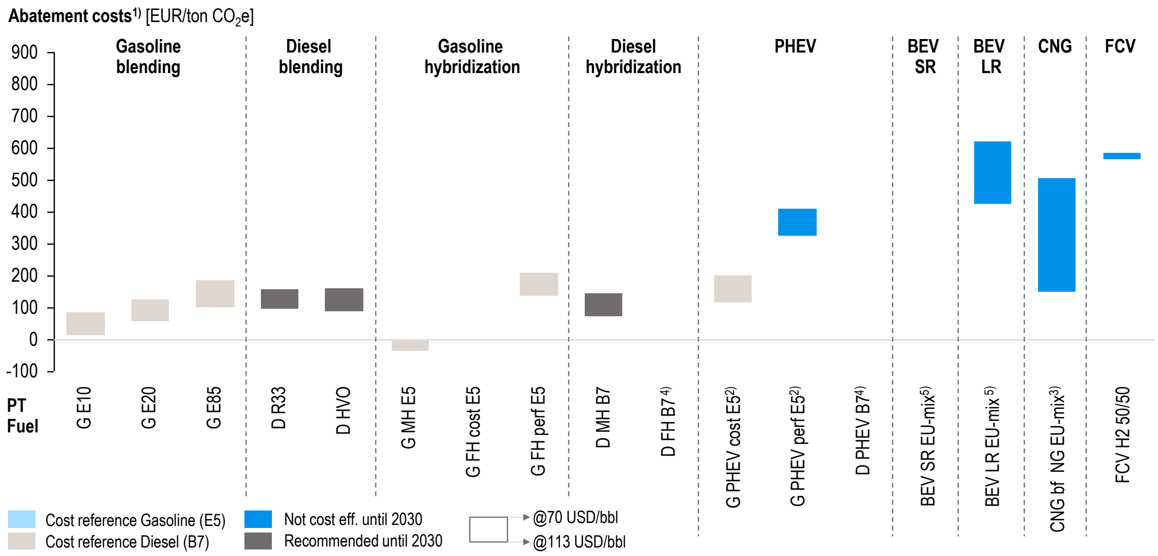
6.8 GHG abatement costs

Figure 93: GHG abatement costs B-segment passenger car 2030 (WTW) [EUR/ton CO_2e]



Source: Roland Berger

Figure 94: GHG abatement costs D-segment passenger car 2030 (WTW) [EUR/ton CO_2e]



1) In comparison to base technology G (E5) or D (B7), all technologies with 250,000 km lifetime mileage 2) Higher e-driving share reduces abatement costs
3) Large range between scenarios driven by decoupling effect of NG price 4) Entire range from cost-efficient to performance-oriented implementation
5) Risk of higher abatement costs due to need of second battery over lifetime

Source: Roland Berger

6.9 Excursus Biofuel policies

Future policies supporting advanced biofuels and their contribution to lowering GHG emissions should favor biofuel blends and drop-in since their GHG abatement costs are lower compared to pure biofuels transport fuels.

Since transport fuel taxation systems vary considerably across the EU, the European Commission can only recommend policies which follow either the path of an entire revision of the taxation system or add new taxation components for transport fuels.

New EU-wide taxation system for transport fuels

1. CO_2 taxation – taxation of fuel only based on a vehicle's TTW CO_2 emissions with a given price per ton CO_2. As part of this conventional biofuels could potentially be charged for 50% of the vehicle's TTW CO_2 emissions, while advanced biofuels will not be charged at all or alternatively based on their WTT CO_2 emissions
2. Energy taxation – taxation based on fuel energy content in MJ/l resulting in a promotion of tax advantages due to different MJ/l between gasoline (e.g. E5/E20) and diesel (e.g. B7, R33) variants
3. Combination of proposals 1 and 2 (e.g. like the Finnish fuel taxation system that contains both an energy-based and a GHG-based taxation element

Taxation component in addition to the country-specific taxation system

1. Biofuel tax exemption – exemption of taxation for advanced biofuels, up to a drop-in/blending limit
2. Bonus/Malus tax component – introduction of a taxation component that provides tax incentives for high biofuel proportions above a defined threshold and tax penalties for biofuel shares below the defined threshold
3. CO_2 tax component – introduction of a taxation component within the fuel taxation system that is based on TTW CO_2 emissions of the fuel in combination with reduced charges for 1st and advanced biofuels up to a cap
4. Combination of proposals 5 and 6
5. Combination of proposals 4 and 6

To allow a comprehensive evaluation of potential policies, the following criteria were defined:

– Policy sets a strong pricing signal to the customer at the point of sale (fuelling station) preferring fuels with a high proportion of biofuel as well as supporting advanced biofuels in particular
– The implementation of the policies is entirely feasible at a (pan) European level
– Results and effects of the policy are long-term in effect and promote efficiency
– To maintain the position of the diesel engine as a highly efficient low emission powertrain type, the diesel price position should not be changed
– Total amount of transport fuel taxation should not be decreased due to reduced consumption and possible expectations for biofuels as it is one the most important pillars of European state financing
– Recommended policies need to support the long-term goal of amalgamating the transport fuel into the ETS scheme (see 5.4.2)

The assessment of the introduced criteria in both quantitative and qualitative terms was based on a simple model set up for quantitative evaluation. To quantitatively compare the effect of the policies, reference fuels E5, B7 were assessed on price and taxation towards E20 and R33. The model focused on the major European countries (Germany, France, United Kingdom, Spain and Italy) thereby covering a significant proportion of the European transport fuel market.

Overall, the potential policies were evaluated as follows (refer to figure 48):

New EU-wide taxation system for transport fuels

1. CO_2 taxation fully meets the requirements for most criteria and hence sets a strong pricing signal to the customer by pulling to R33 diesel and E20 fuels, it has long-term focus and its complexity is reduced to a minimum by being applied as a new taxation system. Furthermore, taxation expectations can be met and compatibility to the ETS by referring to CO_2 emissions as reference size is ensured. But it is unlikely to be applied across the EU as it will replace existing taxation systems and the taxation advantage of Diesel will be removed for some countries (e.g. UK). Hence it works contrary to the studies principle of maintain the taxation advantage of Diesel
2. Taxation by energy content fits the bill as it is long-term in nature, has low complexity as well meeting taxation expectations. However, it does have some weaknesses including lacking a strong pricing signal to the customer and compatibility with the ETS for fuels rendering long-term integration impossible
3. A combination of the proposals 1 and 2 avoid individual disadvantages, but remains unlikely to be implemented as it would only substitute existing country-specific policies.

Taxation component in addition to the country-specific taxation system

1. Biofuel tax exemption can hardly be implemented since tax exemptions will differ across EU28 and hence will make an equal introduction impossible. Furthermore the idea of biofuel tax exemption cannot be integrated into an ETS system as planned for long-term.
2. A bonus/malus system for fuels with a high/low proportion of biofuel meets all criteria with the exception of ETS for fuels compatibility. The reason behind this is that the key driver of a bonus/malus system is the proportion of biofuel contained therein and thereby does not directly reflect specific CO_2 emissions of any given type of fuel. However, as mentioned before, this also lies in complete contradiction to the principal arguments being laid out in the study.
3. A policy recommending that meets almost all criteria though an EU-wide equal implementation may have some weaknesses.
4. The combination of CO_2 tax components and a bonus/malus system compensates for individual disadvantages while being fully compatible with ETS for fuels.
5. The combination of CO_2 tax components and biofuel tax exemptions for biofuels is recommended as this combination compensates for individual disadvantages while being fully compatible with ETS for fuels.

An open policy recommendation has a number of criteria detrimental to long-term character that are critical in terms of complexity for integration into and for compatibility with ETS. With respect to ETS, it is possible that some country-specific policies will not meet the requirements of ETS integration over the longer term through to 2050. Though, such a recommendation is highly likely to be implemented EU-wide due to its degree of freedom for country-specific implementation.

Aiming for EU-wide execution, the recommendation to integrate an additional taxation component as an "add-on" to existing fuel taxation needs is the preferred option over recommending that all member states implement a completely new fuel taxation system. After considering all the possibilities for additional taxation components, two options look promising either,

> a combination of a bonus/malus system depending on the biofuel share and CO_2-based taxation component or

> a combination of a tax exemption for biofuel and CO_2-based taxation component.

Figure 95: Assessment of policy options for taxation for transportation fuel

	Recommendation to member states to introduce new taxation system			Recommendation to member states to intro additional tax components				
Criteria	1 CO_2 tax	2 Energy content	3 Combi CO_2 & Energy	4 Biofuel tax exemption	5 Bonus/ Malus	6 CO_2 tax component	7 Combi CO_2 & BM	8 Combi CO_2 & Exempt.
Strong price signal & advanced biofuel support	✓	⚡	(✓)	✓	✓	✓	✓	✓
Implementation on EU level (incl. tax income effects)	⚡	⚡	⚡	⚡	✓	(✓)	✓	✓
Long-acting	✓	✓	✓	?	✓	✓	✓	✓
Complexity	✓	✓	?	✓	✓	✓	✓	✓
Diesel price position unchanged	⚡	⚡	✓	✓	✓	✓	✓	✓
Fit to expected fuel taxation increase	✓	✓	✓	⚡	✓	✓	✓	✓
Compatibility to ETS for fuels	✓	⚡	✓	⚡	⚡	✓	✓	✓

✓ Criteria fully met (✓) Criteria met ? Criteria likely not met ⚡ Criteria not met

Source: Roland Berger

6.10 Additional levers besides vehicle and fuel improvements

This study focuses on vehicle-based technical measures vehicle powertrains and fuels to reduce GHG emissions. Operational measures that encourage all drivers to reduce GHG emissions allow for a quick greenhouse gas abatement trajectory. Eco-driving can be considered as such a measure. The influence of vehicle manufacturers and fuel suppliers on additional operational measures is limited. Nevertheless, here is a brief outline.

A number of studies acknowledge the positive impact of eco-driving courses on GHG emissions in road transport: Learning to drive more economically reduces fuel consumption and CO_2 emissions. Repeating courses on a regular basis is required to have a lasting effect at customer side. Achieving significant reductions in GHG emissions over the long term requires continuous investment, thus reducing the cost effectiveness of this measure.

Truck platooning is another operational measure to reduce GHG emissions in the commercial vehicle segment. By electronically linking a number of trucks on the highway and reducing the space between the vehicles, the shared aerodynamic drag reduces overall CO_2 emissions by as much as 10%. There are obstacles, however. Firstly, the Vienna Convention on Road Traffic needs to be adjusted to allow for highly automated driving. The reduced gaps between the trucks make it difficult for other road users to overtake long convoys of vehicles. Platooning is another interesting lever with the potential to improve GHG emissions of heavy and medium duty trucks by up to approx. 10%. A number of technical hurdles need to be overcome and working business cases are still unclear.

A greater degree of transport efficiency thanks to optimized traffic flow can be achieved by connected mobility and by the introduction of real time data exchange. By providing additional traffic information, connected cars will potentially be able to reduce “stop-and-go” and related congestion, thereby effectively reducing fuel consumption and CO_2 emissions. The study assumes that customers will gradually change their mobility patterns as they become increasingly aware of environmental technology and its benefits based on services offered related to connected mobility. This will also make a contribution to GHG emissions. It is expected that OEMs will increase penetration of mobility devices, pushing connected mobility features and services as a differentiator. As part of their expanded range of services on offer, OEMs will help their customers to save fuel based on real time data exchange. Thus required infrastructure investment will be at least partly undertaken by OEMs while offering customers new services.

A modal shift in private transport towards car sharing is also expected to have a positive effect on GHG emissions in the road transport sector. Car sharing will replace older cars that have significantly higher CO_2 emissions than the modern, efficient vehicles used in car sharing pools. Additionally, car sharing is the ideal use-case for battery electric cars, with short to medium distances in urban areas and high annual mileage. GHG abatement costs of shared BEVs would be lower than in other use-cases thus helping to increase numbers of BEVs on the streets and improve on the expansion of charging infrastructure.

6.11 Powertrain cost assumptions 2030

The study used for the calculation of profitable manufacturing cost a constant vehicle manufacturer integration cost factor of 1.8. This factor summarizes vehicle manufactures efforts for research and development, effort for the physical integration of components in the vehicle, vehicle manufactures' sales and administrative cost, vehicle manufactures' margins as well as retail cost. This cost calculation approach results in high technology cost than only considering material/component cost.

Figure 96: 2030 Incremental PT costs for Commercial Vehicles, EUR/vehicle pre-tax

Research and development costs		Vehicle integration costs		Selling, general and admin. costs		OEM margin		Retail margin		OEM surcharge factor
incl. system, testing		incl. logistics, assembly								applied on top of component costs
(15%)		(12%)		(10%)		(6%)		(20%)		
1.15	×	1.12	×	1.10	×	1.06	×	1.20	=	1.8x

Source: Roland Berger

Figure 97: Powertrain cost assumptions 2030

Technology		Comments	Cost assumption
Gasoline	**ICE conventional** > GDI, downsized engine > Fully variable valve train > Advanced thermal management > VCR optional > Optimized automated transmission > Road load reduction measures (tires, aerodynamic, vehicle weight reductions) > Gasoline particulate filter		2030 reference technology (average cost approximately 2.265 EUR)
High ethanol	**E20**	More robust powertrain components incl. OEM surcharge	9 EUR = 5 EUR x 1.8
	E85/FFV		180 EUR = 100 EUR x 1.8
Diesel	**ICE conventional** > Common rail direct injection (>2,500 bar) > Partly homogenous combustion > Low and high pressure EGR > High performance SCR aftertreatment > Optimized automated transmission	Diesel powertrain and exhaust aftertreatment components incl. OEM surcharge	1,800 EUR = 1,000 EUR x 1.8

Note: Some figures have been rounded

Technology			Comments	Cost assumption	
Hybrids	**Hybrids**	> 48V system (either BSG or transmission integrated)	Batteries + power electronics + OEM surcharge	720 EUR = 400 EUR x 1.8	
	Full Hybrid (FH)	> 60 kW parallel hybrid system, GDI TC engine	Batteries (1.5 kWh)	2,200 EUR = 198 EUR (99 EUR/kWh + batt. periphery)	3,600 EUR Cost for high-tech performance-focused version of respective powertrain
			+ E-Motor	+ 200 EUR	
			+ Power electronics	+ 550 EUR	
			+ Periphery	+ 200 EUR	
			+ Wiring	+ 50 EUR	
			+ OEM surcharge	x 1.8	
	Plug-in Hybrid (PHEV)	> 80 kW parallel hybrid system with 9 kWh or 14.5 kWh battery capacity > De-contented GDI TC engine and de-contented transmission (4-5 stage) > 40-80 km e-range	Batteries (cost-efficient: 9 kWh high-tech: 14.5 kWh)	3,500 EUR = 1,170 EUR (130 EUR/kWh + batt. periphery)	6,500 EUR = 1,885 EUR
			+ E-Motor	+ 200 EUR	∑ comp.cost of high-tech version: + 1,700 EUR
			+ Power electronics	+ 550 EUR	
			+ Periphery	+ 300 EUR	
			+ Wiring	+ 50 EUR	
			- Decontented GDI	- 300 EUR	No decont.
			+ OEM surcharge	x 1.8	x 1.8

Technology			Comments	Cost assumption	
BEVs	BEV Long-range (LR)	> Li-ion batteries > Range >400 km	Batteries (65 kWh)	9,800 EUR = 6,435 EUR (99 EUR/kWh)	11,000 EUR = 7,085 EUR (109 EUR/kWh)
			+ Other components (incl. E-Motor, Inverter, Charger, add. wiring)	+ 1,300 EUR	+ 1,300 EUR
			- ICE conventional powertrain	-2,265 EUR	-2,265 EUR
			+ OEM surcharge	x 1.8	x 1.8
BEVs	BEV Short-range (SR)	> Li-ion batteries > Range >200 km	Batteries (35 kWh)	4,500 EUR = 3,465 EUR (99 EUR/kWh)	5,100 EUR Cost for high-tech performance-focused version in high oil price of respective powertrain
			+ Other components (incl. E-Motor, Inverter, Charger, add. wiring)	+ 1,300 EUR	
			ICE conventional powertrain	2,265 EUR	
			+ OEM surcharge	x 1.8	

Note: Some figures have been rounded

Technology		Comments	Cost assumption	
CNG bivalent system	> GDI, downsized engine > 80% usage in CNG and 20% usage in G (E5) mode	Component costs + OEM surcharge	1,800 EUR = 1,000 EUR x 1.8	2,200 EUR = 1,200 EUR x 1.8
Fuel Cell (FCV)	> 100 kW fuel cell system > Range of up to 600 km	Fuel cell system (incl. BOP, MEA, BPP, H2 tank)		12,500 EUR = 9,000 EUR
		+ E-Motor		+ 200 EUR
		- ICE conventional powertrain		2,265 EUR
		+ OEM surcharge		x 1.8

Source: Roland Berger

Figure 98: 2030 Incremental PT costs for Commercial Vehicles, EUR/vehicle pre-tax

Segment	Cost Components	Mild Hybrid	Full Hybrid	Plug-in Hybrid	BEV	CNG	LNG	FCV
Light Commercials (LCV)[1] I+II > Gross vehicle weight < 1.8t	Add. PT cost	720 EUR	2,420 EUR	4,100 EUR	9,800 EUR	360 EUR		10,700 EUR
	= Cost of production	= 400 EUR	= 1,340 EUR	= 2,280 EUR	= 8,735 EUR[3]	= 1,200 EUR[3]	No LNG version in LCV segment	= 6,944 EUR
	- ICE conventional PT	N.A.	N.A.	N.A.	- 3,265	- 1,000 EUR[4]		- 1,000 EUR
	+ OEM surcharge[2]	x 1.8	x 1.8	x 1.8	x 1.8	x 1.8		x 1.8
Light Commercials (LCV)[1] III > Gross vehicle weight ≤ 3.5t	Add. PT cost		5,400 EUR	15,900 EUR	13,700 EUR	360 EUR		16,100 EUR
	= Cost of production	No MH version in LCV III segment[5]	= 2,996 EUR	= 8,838 EUR	= 10,900 EUR	= 1,200 EUR[3]	No LNG version in LCV segment	= 6,944 EUR
	- ICE conventional PT		N.A.	N.A.	- 3,265	- 1,000 EUR[4]		- 1,000 EUR
	+ R&D surcharge		x 1.8	x 1.8	x 1.8	x 1.8		x 1.5
	+ OEM surcharge							x 1.8
Medium Duty Trucks (MDT)[6] > Gross vehicle weight ≤ 16t	Add. PT cost	21,600 EUR			47,300 EUR	28,400 EUR		54,100 EUR
	= Cost of production	= 8,000 EUR	No FH version in MD segment	No PHEV version in MD segment	= 24,500 EUR	= 10,500 EUR	No LNG version in MD segment	= 27,000 EUR
	- ICE conventional PT	N.A.			- 7,000 EUR	N.A.		- 7,000 EUR
	+ R&D surcharge	x 1.5			x 1.5	x 1.5		x 1.5
	+ OEM surcharge	x 1.8			x 1.8	x 1.8		x 1.8

Note: Some figures have been rounded
1) LCV costs retrieved from IKA study trend scenario 2) Incl. integration, R&D, SG&A, retail cost 3) Cost assumption based on PC segment 4) Add. comp. cost for Diesel compared to Gasoline ICE 5) Version formerly described as MH now described as FH, as all functions of FH were included 6) MDT costs by coalition feedback

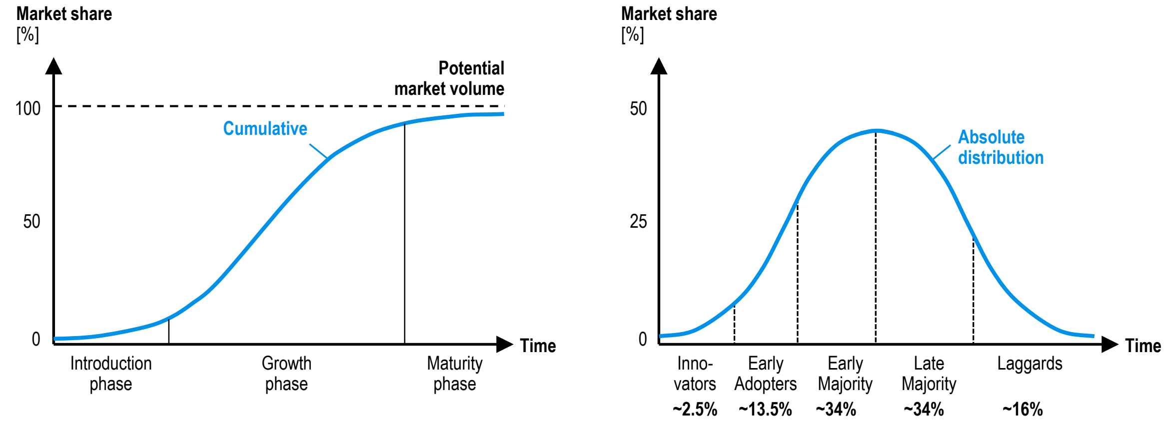
Segment	Cost Components	Mild Hybrid	Full Hybrid	Plug-in Hybrid	BEV	CNG	LNG	FCV
Heavy Duty Trucks (HDT)[1] > Gross vehicle weight > 16t[2]	Add. PT cost	27,000 EUR				37,800 EUR	30,000 EUR	72,900 EUR
	= Cost of production	= 10,000 EUR	No FH version in HD segment	No PHEV version in HD segment	No BEV version in HD LH segment	=14,000 EUR[3]	= 11,100 EUR	= 37,500 EUR
	- ICE conventional PT	N.A.				N.A.	N.A.	- 10,500 EUR
	+ R&D surcharge	x 1.5				x 1.5	x 1.5	x 1.5
	+ OEM surcharge	x 1.8				x 1.8	x 1.8	x 1.8
City Bus[4] > Short distance, public transport	Add. PT cost	27,000 EUR			100,000 EUR	37,800 EUR		72,900 EUR
	= Cost of production	= 10,000 EUR	No FH version in City Bus segment	No PHEV version in City Bus segment	= 47,540 EUR	= 14,000 EUR	No LNG version in City Bus segment	= 37,500 EUR
	- ICE conventional PT	N.A.			- 10,500 EUR	N.A.		- 10,500 EUR
	+ R&D surcharge	x 1.5			x 1.5	x 1.5		x 1.5
	+ OEM surcharge	x 1.8			x 1.8	x 1.8		x 1.8
Coach[4] > Long distance tours	Add. PT cost	27,000 EUR						
	= Cost of production	= 10,000 EUR	No FH version in Coach segment	No PHEV version in Coach segment	No BEV version in Coach segment	No CNG version in Coach segment	No LNG version in Coach segment	No FCV version in Coach segment
	- ICE conventional PT	N.A.						
	+ R&D surcharge	x 1.5						
	+ OEM surcharge	x 1.8						

Note: Some figures have been rounded
1) HD costs by coalition feedback 2) Incl. some delivery trucks 3) Niche application for utilities delivery 4) Cost assumptions based on HD segment, efficiencies and specific mileage from RB

Source: Roland Berger, Expert interviews, IKA CO_2 study

6.12 Details Customer Acceptance Model (CAM)

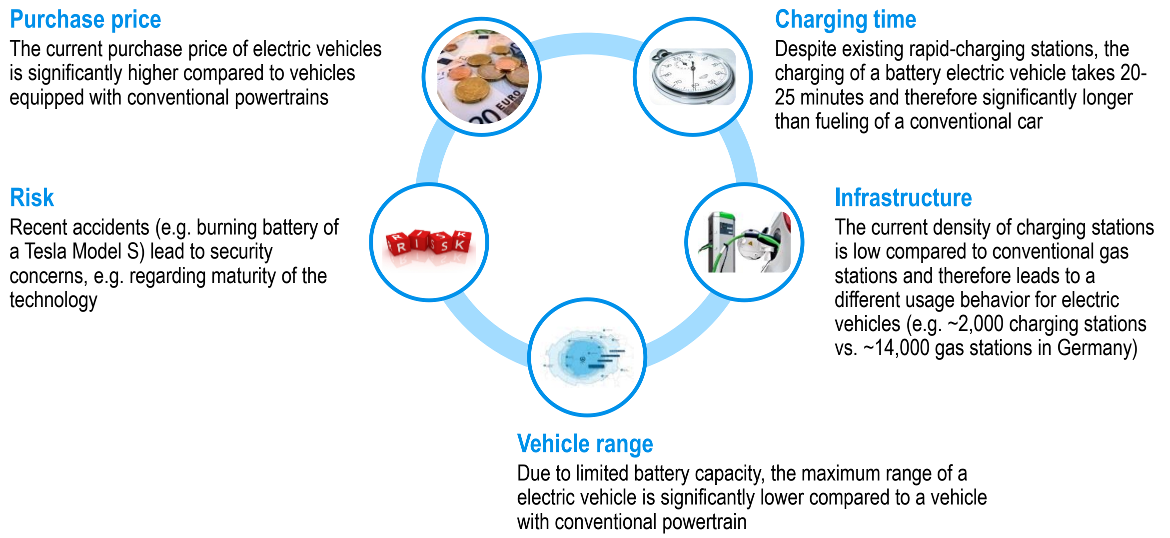
Figure 99: Rogers' market diffusion of innovations



> Acceptance of potential users is the main prerequisite for diffusion of innovations
> Rogers' market diffusion model is the standard theory for the explanation of adaption and diffusion processes

Source: Rogers (1962)

Figure 100: Main hurdles for e-mobility based on newspaper articles



Source: Roland Berger

Figure 101: Acceptance of e-mobility

Acceptance of e-mobility

Development and validation of a model considering the usage of car sharing

Dissertation by **Dr. Ludwig Fazel, Project Manager Roland Berger Strategy Consultants**

Springer Gabler Verlag, Reihe "Schriften zum europäischen Management"

ISBN 978-3-658-05089-4

Source: Roland Berger

Figure 102: Considered customer groups

Private customers

> People with exclusively private use of the vehicle and low annual mileage (< 20,000 km)
> Assumed average holding period: 7 years
> Share new car registrations: ~55%

> High importance of purchase price
> Only a small share of customers calculates total cost of vehicle usage
> Still strong concerns regarding electric powertrains

Company car buyers

> People with private and commercial use of the vehicle and medium annual mileage (< 30,000 km)
> Assumed average holding period: 3 years
> Share new car registrations: ~21%

> Purchase price of importance, running costs with low/no relevance

Commercial customers

> Companies or people with exclusively commercial use of the vehicle and high annual mileage (mostly > 30,000 km)
> Assumed average holding period: 3 years
> Share new car registrations: ~24%

> High importance of running costs

1 Acceptance model E-mobility

2 Extended TCO model[1)]

1) Explanation model with dominant relevance of TCO of vehicle usage

Source: Fraunhofer; NPE; Roland Berger

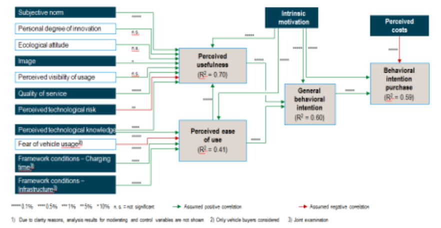
Figure 103: Acceptance model – E-Mobility and Extended TCO model

1 Acceptance model – E-Mobility

Model

All major relationships within research model show highly significant correlations – Model applied to European environment here

Explanatory model for the acceptance of e-mobility in Germany

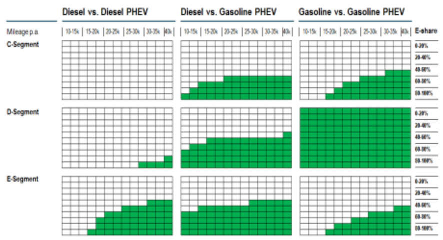


> Basis is technology acceptance model measuring the customers' readiness for the use of a certain technology
> This includes an analysis of behavior intentions depending on subjective values (i.e. individual norms) and impact factors influencing the acceptance of the new technology
> Any relevant connections of this model show a significant correlation

2 Extended TCO model

Model

Diesel PHEVs only cost-efficient in E-segment with high mileage – Gasoline PHEVs mainly cost-efficient in D-segment

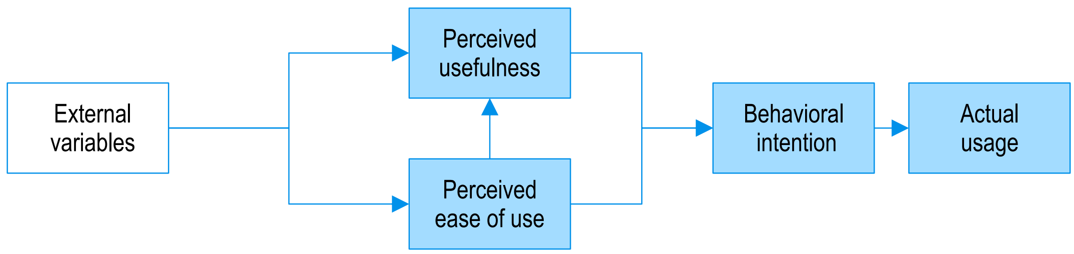


> The TCO model serves as a basis for calculating costs occuring due to the implementation of BEVs and PHEVs, compared to conventional powertrains and depending on average mileage per year and share of e-driving
> The model compares Diesel PHEVs, Gasoline PHEVs and EVs by segment (C, D, and E segment considered)
> Therefore, the model calculates potential savings in pure operating costs but also operating costs including maintenance and TCO (operations, maintenance, loss in value)

Source: Roland Berger

Figure 104: Technology Acceptance Model (TAM) by Davis

Independent variables | **Mediators** | **Dependent variables**



e.g.
– Subjective norm
– Image
– Working relevance
– Visibility of results
– ...

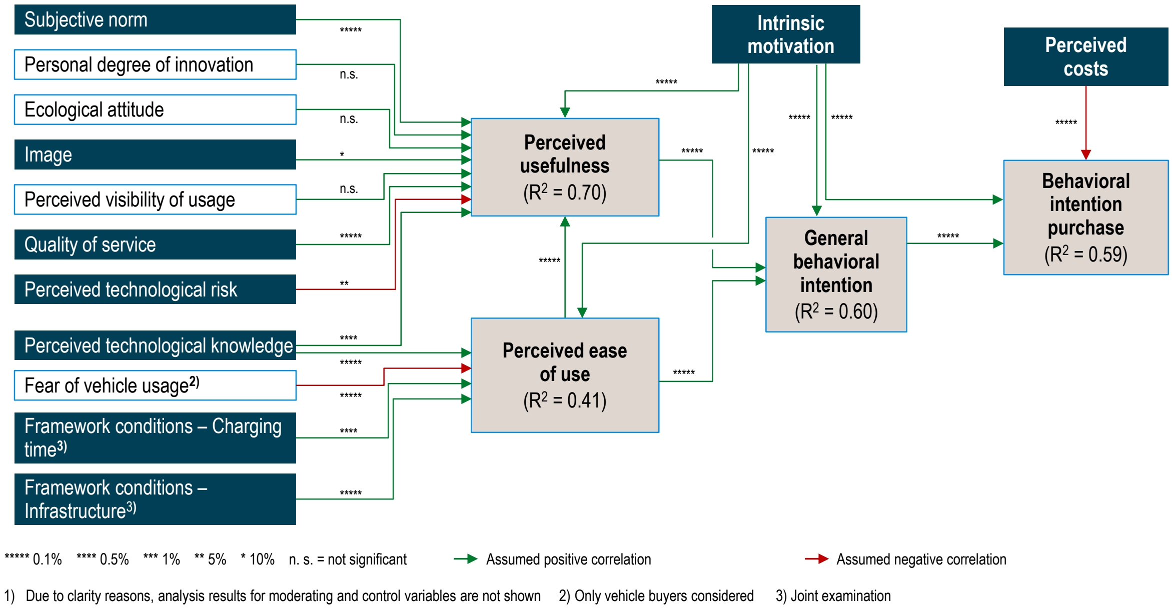
Main factors influencing the acceptance of new technologies

Strong dependence between intention and actual usage has been scientifically demonstrated

Exogenous variables | Endogenous variables | Correlation

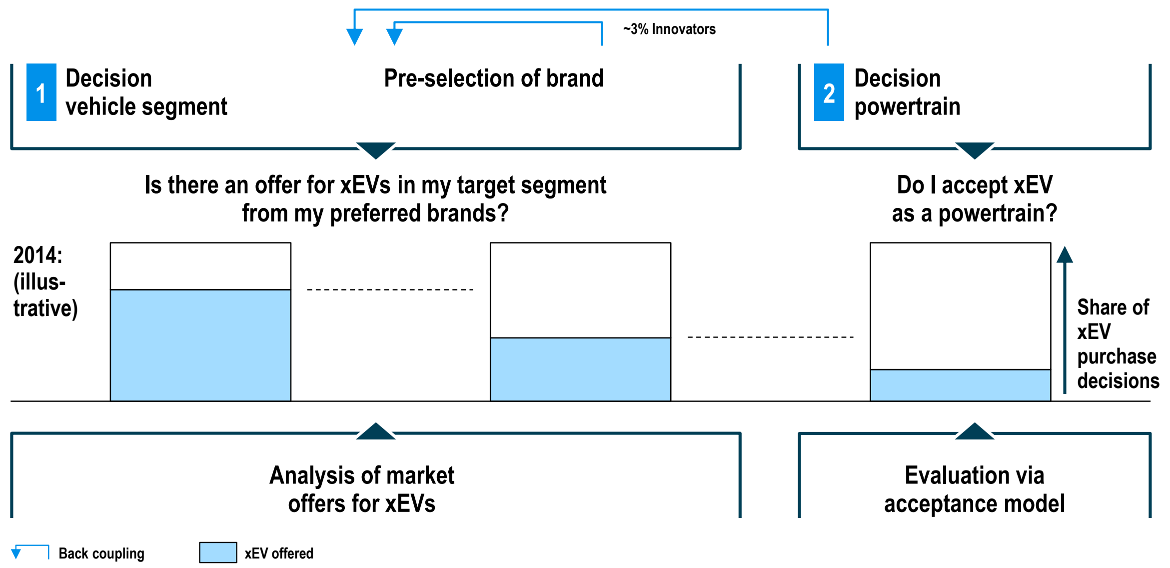
Source: Davis (1989

Figure 105: Explanatory model for the acceptance of e-mobility in Germany



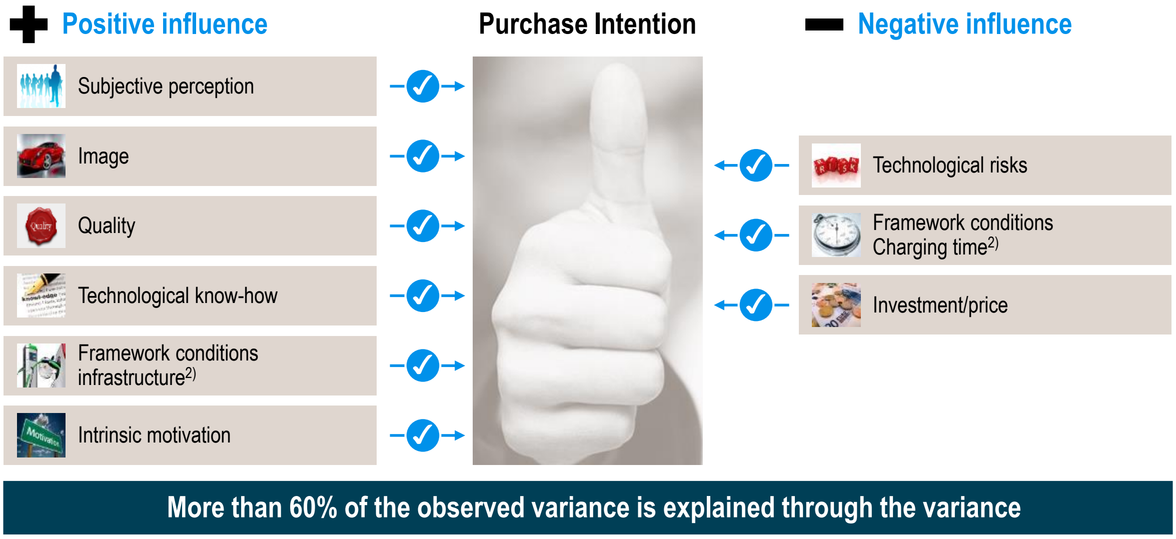
Source: Fazel

Figure 106: Model assumptions for derivation of xEV purchase decision:



Source: Roland Berger

Figure 107: Base model



Empirical correlation on the basis of structural equation modelling validated

1) A significant correlation was established – the reverse effect is valid for negative influence 2) Joint reflection

Source: Roland Berger

Figure 108: Results of the empirical validation of the base model (1/2)

The subjective perception has a very strong positive effect on the acceptance of xEVs: The higher the pressure of the social environment (e.g. through friends and family), the stronger is the realization about the usefulness of EV usage.

The image has a positive effect on the acceptance of xEVs: The more users think that they can improve their social status through EV usage, the stronger is the realization about the usefulness of xEV usage.

Quality has a very strong positive effect on the acceptance of xEVs: The more people rely on the technological performance of EVs, the stronger is the realization about the usefulness of xEV usage.

Framework conditions – Charging infrastructure has a very strong positive effect on the acceptance of xEVs: The better the charging infrastructure with respect to proximity and availability, the stronger is the realization about the usefulness of xEV usage.

The intrinsic motivation has a very strong positive effect on the acceptance of xEVs: The higher the inner pressure of people through the driving itself (e.g. feeling of fast acceleration and noiseless driving), the stronger is the realization about the usefulness of xEV usage and ease of use.

Alleged technological risks have a negative effect on acceptance of xEVs: The higher the number of people is that mistrust the safety of new xEV technology, the less the individual usefulness is assessed.

The fear of vehicles has a very strong negative influence on acceptance of xEVs: The higher the general fear of the usage of the vehicles, the lower is the acceptance of xEVs

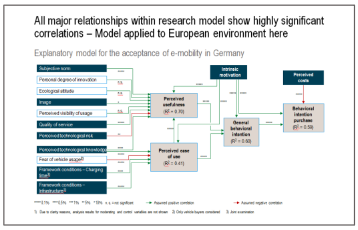
Framework conditions – Charging time has a strong negative effect on acceptance of xEVs: The higher (longer) the time to charge an xEV, the lower the perceived ease of use of the new technology. Therefore, the relatively longer time to charge an EV compared to a conventional vehicle is a significant obstacle for potential users and reduces the intention for usage.

The perceived costs have a very strong negative effect on the intention to the purchase an xEV: The higher the purchase price of an xEV, the lower is the intention to purchase an xEV.

With respect to the usage behavior, the intention of potential customers to use an xEV in connection with e-carsharing is higher than to purchase an xEV. This statistical effect is already considered through the influence of the purchase price on the intention to purchase an xEV (see perceived costs). On the one hand side, this fact shows the desire of people to test a new technology before purchasing is, on the other hand does this reflect the general trend of the sharing economy.

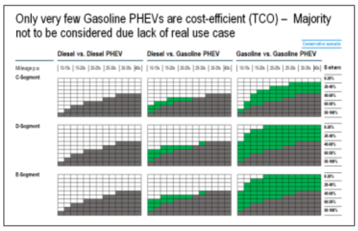
Source: Roland Berger

Figure 109: PC new car sales shares by powertrain, 2030, Scenario A [%]



1 Acceptance model E-mobility

2 Extended TCO model

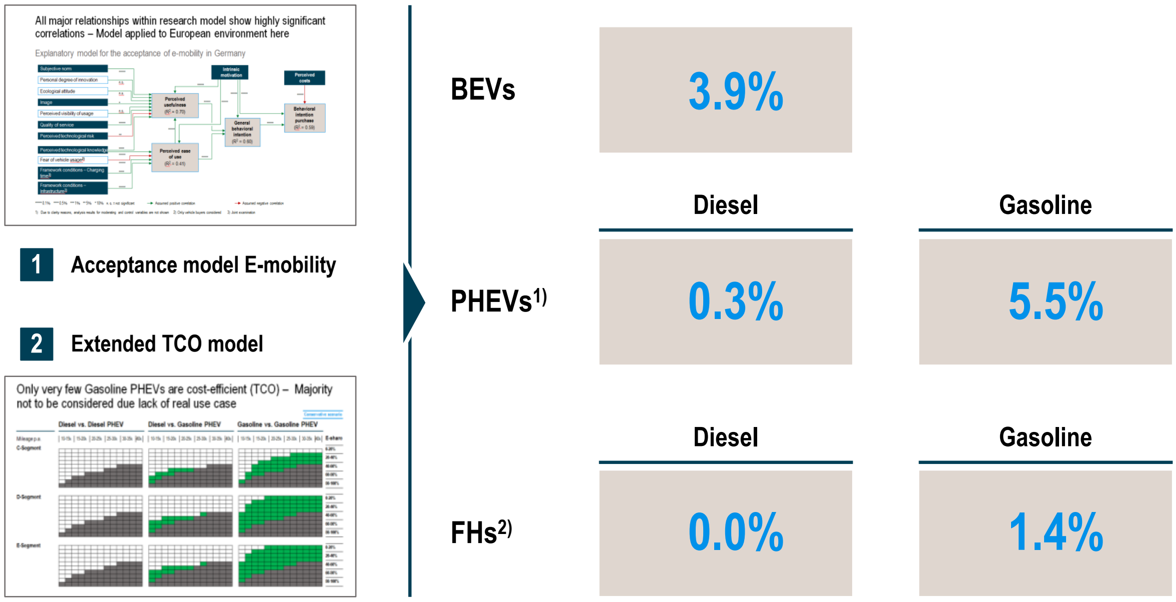


	Diesel	Gasoline
BEVs	3.0%	
PHEVs[1)]	0.2%	3.2%
FHs[2)]	0.0%	1.3%

1) Share between Diesel PHEV and Gasoline PHEV by assumption 2) Share between Diesel FH and Gasoline FH by assumption

Source: Roland Berger

Figure 110: PC new car sales shares by powertrain, 2030, Scenario B [%]



1) Share between Diesel PHEV and Gasoline PHEV by assumption 2) Share between Diesel FH and Gasoline FH by assumption

Source: Roland Berger

6.13 Cost calculation for EU-wide retail station coverage

Figure 111: Overview approaches infrastructure investments and summary results

Key assumptions

> Calculation of the investment cost required for a retail network, that needs to be in place for the **customer to "accept" the vehicle technology from an infrastructure perspective**

> Infrastructure size is **independent from the fleet size**!

Fuel/vehicle technology	EU-wide infrastructure estimation approach	Annualized cost [EUR m]
1 CNG	Based on replacement model of conventional retail stations	430
2 Hydrogen	Based on replacement model of conventional retail stations	2,300
3 Electricity for BEVs/PHEVs	Based on number of charging stations per square kilometer for public chargers (urban/intermediate areas) and distance at highways for DC fast chargers	6,250
3 E85	Based on replacement model of conventional retail stations	247

Source: Roland Berger

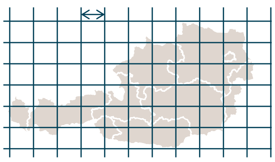
Figure 112: Methodology to estimate size of EU-wide retail station network – Illustrative

Step 1

> The maps of different European countries is divided into a grid of squares of a specific length

> Length of square represents ~10 minutes driving distance (10 km)

10 km ~ 10 mins driving distance

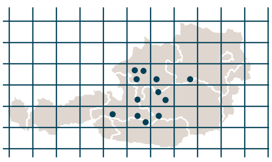


Picture is illustrative

Step 2

> Mapping of conventional gasoline/diesel retail stations in Europe

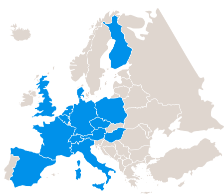
> The number of squares including retail stations is determined



Picture is illustrative

Step 3

> Steps 1 and 2 are conducted for 15 European countries covering ~90% of the European vehicle fleet



Step 4

> Assumption that in each square with at least one conventional retail station, one CNG retail station (dispenser) would also have to be built

> Scale-up of the resulting number of retail stations from EU15 to EU28 to simulate EU-wide coverage

Result:
~23,000 retail stations (dispensers) for EU wide coverage

Source: Volkswagen, Roland Berger

Figure 113: Cost assumption for the CNG retail network

Key assumptions

Assumptions for average retail station

> Investment cost in 2015	EUR 0.25 m	coalition
> Specific capacity	150Nm³/h	RB assumption
> Progress ratio	99%	coalition
> Annual operating hours	8,760 hours	RB assump.
> Technical lifetime	20 years	RB assump.
> Operation & maintenance	2.7%	Fraunhofer
> Interest rate	4%	Cost to society

EUR 0.019 m
Annualized cost per retail station

Total infrastructure investment cost

> Number of available retail stations today	~3,300	cngeurope.com
> Required retail stations	23,000	modeled

~19,700
Additional required retail stations

~430 m EUR
annualized cost for total retail infrastructure

Source: Roland Berger

Figure 114: Size of and investment cost for EU-wide H2 retail station network

EU-wide network size

- For derivation of the EU-wide number of retail stations, the same approach as for CNG is used
- It is assumed that such a coverage (~10 minutes driving distance) is required for the customer to be able to accept the technology from an infrastructure perspective
- Resulting number of retail stations to be installed for EU-wide network: 23,000[1)]

Investment cost for H2 retail station

> Investment cost in 2015	EUR 1.4 m	coalition
> Specific capacity	400kg/h	coalition
> Progress ratio	97.8%	coalition
> Annual operating hours	8,760 hours	coalition
> Technical lifetime	20 years	coalition
> Operation & maintenance	2.7%	coalition
> Interest Rate	4%	Cost to society

Annual cost per station EUR 0.101 m

Total cost for EU-wide network

> Number of available retail stations today	~50	coalition
> Required retail stations	23,000	modeled
> Additionally required retail stations	~22,950	RB calc.
> Annual cost per station	EUR 0.101 m	RB calc.

EUR ~2,300 m
annualized cost for total retail infrastructure

1) Including already installed H2 stations (~50 stations)

Source: Roland Berger

Figure 115: Methodology to calculate EU-wide EV charging infrastructure

Urban/intermediate areas

- Based on NUTS3[1)] Eurostat data, derivation of area of urban regions and intermediate regions
- Assumption on EV-charging density per 1000 inhabitants based on JRC[2)]
- Assumption that public level II chargers are relevant chargers for urban/intermediate areas
- Calculation of number of EV chargers in urban and intermediate area as product of inhabitants and EV charging density

Motorways

- Based on Eurostat data, derivation of length of motorways in EU28
- Assumption that DC fast chargers are relevant chargers for urban/intermediate areas
- Based on expert interviews with coalition members estimation of average distance between chargers and charging points per charging station
- Calculation of number of EV chargers on motorways as quotient of length of motorway and average distance between charging stations times number of charging points per station

Private/corporate chargers

- Not included in this calculation, as the number of private/corporate chargers depends on the actual uptake of electric vehicles (and is not independent from fleet size)

1) NUTS: Nomenclature of Territorial Units for Statistics referencing the subdivisions of countries for statistical purposes 2) Nemry & Brons, Plug-in Hybrid and Battery Electric Vehicles Market penetration scenarios of electric drive vehicles (2010)

Source: Roland Berger, JRC

Figure 116: Assumptions for number of EV chargers

	Urban/Intermediate Area			Motorways		
Key assumptions	> Number of available retail stations today	~10,750	EC	> Number of available retail stations today	~1,250	supercharge.info
	> Urban population	221,239,015	Eurostat	> Length of Motorways in EU	71,405 km	Eurostat
	> Intermediate population:	175,339,388	Eurostat	> Posts per charging station	8	RB assumption
	> No. of charger/inhabitant	0.013	JRC	> Average Distance between chargers	60 km	Coalition
	> Only level II public chargers will be installed			> Only DC fast chargers will be installed		
Required number of EV chargers	5,025,500 Required level II public chargers			9,520 Required DC fast chargers		
Additionally required number of EV chargers	5,014,750 Additional required level II public chargers			8,270 Additional required DC fast chargers		

Source: Eurostat, JRC, Roland Berger

Figure 117: Cost assumptions for EV charging infrastructure

	Level II public charger			DC fast charger		
Key assumptions	> Investment cost in 2015	EUR 5,280	DAFI[2]	> Investment cost in 2015	EUR 41,000	JRC[3]
	> Specific capacity:	22kW	DAFI[2]	> Specific capacity:	40kW	JRC[3]
	> Progress ratio:	99.7%	coalition	> Progress ratio:	99.7%	coalition
	> Annual operating hours:	8,760 hours	RB assump.	> Annual operating hours:	8,760 hours	RB assump.
	> Technical lifetime:	10 years	RB assump.	> Technical lifetime:	10 years	RB assump.
	> Operation & maintenance:	12%[1]	coalition	> Operation & maintenance:	5%[1]	coalition
	> Interest Rate:	4%	Cost to society	> Interest Rate:	4%	Cost to society
Total annualized cost per charger type	EUR 1,231 annualized cost per charger			EUR ~6,800 annualized cost per charger		
Required number of EV chargers	5,014,750 Additional required public chargers			8,270 Additional required DC fast chargers		

EUR ~6,250 m
annualized cost for total retail infrastructure

1) Excluding connected services 2) Impact assessment of Directive on the deployment of alternative fuels infrastructure 3) Plug-in Hybrid and Battery Electric Vehicles: Market penetration scenarios of electric drive vehicles

Source: Roland Berger

Figure 118: Cost assumption for E85 at all retail stations

	Assumptions for average retail station			Total infrastructure investment cost		
Key assumptions	> Investment cost in 2015	EUR 0.1 m	Coalition	> Number of retail stations today	~3,000	t-ec2
	> Specific capacity	375l/h	RB assump.	> Required retail stations	23,000	modeled
	> Progress ratio	99.5%	RB assump.			
	> Annual operating hours	8,760 hours	RB assump.			
	> Technical lifetime	10 years	RB assump.			
	> Operation & maintenance	1%	RB assump.			
	> Interest rate	4%	Cost to society			
	EUR 0.012 m Annualized cost per retail station			~20,000 Additionally required retail stations		

~247 m EUR
annualized cost for total retail infrastructure

Source: Roland Berger

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