The automotive industry and climate change

Framework and dynamics of the CO_2 (r)evolution

PricewaterhouseCoopers

”Inventing is indefinitely more beautiful than having invented“

Karl Benz

Foreword

As we head towards the opening of the 2007 International Motor Show Cars (IAA) in Frankfurt, the CO_2 discussion in the automotive industry is continuing at an intense pace. Climate change and CO_2 reduction have garnered enormous quantities of press coverage in both industry and general media. As a result, we are witnessing today a heightened public awareness which is in turn stimulating strong consumer expectations for regulators and the automotive industry to address this top priority issue.

Due to mounting public debate and regulatory pressures, we are currently seeing strong efforts and renewed investments by manufacturers and suppliers in providing solutions to the CO_2 reduction challenge. As opposed to other environmental regulations affecting the auto industry, this time the solutions and strategies available are more complex and go far beyond the simple question of which is the most suitable engine technology. Both the auto industry's response to a regulatory framework as well as its competitive positioning as a result of it, will depend on the nature of the detailed legislation itself. Environment protection groups are calling for greater legal enforcement and new, stricter laws, the EU and local governments are themselves considering a variety of regulatory measures, like CO_2 emission limits or emission-based taxation. Responding to this, automakers emphasize the negative effects a proposed legislation might have and refer instead on technological improvements either already achieved or still upcoming. Furthermore, competitive battle lines between German, French and Italian manufacturers are being drawn up as to which strategic course of action the EU should employ to regulate CO_2 emissions. Given their fleet structure, the Italians and French prefer a blanket approach in line with a uniform fleet limit, while most German companies call for a differentiated approach, based for instance on weight or segment of the vehicles and thereby request an equitable contribution to the required increase in fuel efficiency by all manufacturers.

On the other side of the spectrum, consumers continue to face uncertainties and have a myriad of questions that still need to be addressed.

Our study aims to investigate and analyse the framework, the challenges and the dynamics of the CO_2 reduction puzzle in the automotive sector by shedding light on the fundamental issues and putting them in context: What are the overall motivating factors behind the environmental ambitions of the regulators? Where does the automotive industry stand in view of vehicle emissions and the efforts to reduce them? What are the current regulatory approaches towards achieving stricter CO_2 targets and what supply-side approaches are there available to achieve such emission levels? Finally, the question needs to be examined as to what the consumer's position is in all this and how the demand for cleaner vehicles can best be stimulated?

These are complex, interdependent and vital questions for the auto industry, explored by the experts of the PwC Automotive Advisory Practice and the PwC Automotive Institute (AUTOFACTS), namely Andreas Bockwinkel, Christian Johansson and Calum MacRae, whom we wish to cordially thank for the production of this study.

Stuttgart, September 2007

Karl Gadesmann
Partner, EMEA Automotive Leader
PricewaterhouseCoopers AG

Felix Kuhnert
Partner, German Automotive Advisory Leader
PricewaterhouseCoopers AG

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Abbreviations

a/c	Air conditioning
ABS	Antilock Braking System
ACEA	European Automobile Manufacturers' Association
ACT	Annual Circulation Tax
AMT	Automated Manual Transmission
AT	Automated Transmission
AWG	Ad hoc Working Group
B100	100% Biodiesel
B20	20% Biodiesel
bar	Units of pressure
BioKraftQuG	Biokraftstoffquotengesetz (German Biofuel Quota Act)
BRIC	Brazil, Russia, India and China
BtL	Biomass to Liquid
CAFE	Corporate Average Fuel Economy
CAGR	Cumulative Annual Growth Rate
CARB	California Air Resources Board
CARS 21	A Competitive Automotive Regulatory System for the 21st century
CCE	Combined Combustion Engine
CEE	Central and Eastern Europe
CEO	Chief Executive Officer
CFC	Chlorofluorocarbon
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
COP	Conferences of the Parties
CVT	Continuously Variable Transmission
c_w	Drag coefficient
DAT	Deutsche Automobil Treuhand GmbH
DB	Deutsche Bank
DCT	Dual-Clutch Transmission
DEFRA	Department for Environment, Food and Rural Affairs
DISI	An ICE using the Direct Injection Spark Ignition technology
DIW	Deutsches Institut für Wirtschaftsforschung (German Institute for Economic Research)
DME	Di-Methyl-Ether
DPF	Diesel Particulate Filter
E100	100% Ethanol
E85	85% Ethanol
EBB	European Biodiesel Board
EC	European Commission
EIA	Energy Information Administration
EIT	Economies in Transition
ELV	End of Life Vehicle
EU	European Union
FC	Fuel cell
FFV	Flexible Fuel Vehicles
FOB	Free on Board
g	Gram
GDP	Gross Domestic Product
GHG	Greenhouse gas
GtL	Gas to Liquid
H_2O	Water
HC	Hydrocarbons

HCCI	Homogeneous Charge Compression Ignition
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IVT	Infinitely Variable Transmissions
JAMA	Japanese Automobile Manufacturers Association
KAMA	Korean Automobile Manufacturers Association
KBA	Kraftfahrt-Bundesamt (German Federal Motor Transport Authority)
KERS	Kinetic Energy Recovery Systems
kg	Kilogram
km	Kilometre
kph	kilometres per hour
kW	Kilowatt
l	Litre
LEV	California Low Emission Vehicle Legislation
LPG	Liquefied Petroleum Gases
mg	Milligram
mi	Mile
mm	Millimetre
Mpa	Mega Pascal, unit of pressure (1 MPa = 10 bar)
mpg	Miles per gallon
MY	Model Year
NaSE	Nationale System Emissionsinventare in Deutschland (National System Emissions Inventory)
NO_x	Nitrogen oxide
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
PED	Price Elasticity of Demand
PISI	An ICE using the Port Injection Spark Ignition technology
PM	Particulate matter
ppm	Parts per million
Q&A	Questions & Answers
R&D	Research and Development
RME	Raps-Methyl-Ester
RT	Registration Tax
SUV	Sports Utility Vehicle
TDI	Turbodiesel Direct Injection
TPMS	Tyre Pressure Monitoring Systems
TREAD	Transportation Recall Enhancement Accountability
TtW	Tank to Wheel
UBA	German Federal Environment Agency (Umweltbundesamt)
UK	United Kingdom
ULSAB	Ultra Light Steel Automotive Body
UNFCCC	United Framework Convention on Climate Change
US	United States
USDA	United States Department of Agriculture

vans	Light-commercial vehicles
VAT	Value Added Tax
VCD	German traffic organisation (Verkehrsclub Deutschland)
VDA	German Association of the Automotive Industry (Verband der Automobilindustrie)
VGT	Variable Geometry Turbocharger
VP	Vice President
Wh/kg	Watt-hour/kilogram
WtW	Well to Wheels

Executive summary

External drivers of the CO_2 reduction debate in the auto industry

Climate change and energy security concerns are in our view the primary drivers in the current discussions on CO_2 reduction in the automotive industry. Even though it has not been finally proven by scientists, it is widely assumed that global warming is caused by anthropogenic greenhouse gases (GHGs), with CO_2 playing the most prominent role. Recent weather phenomena, natural catastrophes and changes in nature are attributed to global warming and thus indirectly to CO_2 emissions. In 1997, a variety of countries passed the Kyoto Protocol, setting targets for their CO_2 reduction. Even though some countries never ratified the Kyoto Protocol, it is widely accepted as the underlying global standard for expressing a commitment to reduce CO_2.

Recent studies concluded that the economic impact of climate change in Germany would amount to costs in the region of 800 billion euros by 2050. The need for a global response seems to be the order of the day for both politicians and regulators, thus putting further pressure on the industry. With particular reference to the automotive industry, two major challenges arise: fuel saving and emission reduction – two different problems, leading to the same challenge – how to make vehicles more efficient, while keeping additional costs at an acceptable level so as to make ‘green’ vehicles attractive to consumers.

Consumer preferences and behaviour

Over the last decade we have seen an increasing demand for vehicles with improved performance not just in terms of higher output, but also additional safety features, electronics and other luxury or premium equipment. At the same time, environmentally friendly cars offered by carmakers as a test of demand could boast only limited market success.

As a result of these dynamics, a large part of the technological successes in the past in terms of increased fuel efficiency *was* taken up by consumer demand and fulfilling additional regulatory requirements (e.g. safety regulations). Given the environmental debate today, one of the most critical issues automotive companies face is the willingness of consumers to adjust their preferences and under what circumstances they are likely to do so. Secondly, the question needs to be examined whether carmakers are in the position to demand a price premium for applying new and costly technology so as to recover investments in additional research and development.

Without an available assessment of these key aspects, the automotive industry will not be able to respond effectively. We therefore found it necessary to conduct a market survey of consumers, the key results of which are summarized below:

- Highly abstract awareness of the problem and the environment

  In the minds of the drivers questioned, the connexion between driving and the greenhouse effect is apparent, but only at second glance. When one poses an open (i.e. unaided) question about the problems of driving today, hardly anyone thinks of the environmental issue and instead three other topics seem to spring to mind: the (too) high price of petrol, the (excessive) congestion on the roads and the careless or aggressive driving of other road users.

  However, as soon as the problem of the environment and climate change is raised obliquely, it is demonstrably linked to the subject of driving. When addressing the problem of the environment directly, drivers do, on the whole, acknowledge its existence. Indeed, 70% of those questioned believe that greenhouse gasses are responsible for the global rise in temperatures and even 72% of all drivers accept that CO_2 emissions caused by cars on the road make a substantial contribution to global warming. The link, however, between the environmental issue and driving is not a pivotal one[1]. The subject seems too large to pit against the individual motorist, who tends to acknowledge the problem passively, to discuss the subject in abstract terms and yet doesn't see him or herself as a part of the problem. People are aware that in many areas more needs to be done for the environment but the same people do not have the feeling that they, as individuals, are able to contribute to reducing the greenhouse effect.

- Hardly any concrete desire to change driving behaviour for environmental reasons

  The current contributions of various social groups towards reducing carbon dioxide emissions tend to be greeted with scepticism. Government, industry and consumers are all rated similarly, whereas motorists themselves rank as the one social group that can make the least contribution to reducing carbon dioxide emissions. A total of 42% of the motorists questioned stated that they had made a change in their driving behaviour in the last years. When questioned obliquely about the nature of this change in behaviour, only a marginally small minority (6% out of 42%) placed it explicitly within an ecological context. Although the changes most frequently mentioned (driving with more caution, more slowly and more economically) may well have a positive ecological impact attributed to them, these changes in behaviour do not seem, in themselves, to be ecologically motivated. They connote positive ecological spin-off effects, but essentially appear to be responses to perceived stress factors and strains created by increased congestion and higher fuel prices.

- The use of new technologies to help the global climate is often not greeted with a thorough understanding

  Sixty-seven percent of all those questioned are of the opinion that biofuels will play an important role for the future. At 57%, hybrids rank second place, but were completely unknown by 23% of those surveyed. Fuel cells, which came in third place with 50%, were unheard of in 19% of those questioned. Electric vehicles were rated ambivalently: 46% thought they had good prospects for the future and 47% did not believe in them. When the mild or micro hybrid drive technology (e.g. start/stop) was put forward to them, 31% of those questioned had nothing to say about it at all.

- Moderate willingness to purchase hybrid cars, price premiums considered critical

  Thirty-one percent of the drivers surveyed claimed they would consider purchasing a hybrid car as their next vehicle. Of this 31%, as much as a third would change their minds if the hybrid vehicle was more expensive than a conventional one, the remaining consumers do not seem to be willing to pay a significant price premium. Only 6% of these questioned would consider purchasing a hybrid car, if the price premium were to exceed 2,000 euros. This once again confirms that 'green technologies' only become sellable to the public if they do not cost considerably more than 'non-green technologies'.

[1] Following research findings on the effects of advertising, this phenomenon can be labelled as either 'aided' or 'unaided' awareness of the environmental issues of driving. Unaided awareness is the more important of the two since it has the potential to alter behaviour. It is also something that is not easily attainable. Here, the consumer actively makes the connexion, creating a link, which then becomes so pivotal and significant, that it in all probability informs his or her further actions. Aided awareness is, in contrast, easy to achieve, it is little more than the passive affirmation of an other's demand – and for this reason as a rule holds neither particular significance nor potential to alter behaviour at all in the mind of the person being surveyed.

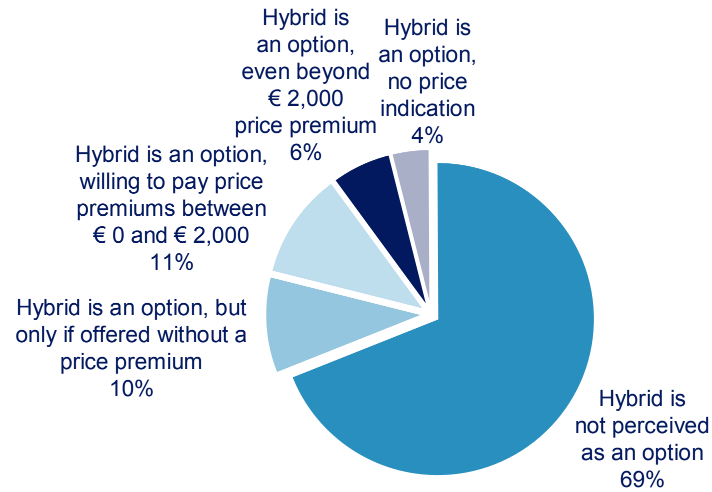


Fig. 1 Customers' judgement on hybrids

- Roughly three out of ten drivers cannot be moved to change their driving behaviour

  Fifty-eight percent of the drivers questioned stated that they had not altered their driving behaviour over the last years and of these, the majority (54%) could not envisage that there could be any particular event which would force them to change their behaviour. Roughly three out of ten drivers cannot be moved to alter their behaviour significantly, at least not through abstract argumentation or appraisement.

The above stated outcomes define the consumer framework, which policy makers and automotive companies need to acknowledge when setting their regulatory goals and strategies. Before going directly into the potential responses and available concepts for the automakers, we need to consider past achievements and developments in order to understand the dynamics and framework of the CO_2 reduction puzzle.

The automotive industry – the usual suspect

About 19% of European CO_2 emissions are attributed to road transportation, giving it a strong social responsibility. We have already seen significant gains in efficiency and achievements in CO_2 reduction, in particular among the German carmakers, but the newly discussed emission reduction levels will not be achievable without further significant efforts being made.

The majority of the German carmakers are competing in the premium segment which is attracting a growing number of consumers around the world. This segment has the demerit of having, in absolute numbers, higher CO_2 emissions, resulting from their high performance and additional features, including safety and other equipment. Our study and research suggest that the premium segment has been, and should remain, the breeding ground for innovative concepts. Attainable price premiums in the premium segment provide the necessary incentives for innovations, before experience and economies of scale allow for them to be deployed in other price-sensitive segments. The premium segment is often blamed, without the achievements and contributions that it makes in reducing its own emissions being given due recognition. More importantly though, its own role as an incubator for new technological advancement across all segments is largely ignored.

In 1998, under growing pressure from the regulatory bodies and margin pressures from the highly competitive market, the members of the ACEA together with their Korean and Japanese counterparts voluntarily committed themselves to the goal of reducing CO_2 emissions to 140 g/km (by 2008 for the ACEA and 2009 for the JAMA and KAMA), applying to all cars sold in Europe. Even though German carmakers had previously been successful in fulfilling and even surpassing their own voluntary pledges made to the German government, this time questions were raised as to whether most manufacturers would be able to achieve the ACEA levels by 2008. This in turn led the EU's Commissioner for the Environment, Mr Dimas, to rethink future EU climate policy for the automotive sector.

In February 2007, the EU confirmed its targets for the reduction of CO_2 emissions in cars and light commercial vehicles: automobiles are to produce no more than 120 g/km of CO_2 by 2012, bearing two separate provisions. These provisions will allow new vehicles to be sold to produce no more than 130 g/km by 2012, with the overall target to be met by way of biofuels and other technical advancements. However, the extent to which this reduction target is to be applied to the industry overall remains open. Is it to be applied as a uniform fleet limit to all manufacturers or will it be set as an overall industry average with different thresholds for different segments, for instance using the parameter of weight (kg) or output (kW)?

We consider it essential that whatever form the new system takes, it does not impact on and distort competition unduly; and that other competing regulations such as safety standards should not be overlooked in favour of efforts to reduce CO_2 emissions. We therefore share the view unanimously expressed throughout our expert interviews exemplified by Dr Thomas Schlick of the German Association of the Automobile Industry (VDA): *"A fair and equitable piece of legislation must aim to take everybody into account and deliver towards the overall goal of CO_2 reduction. A blanket, uniform emission target for every automotive manufacturer would have the adverse effect that volume-oriented small-sized car manufacturers will not have to contribute to CO_2 reductions, while premium manufacturers would be overstrained."* We believe that in all segments significant technological improvements can still be made to deliver an optimised contribution in terms of costs and reduction.

The supply-side enigma – searching for technological salvation

The various technological options to contribute to CO_2 emission reduction can be categorized into three main areas: engine concepts, alternative fuels and 'beyond engine technology'.

Summarizing the options currently under discussion regarding the use of alternative fuels, biofuels have come out with the greatest of interest, arousing a degree of curiosity and excitement. The technological changes that are required are limited, as most biofuels can be blended with traditional fuels and thus be used in existing vehicles and distributed via the existing infrastructure. However, the amount of arable land available is limited and there is a potentially severe risk in linking the food market and the fuel market, something which would have to be watched carefully. Furthermore, biofuels could enter into competition for arable land in regions containing rain forests, which would subvert their initial purpose and severely and irrevocably damage the environment. On the other hand, gas, either liquefied (LPG) or compressed (CNG), already presents an alternative to traditional fuels. Gas, even though a fossil fuel, achieves better emission ratings than traditional fuels. The technological adjustments necessary are rather simple and affordable, so that coupled with low prices and tax incentives, gas represents an attractive short-term alternative available for the future.

Most of the experts we interviewed agree with our assessment that traditional gasoline and diesel engines will continue to dominate over the next decades. For instance, Dr Klaus Draeger from BMW states: *"Based on our current technological know-how, we expect the combustion engine to remain the dominant powertrain concept over the next decades."* Improvements through downsizing, charging and direct injection provide an adequate pathway and potential for future emission reduction. Diesels, similar to gasoline, will continue to play their successful and dominant role, although regulatory requirements in terms of other exhaust emissions are putting an extra burden on diesel development and its costs. The convergence of diesel and gasoline engines is also a viable option, as it combines the advantages of both technologies.

The efficiency of internal combustion engines will further be improved by moves towards electrification and hybridisation. Small electric engines will be used for start-stop systems, regenerative braking and engine assistance. Further levels of hybridisation to follow will depend on the CO_2 'footprint' of each individual automaker and their own requirements to meet their particular CO_2 target. It will also be dependent on the EC's final decision on how CO_2 emissions are to be accounted for across Europe. With respect to full hybrids, given their high cost and far from perfect ecological rewards, we expect the market for them to develop further but only on a low level – due in part to the fact that they are not being extensively pushed by the manufacturers and also because the average customer is unlikely to be willing to pay a substantial price premium for the technology. A further problem for full hybrids is that energy storage still poses a weak point. Prof. Bullinger from the Fraunhofer Gesellschaft stated his point of view as follows: *"Full hybrids will only play a minor role (with a maximum 5% market share by 2020) due to ongoing problems with the battery."*

With respect to the long-term future we expect that the ICEs dominant position is likely to be substituted by the fuel cell which takes advantage of the existing electric components used in hybrids. This step is not so far different from the hybrid than as it would be from a pure ICE engine and therefore will reduce the cost for manufacturers in moving from one concept to another. However, complete fuel cell dominance is still decades away. Even if introduction to the market was on time by the middle of the next decade, it would still take years for the fuel cell to come to be fully accepted by consumers. Not only would the price and functionality of the designs need to be attractive, but it would also require that the infrastructure be fully set up and that the vehicles themselves be able to boast proven durability, low error rates and attractive lifetime costs, which all take time. However, the fuel cell is already an important field to explore, and is something which no manufacturers can afford to disregard.

The consequence of all this is that the internal combustion engine will remain an important part of road transport over the next decades. Even though this seems a disenchanting prospect, pushing the dream of a 'zero emission' form of transport further away, it does still demonstrate that improvements of current engines are crucial for the environment and are not just short-term solutions. The same is true for hybrids, which many of the experts we interviewed saw as the 'bridging' technology that will become outdated as soon as the fuel cell is available.

The following table provides an assessment on the general reduction options of different engine and fuel technologies.

	Reduction of green house gas emission	Mature technology	Infrastructure availability	Fuel availability
Gasoline	0	++/+	++	+
Diesel	0	++	++	+
Biofuels	+	++/+	+	0/–
CNG/LPG	+	+	–	+
Hydrogen (fuel cell)	++	– –	– –	–
Hybrid	+	0	++	+
Source: PwC Automotive Institute				

Fig. 2 Overall assessment of emission reduction technologies – as of today

Besides the area of engine technology and alternative fuel, automakers face additional CO_2 reduction potential in the periphery or construction of the vehicle, such as:

- Transmissions
- Driver assistance systems
- New construction techniques and alternative materials
- New tyre technology and design

- Vehicle design affecting aerodynamic drag,

- Energy management within the vehicle

The key in achieving cost effective, short-term CO_2 emission limits will require automakers as well as governments to broaden their outlook. A holistic approach to the problem will become essential, reaching beyond the passing of rules and regulations and the redesign of present engine technology. At the same time, the change in the demand patterns will be key to the impact of any approach available today. Given current consumer preferences, the automotive industry will need to influence the market and actively entice consumers and not simply supply it with vehicles that people don't want to buy. However, in order to achieve such a difficult goal without putting the competitiveness of the industry at risk, policy makers and regulators will need to find balanced and effective incentives, such as those through taxation, to support such a process.

In conclusion then, a few selected quotes, gathered from our expert interviews, may serve as an example for the complexity we are all faced with:

"Future development as well as technical feasibility remains to a large extent uncertain, thinking in options is therefore important for politics and industry." Dr Uwe Lahl, German Federal Ministry for the Environment.

"We need to act globally. If we sell 'low tech' vehicles to emerging markets, the corresponding negative effect on CO_2 emissions would be far higher than the greatest possible CO_2 reduction we could achieve in our local markets." Thomas Kamla, Audi AG.

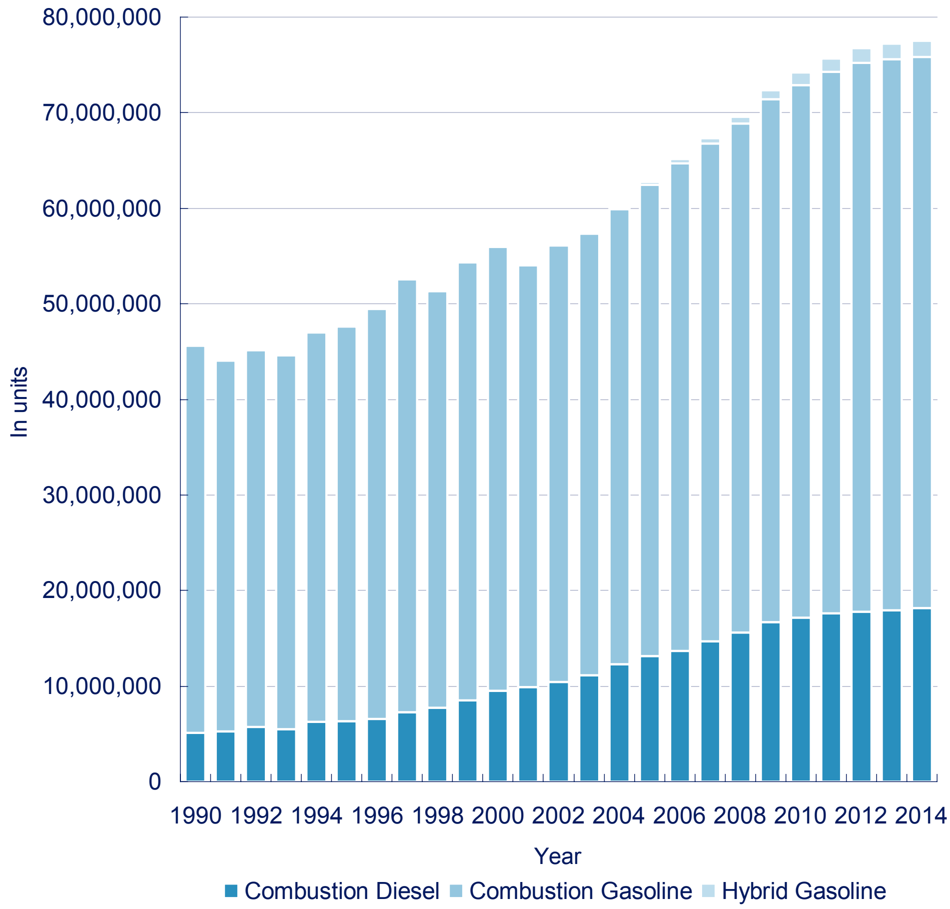
"The discussion should focus more on saving energy instead of reducing CO_2 emissions." Professor Hans-Jörg Bullinger, Fraunhofer Gesellschaft.

"We need to shift the discussion towards an integrated approach covering safety, emissions and the flow of traffic." Prof Ulrich Seiffert, Technical University of Braunschweig.

"Energy from renewable sources will always appear to be less efficient than energy from fossil fuels since we usually make the mistake of not taking into account the energy which was needed to create the fossil fuel (e.g. prehistoric sunshine) in the first place." Peter Fröschle, DaimlerChrysler AG.

"Predicting customer behaviour is pretty difficult. We therefore need to have solutions to all kind of needs. Influencing customer behaviour actively is usually not far reaching enough; results quite often differ from the intention so that overall effects do not go in the right direction even if intentions are good." Dr Thomas Schlick, VDA.

Considering these trends in the auto industry and based on a bottom up forecasting methodology by nameplate, our PwC auto analysts expect the following development of light vehicle assembly globally for the years 2007 to 2014:



Source: PwC Automotive Institute

Fig. 3 Development of global powertrain production

A Living in a changing environment

"Climate protection and the reduction of CO_2 emissions will be one of the, if not the biggest, challenge of the next decade." Professor Ulrich Seiffert, Technical University of Braunschweig.

1 Climate change – the global challenge of the 21st century

Record temperatures during the last few years, together with natural catastrophes are inflaming media attention and making the general public ever aware of climate change and its potential consequences.

Two different definitions of 'climate change' prevail in common usage today. The Intergovernmental Panel on Climate Change (IPCC) uses a non-specific definition which includes any change in climate over time, irrespective of whether it is due to natural variability or a direct result of human activities. The United Nations Framework Convention on Climate Change (UNFCCC) defines it only as directly or indirectly attributable to human activity. The UNFCCC definition, with its reference to human activity, is the definition that has generated the most intense attention of late.

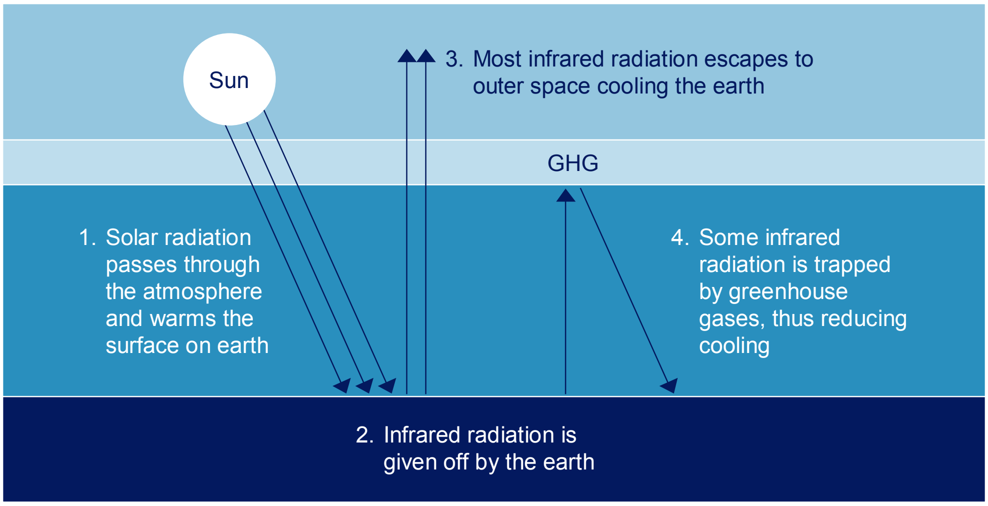
How is the climate changing?

Climate change – specifically global warming – is indicated by a rise in the average of the earth's surface temperature over the past decades. Between 1906 and 2005, records show that global average air temperature near the earth's surface increased by 0.74 ± 0.18 °C (1.33 ± 0.32 °F). Furthermore, 2005 was the warmest year in the last 100 years. According to the IPCC, 11 of the last 12 years (1995 to 2006) rank among the 12 warmest years on record when measuring global surface temperature since 1850. All these scientific readings provide incontrovertible signs of global warming.

Who and what is causing global warming?

The monitored increase in the concentration of anthropogenic (i.e. derived from human activity) greenhouse gases (GHG)[2] is thought to be responsible for the recorded climate change, as the greenhouse effect is heating the earth's surface. CO_2 is the most important anthropogenic GHG, which has increased from a pre-industrial value of about 280 ppm (in 1750) to 379 ppm in 2005.

[2] GHGs, as defined in the Kyoto Protoco,l are the following: CO2, methane (CH4), nitrous oxide (N20), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6).



Source: PwC survey

Fig. 4 Model of greenhouse effect

Of the GHGs, CO_2 also takes up the largest proportion with 56%, more than other significant gases such as methane and CFCs.

The annual CO_2 concentration rate of increase was larger over the last ten years (1995 to 2005 average: 1.9 ppm per year), than it had been since the beginning of continuous direct atmospheric measurements (1960 to 2005 average: 1.4 ppm per year) although it must be said there is also year-to-year variability between the particular rates of increase. According to diverse reports, the primary source of the increased atmospheric concentration of CO_2 is the use of fossil fuels and land-use change, although the contribution of land-use change is assumed to be much smaller. While being the primary source of global warming, human endeavour is at the same time the prevailing source of conventional thinking and some scientists remain sceptical of, and disagree with, the conclusions described. These scientists doubt the robustness of the data models provided and therefore the results derived from them, stating the relatively short viewpoint of the findings, given that life has existed on earth for 3.5 billion years.

How will the climate change in the future?

Climate change models, referenced by the IPCC, project that global surface temperatures are likely to increase by 1.1 to 6.4 °C (2.0 to 11.5 °F) between 1990 and 2100. Nevertheless, the rate of increase in global surface temperature depends on the growth rates of the future GHGs. Although most studies focus on the period up to 2100, warming and sea level rises are expected to continue for a lengthy period of time even if GHG levels are stabilized at year 2000 levels.

What are the impacts of climate change?

There are ecological and economic impacts, although it is difficult to connect specific events to global warming. Not every catastrophe is attributable to the effect of global warming and there are certainly other environmental issues causing problems, however there are clear signs, such as sea level rises and changes in the amount and pattern of precipitation, resulting in floods and drought that are likely to be linked to global warming. *"The current CO_2 discussion is of major importance; however we should keep in mind that we look out for other environmental topics too."* Dr Uwe Lahl, German Federal Ministry for the Environment. Furthermore there may be changes in the frequency and intensity of extreme weather events such as hurricanes. Other effects may, for example, include changes in agricultural yields, glacier and ice cap retreat, reduced summer stream flows, species extinctions and increases in the ranges of disease vectors (heat-related illness).

An alarming current example is the drought as shown in the picture below.

Fig. 5 Impacts of the climate change – aridity landscape

The impact of climate change is not limited to ecological phenomena – it will impair the global economy even though there are wide-ranging estimates as to the scope of the losses. A 2005 study in the journal of the DIW Berlin reported that unfettered climate change would cost the global economy up to 200 billion US dollars by 2050, while a 2007 survey conducted by the DIW calculated the cost for Germany alone would amount to 800 billion euros by 2050. The Stern Review, published in October 2006, estimates that if society fails to act, the overall costs and risks of climate change will be equivalent to losing 5–20% or more of global GDP each year. Reducing GHG emissions in order to avoid the worst impacts of climate change would limit the cost of action to around 1% of global GDP each year. *“The limitation of the anthropogenic greenhouse effect and its consequences is one of the most important challenges of today. As the Stern Report clearly indicated, the cost of reducing CO_2 emissions will be high; but no or inadequate action will lead to an even higher cost in the future.”* Professor Hans-Jörg Bullinger, Fraunhofer-Gesellschaft.

2 Energy security – the risk of inaccessible or uneconomic resources

“We have a serious problem. America is addicted to oil, which is often imported from unstable parts of the world.” President George W. Bush.[3]

Energy availability and concerns about oil prices are clearly other primary drivers for interest in low fuel consumption vehicles. President Bush’s statement is not only true for the US; it is a concern universally valid for the industrialised countries.

“We are already dependent on our energy partners like Russia; this trend is likely to intensify over the next few years,” Professor Ulrich Seiffert, Technical University of Braunschweig.

[3] United States Capitol: "State of the Union address by the President", 31 January 2006, Washington, D.C. www.whitehouse.gov/stateoftheunion/2006/.

In the immediate aftermath of Hurricane Katrina in August 2005, crude oil prices exceeded the 70 US dollars per barrel[4] barrier for the first time ever, causing serious concern for government, industry, and perhaps also for the first time in decades, consumers themselves. Not since the 'oil shocks' of the 1970s and 1980s has the public consciousness been affected so strongly by the rising price of oil. Since then, oil prices have shown no real signs of abating – the days of 30 US dollars per barrel seem to be truly gone forever, due to fundamental changes in oil supply and demand. After reaching a height of over 70 US dollars per barrel on January this year and as a result of the extraordinarily warm winter, oil prices dropped to 48.2 US dollars per barrel.[5] It was the largest drop in two years. On July 31, 2007, a new high of 78.20 US dollars a barrel was reached after the Energy Information Administration (EIA) announced that oil stocks in the US were below market expectations and refinery output had increased.[6]

Source: EIA

Fig. 6 Oil price development (1999–2007)

Demand depends highly on global macroeconomic conditions. Industrialisation and economic development have taken hold across the globe and demand for oil has risen inexorably. Yet it has been the developments of the past couple of years that have caused the most fundamental change of all.

China's phenomenal 75% increase in oil demand from 1980 to 2006 and the enormous growth in demand of other emerging markets have been the driving force behind recent market changes. For the first time since the 19th century, an oil price crisis has been linked to issues of demand, as opposed to artificial supply constraints. As the world's fossil fuel resources are undeniably finite, there will come a point in time when the market faces real supply constraints, which will bring even greater pressure to bear on the market for oil. With peak supply of oil from the US being passed in 1970, the debate has moved to when the world reaches its 'peak oil' point, as when this point is reached, the market for oil will fundamentally change, turning this commodity into a scarce and expensive luxury product.

It is debatable when this production peak will occur, and expert opinion varies widely. The best synthesis of the debate is the International Energy Agency's (IEA) prediction in its July 2007 report, which, while it still does not acknowledge peak oil, predicts a 'supply crunch' somewhere between 2010 to 2012. In light of four years of high oil prices, the IEA

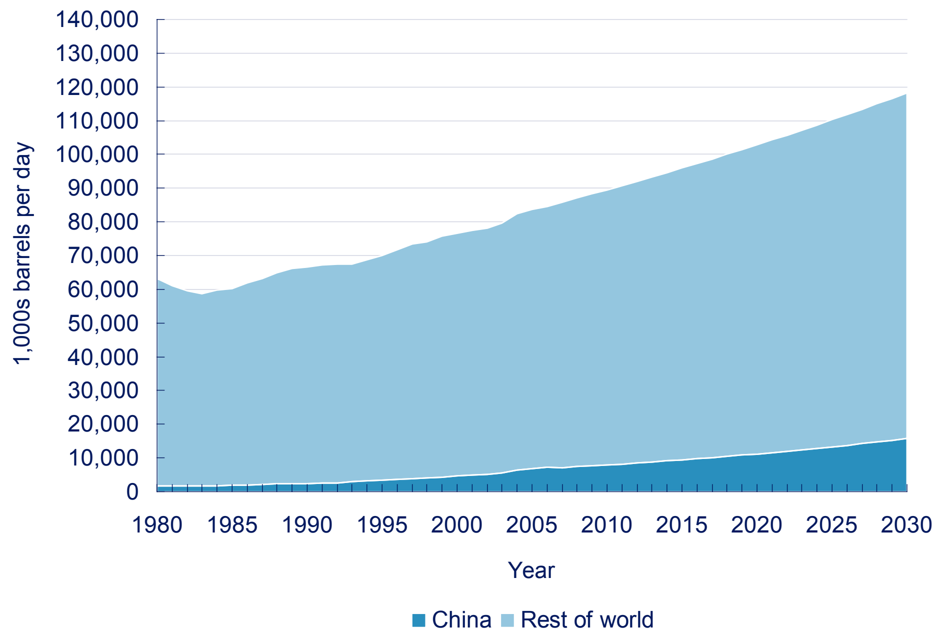
4 Oil prices reached 70.85 US dollars, the day after Hurricane Katrina reached the US mainland. Note that this event does not appear on this chart as it is based on World Oil Price weekly data, all countries spot price FOB weighted by estimated export volume in US dollars per barrel.

5 Based on World Oil Price weekly data from the third week of January 2007 (19 January 2007), all countries spot price FOB weighted by estimated export volume in US dollars per barrel.

6 Oil price according to the Cushing, Oklahoma, West Texas Intermediate spot price FOB.

'Medium-Term Oil Market Report' predicts increasing market tightness beyond 2010, with OPEC spare capacity declining to minimal levels by 2012.[7]

Whatever the prognosis for 'peak oil' the upshot is this: trend consumption for oil is increasing; which is both a great cause of concern, and ultimately unsustainable. Global oil use is expected to increase dramatically from some 80,000,000 barrels per day today to nearly 120,000,000 barrels per day by 2030. The oil demand of China in particular is expected to increase by more than 50% by 2030, although this rise could be tempered by Chinese industry shifting to more efficient means of production or the building of more coal-fired power plants (with all the other environmental issues that that would entail), with the result that Chinese demand could reduce rising oil prices. Nevertheless, the IEA expects that the fastest growth in demand for oil will occur in Asia and the Middle East.



Source: EIA

Fig. 7 Expected world oil demand (1980–2030)

As oil becomes more expensive consumers and industry as a whole will attempt to reduce their consumption by avoiding unnecessary waste, developing and also using more efficient technology and replacing oil consumption through renewable energy sources. Such a development however takes time and is at least partly eroded by increasing energy requirements. Combined with the global increasing demand, oil will remain the dominant global energy source for the foreseeable future, putting further pressure on governments, industry and ultimately the consumers themselves to ensure a stable energy supply, to invent alternatives and to reduce consumption. Thus alongside global warming itself, the coming supply shortage acts as a second important driver for fuel efficiency improvements in vehicles and the search for new technologies and alternative fuels.

3 Kyoto Protocol – the underlying global commitment

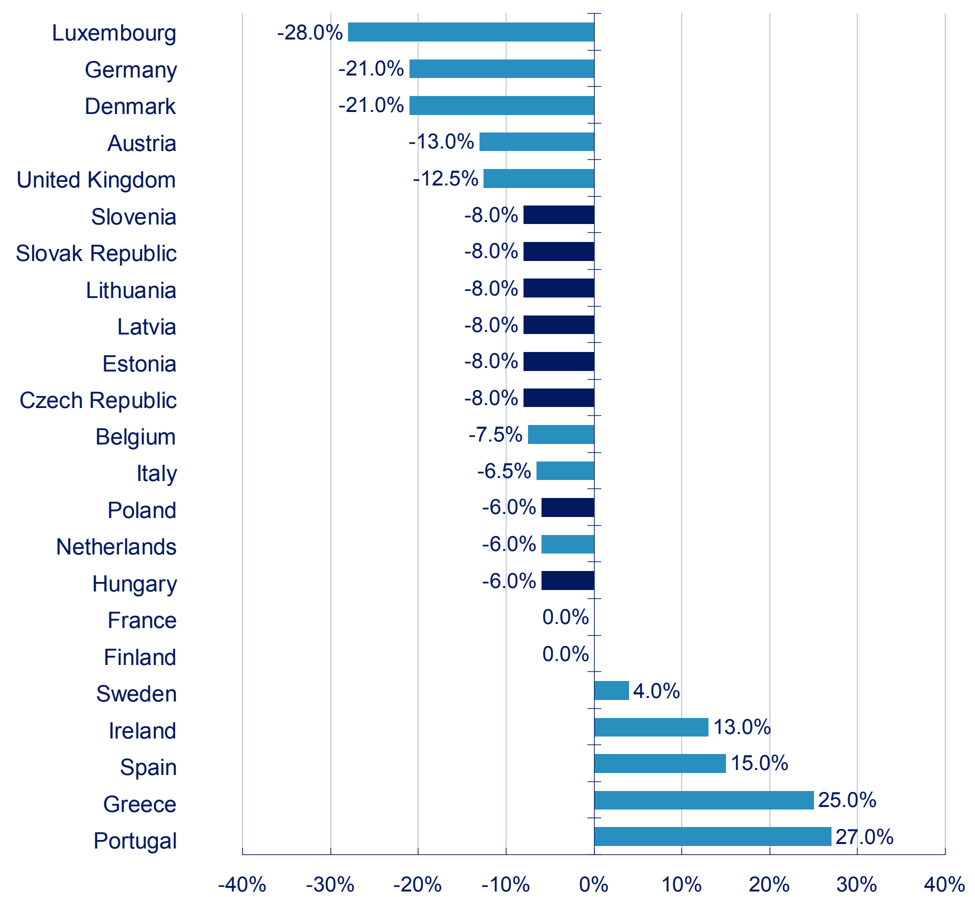
The United Nations and its member states are currently engaged in addressing climate change at a global level through the United Nations Framework Convention on Climate Change (UNFCCC), an international environmental agreement produced at the United Nations Conference on Environment and Development (UNCED), held and opened for signature in Rio de Janeiro in 1992. The agreement focuses on reducing emissions of GHGs in order to combat global warming. It entered into force in 1994. Since then, the

[7] Germany's Federal Ministry of Economics and Technology (have noted that current reserves would last 21 years.

member states have held annual meetings in Conferences of the Parties (COP) to assess progress in dealing with climate change.

The Kyoto Protocol, which has become much better known than the UNFCCC itself, was adopted by COP 3, in December 1997 in Kyoto, Japan. The Kyoto Protocol entered into force on 16 February, 2005 and targets legally binding reductions in GHG emissions of an average of 5% below 1990 levels in the years 2008 to 2012. It lays claim to being the first emission budget period for most industrialised nations and some central European economies in transition.

As an industrialised nation, the US would be required to reduce its total emissions on average by 7% below 1990 levels. However, neither the Clinton administration nor the Bush administration sent the Protocol to Congress for ratification. Certain countries accepted different levels of reductions in GHG emissions. For example Japan accepted a reduction of 6%. The target for the EU was divided between its member states according to the burden sharing agreement as shown below.



Source: EEA

Fig. 8 EU burden sharing agreement of Kyoto Protocol targets 2008 to 2012

The Kyoto Protocol offers the possibility to achieve a partial reduction of GHG emissions by way of so-called ‘flexible mechanisms’. This includes Emissions Trading, Joint Implementation and the Clean Development Mechanism, which allow industrialised countries to fund emission reduction activities in developing countries as an alternative to domestic emission reductions.

By June 2007, a total of 175 states had joined the Kyoto Protocol, accounting for 61.6% of CO_2 emissions of all Annex I Parties (the industrialised countries that were members of the Organisation of Economic Co-operation and Development or OECD, in 1992, plus countries with economies in transition also known as the EIT Parties, including the Russian Federation, the Baltic States, and several Central and Eastern European States).[8] Today, the Kyoto Protocol is the most universally applied agreement for CO_2 reduction. However, a major shortfall of the Kyoto Protocol is the lack of assertive sanction mechanisms, so that it will be difficult to ascertain its effectiveness as a mechanism for reducing CO_2 emissions.

What follows when the Kyoto Protocol expires after 2012? The Subsidiary Body for Implementation recommended a draft decision on obtaining an agreement about CO_2 reductions after 2012 for adoption by the COP 13 at Bonn in 2007. In this case, one of the desired outcomes of the Ad Hoc Working Group (AWG) on Further Commitments for Annex I Parties under the Kyoto Protocol, hosted in Vienna in late August 2007 and set to continue in Bali in December 2007, is to point out and set early benchmarks to the market beyond the first commitment period.

[8] The status of ratification of the Kyoto Protocol was last modified on 6 June 2007.

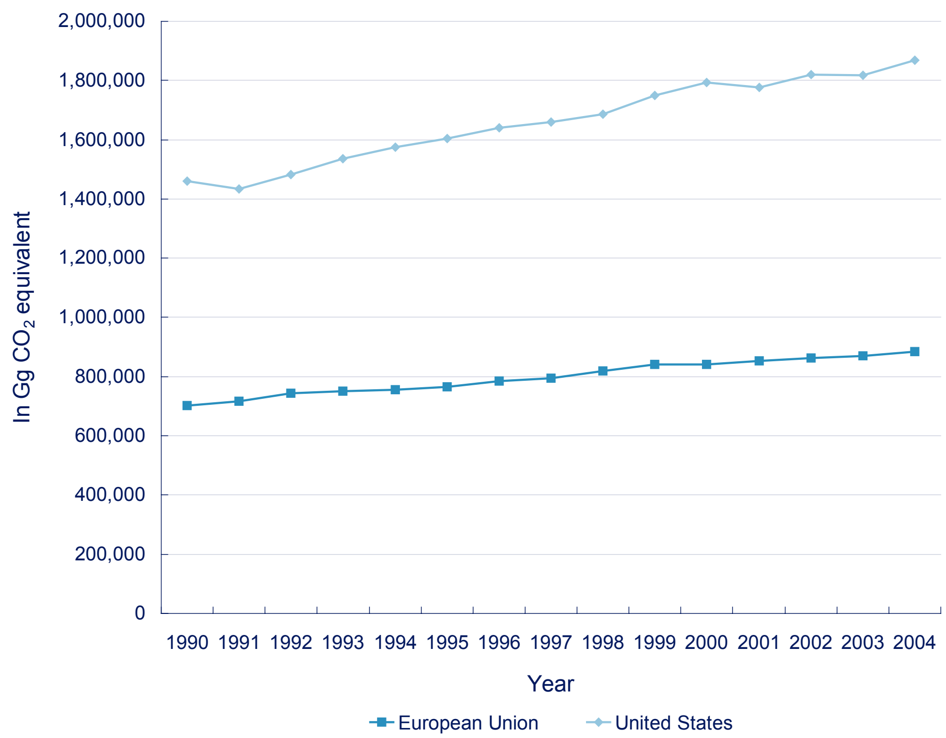
B The automotive industry – the usual suspect

1 The automotive industry in light of emissions

1.1 The role of the automotive industry in the CO_2 discussion

Most national governments have signed and ratified the Kyoto Protocol. However, in the absence of effective action, the growth in emissions from passenger road transport is set to continue in the years to come, counteracting the efforts of nations to reduce their emissions of GHGs under the Kyoto Protocol. Furthermore, according to the Stern Review, if the rate of climate change were to be halted and maintained at current levels, it would still require annual emissions to be reduced by more than 80% from their current rates. *"CO_2 emissions from transport alone have risen by 32% since 1990. There is no way to achieve overall emission targets without focusing on areas like transportation."* Jos Dings, T&E European Federation for Transport and Environment.

The absolute need to reduce CO_2 emissions in the road transport sector is undeniable, but the estimates for CO_2 emissions from road transport differ and depend on the economic influence of the transport sector in different regions. According to the Stern Review, 14% of the world's greenhouse emissions stem from transport alone and they keep rising as shown in the chart below.



Source: UNFCCC

Fig. 9 GHG emissions from the transport sector

According to 2005 data from the German Federal Environment Agency (UBA), the transport sector in Germany is the second largest contributor of CO_2 emissions after the energy sector, with 21% and 46% respectively. Road transport as part of the transport sector accounts for 19% of total CO_2 emissions in Germany according to VDA.[9]

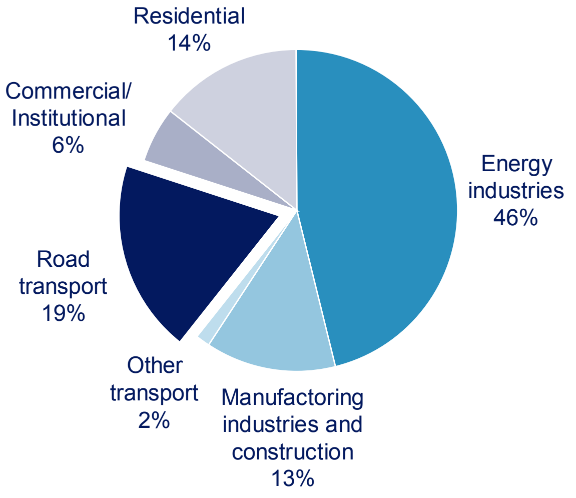
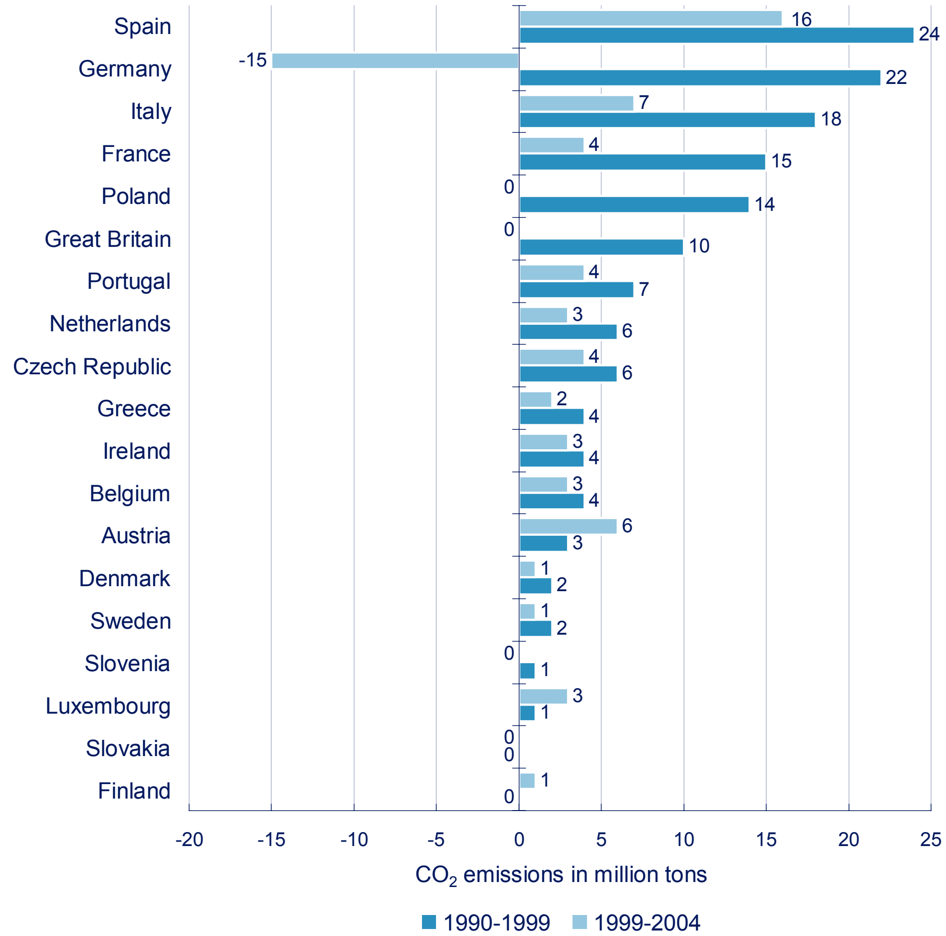


Fig. 10 Distribution of CO_2 emissions by sector

In terms of combating increasing CO_2 emissions, Germany is setting the European standard for CO_2 reduction, with emissions in the period 1990–2004 declining almost down to the 1990 levels. *"The automotive industry makes great efforts already; unfortunately this is not properly communicated,"* Professor Ulrich Seiffert, Technical University of Braunschweig.

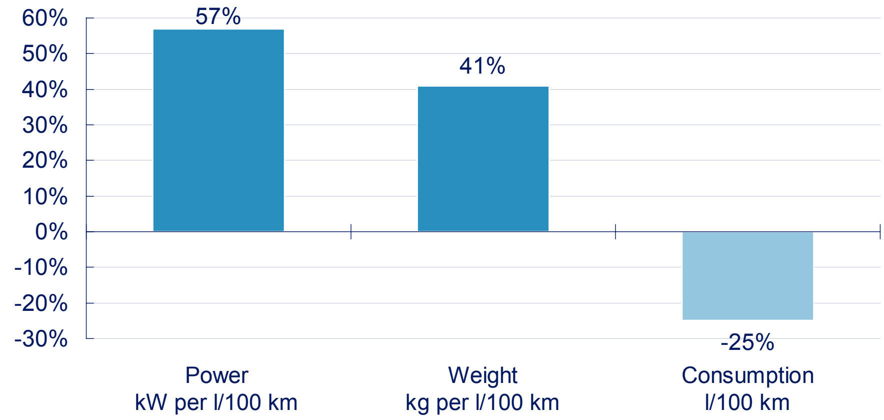
[9] According to the official German national emissions inventory, 795.2 million metric tons are attributed to German fuel combustion (energy) whereof 152.2 million metric tons are added to road transport in 2005.



Source: VDA

Fig. 11 Development of CO_2 emissions in the transport sector by country

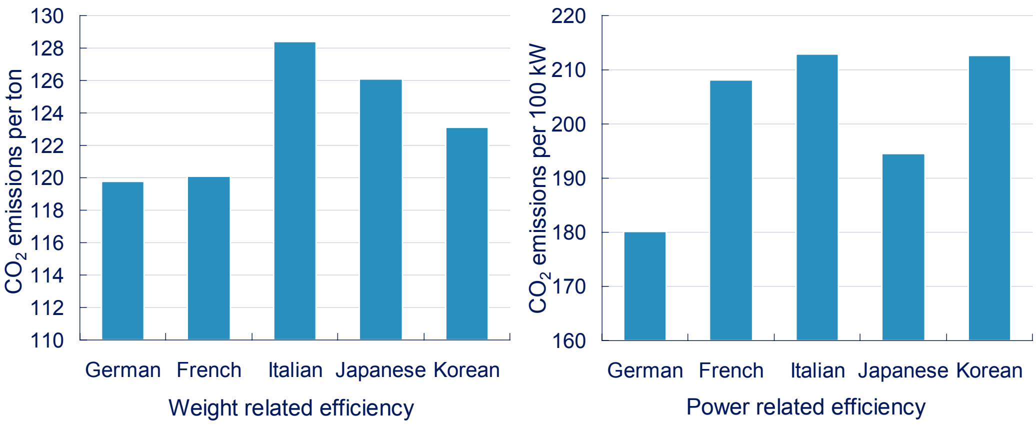
The reduction in CO_2 emissions for the period 1999–2004 versus 1990–1999 is a result of the efforts of German vehicle manufacturers to improve the fuel efficiency of their fleets, arising directly from the 1998 ACEA voluntary agreement (see chapter B 1.2). The task of German manufacturers in reducing CO_2 emissions in the European context is not easy. Most German manufacturers compete in the premium sector, where consumers demand quality and image, which often translates into more power – expressed in a change of nearly 60% kW per l/100 km between 1990 and 2005 – more size, additional security and onboard entertainment equipment which all again tend to increase vehicle weight. Indeed, between 1990 and 2005 the power of German manufacturers' vehicles increased by nearly 60%, while weight, expressed in kg per litre, increased by around 40%.



Source: VDA

Fig. 12 Change in efficiency and consumption of German vehicles

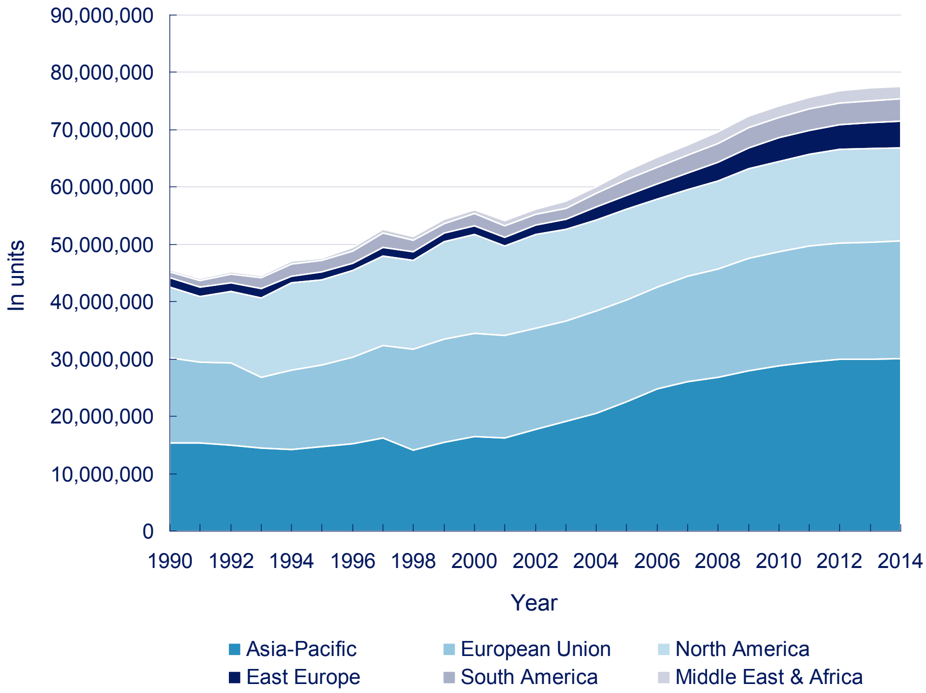
Despite increasing power and weight in the years between 1990 and 2005, the German automotive manufacturers were able to reduce fuel consumption (l/100 km), directly linked to the reduction of CO_2 emissions, by 25% over the same period. Looking at CO_2 emissions shows that the German manufacturers are today leading in terms of weight-based and power-based efficiency compared with their French, Italian, Korean and Japanese counterparts.



Source: VDA

Fig. 13 Weight-based and power-based efficiency by country of brand origin

These achievements however can only be regarded as a step in the right direction and are still not sufficient to meet the CO_2 reduction goals. Furthermore, the CO_2 reduction imperative is global, but comes at a time when the industry itself is becoming more global than ever before, with the rapid emergence of countries such as China and India as major automotive markets. *"We need to act globally. If we sell 'low tech' vehicles to emerging markets, the corresponding negative effect on CO_2 emissions would be far higher than the greatest possible CO_2 reduction we could achieve in our local markets."* Thomas Kamla, Audi AG.



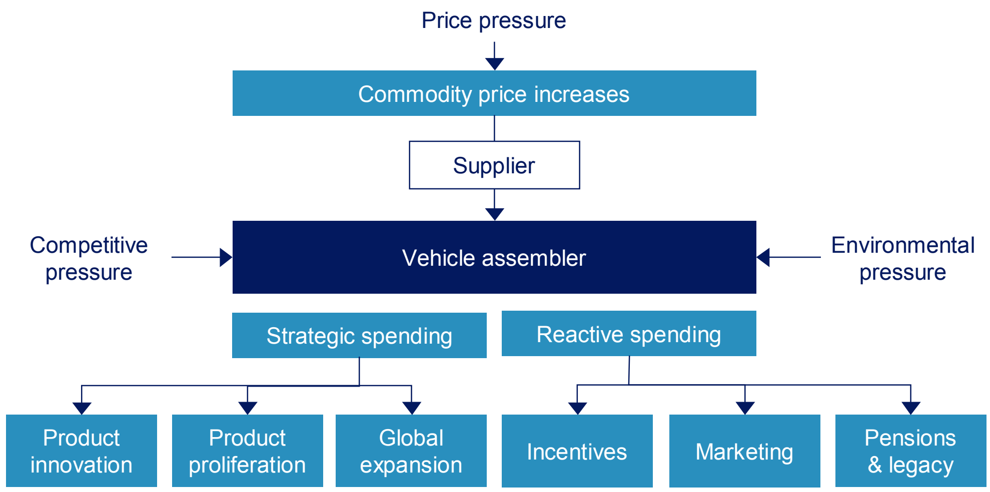
Source: PwC Automotive Institute

Fig. 14 Global light vehicle assembly by region

As shown in the chart above, light vehicle assembly has steadily grown since 1990 in all regions. Global assembly grew by 19.6 million units to 65.1 million units between 1990 and 2006, representing a cumulative annual growth rate (CAGR) of 2.3%.

Looking at the EU, the yearly light vehicle output increased from 14.8 million units in 1990 to 17.8 million units in 2006. The CAGR over this period was relatively low with 1.2% due to the underlying fact that the major European Markets are saturated.

The automotive industry is in a constant state of flux – social, economical and ecological changes lead to continuous new challenges for the industry. In Europe alone, automotive manufacturers are faced with a stagnating demand for new vehicles, coupled at the same time with an increased demand for greater numbers of variants and body styles, rising input prices (raw material costs), excess capacity and fierce competition, which again all serve to limit their pricing power in the market and their ability to overcome cost challenges. In this intensely competitive environment, increasing ecological pressures are only adding to the demand for automotive manufacturers to come up with even more innovations just to remain competitive, but at the same time, at a cost that seemingly cannot be recouped.



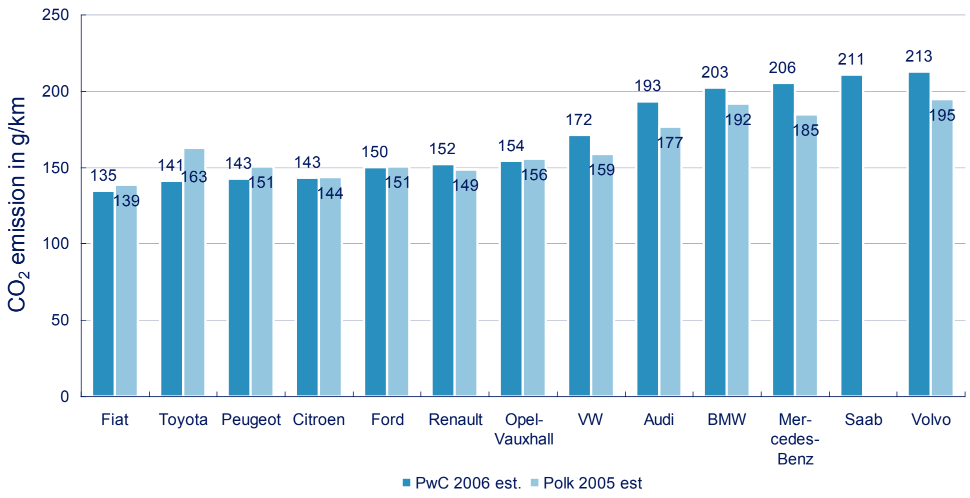
Source: PwC Automotive Institute

Fig. 15 Price, competitive and environmental pressures

1.2 Automotive manufacturers – the voluntary offer to reduce emissions

When it comes to reducing CO_2 emissions, much has been made of the ACEA's 1998 voluntary agreement. In fact, the German automotive industry already had a voluntary agreement covering fuel efficiency which predated the ACEA agreement by ten years. In 1978, the German automotive industry pledged to improve fuel efficiency by 15% from 1978 to 1985 and then followed this initial pledge by targeting a further 25% improvement for 2005 against 1990 levels. Both of these German voluntary agreements (VDA Agreements) were achieved successfully.

The later agreement of the wider European automotive industry, the ACEA agreement, was in response to the EC's 1996 objective to reduce the average CO_2 emissions of new passenger cars to 120 g/km by 2005, or 2010 at the latest, which stemmed from the EC's desire to implement UNFCCC's guidelines and the Kyoto Protocol. Together with the commitments of the Japanese and Korean Automobile Manufacturers Associations (the JAMA and KAMA), the target was to achieve a total fleet average CO_2 emission of 140 g CO_2/km by 2008 (ACEA) and 2009 (JAMA and KAMA) for all new passenger cars sold in Europe by members of the associations. The commitments' targets were mainly to be achieved by technological developments affecting different car characteristics and market changes linked to these developments, thus providing manufacturers with the flexibility to find a suitable solution themselves. Therefore the commitments provided the manufacturers with a certain transitional comfort zone, which reflected an overriding desire to avoid imposed legislation.



Source: PwC Automotive Institute and R.L. Polk
Polk methodology is based on vehicles sold in EU; PwC's based on vehicles built in EU

Fig. 16 CO_2 emissions by brand

However, in 2006 the EC announced that it was working on a proposal for legally binding measures and limits based on the fact that the manufacturers reduced average CO_2 emissions to only 161g/km by 2004, indicating that the voluntary ACEA commitment will not be met by 2008. All evidence, including the EC's own progress report of 2004 and more recent data from the European Federation for Transport and Environment, indicates that manufacturers will not as a whole meet the 1998 commitment by 2008. *"The automotive industry is currently not doing enough to reduce emissions, however since the respective benefits are accrued by the consumers but the cost of these measures is falling on the industry, this is not surprising. Regulation is the only way to avoid the prisoners' dilemma carmakers are in."* Jos Dings, T&E European Federation for Transport and Environment. For this reason, in February 2007 the EC announced the imposition of CO_2 emission targets for 2012, which will see the EU join the US, China and Japan in passing legally binding fuel economy targets. These targets are described in the next chapter.

2 Enforcing the automotive industry – the legal framework

2.1 Current regulatory environment – setting the scene

On 7 February 2007, the EC published its parallel communications on the 'Results of the review of the Community Strategy to reduce CO_2 emissions from passenger cars and light-commercial vehicles' and on the 'Competitive Automotive Regulatory Framework for the 21st Century' (CARS 21). As outlined in these communications, the EC has decided to pursue an integrated approach across the EU with the objective of reducing emissions from the average new car to 120 g CO_2/km[10] by 2012.

The EC's [11] integrated approach is structured in such a way that automakers will be required to achieve a maximum of 130 g CO_2/km for the new car fleet by 2012 through improvements in motor vehicle technology. The remaining 10 g CO_2/km may be achieved by the increased use of biofuels and other technological improvements such as:

- setting minimum efficiency requirements for air-conditioning systems;
- the compulsory fitting of accurate tyre pressure monitoring systems;

[10] This is equivalent to 4.5 l/100km for diesel cars and 5 l/100km for gasoline cars.
[11] COM(2007) 19 final

- the setting of maximum tyre rolling resistance limits in the EU for passenger cars and light commercial vehicles;

- the use of gear shift indicators, taking into account the extent to which such devices are used by consumers in real driving conditions;

- improving fuel efficiency in light-commercial vehicles (vans) with the objective of reaching 175 g/km CO_2 by 2012 and 160 g/km CO_2 by 2015.

The above must be measurable, monitorable and accountable, while ensuring that each CO_2 reduction is only counted once.

According to the Commission, the legislative framework requires that the average new vehicle fleet target will be designed to ensure competitively neutral, socially equitable and sustainable reduction targets that will be fair to all European automotive manufacturers, thereby avoiding an unjustified distortion of competition between manufacturers. *"Establishing a meaningful and technically neutral regulation without any competition policy would be the best support the government can provide the automotive industry with – we do not expect more."* Dr. Thomas Schlick, VDA.

"We do not intend to intervene in the industry in terms of defining what the appropriate technology is for achieving the emission targets. We believe that the industry will use the most cost efficient technology." Dr Uwe Lahl, German Federal Ministry for the Environment.

EU environment ministers confirmed the EC proposal for an integrated approach on 28 June 2007, but no agreement was reached on how it would be applied to different carmakers. It still remains open whether to apply the same standards at individual fleet level or to set targets for each separate vehicle class according to size and/or weight. Ministers required the EC to make a proposal for a legislative framework by late 2007 or early 2008, including long-term strategies for 2020. Beyond the legislative framework and supply-oriented measures, the EC strategy is reliant on additional efforts by other means related to road transport, such as CO_2-related taxation and other fiscal incentives, improved traffic management and infrastructure in the Member States, as well as better informed buyers ('labelling'[12]) and the institutionalisation of responsible driving ('eco-driving'[13]).

The Commission will probably follow the recommendations of the recently published Biofuels Progress Report, which proposes a minimum binding target of 10% biofuels by 2020; to put forward a proposal to amend Directive 2003/30/EC on the use of biofuels or other renewable transport fuels in 2007.

While Europe is still working on a specific regulatory policy to reduce CO_2 emissions from passenger vehicles, Japan is already on the path to more stringent fuel economy standards having passed legislation in 2006. A recently published comparison of global fuel economy standards by the International Council on Clean Transportation (ICCT) that the Japanese average fuel economy in the financial year 2004 was approximately 13.6 km/l (7.4 l/100 km or 32 mpg US). The new standard will raise fuel economy values by 23.5% for passenger vehicles to 16.8 km/l (6.0 l/100 km or 39.5 mpg US). The Japanese system sets average fuel economy targets for different vehicles based on weight. Additionally, the standard expanded the number of weight segments from nine to sixteen and allowed for credits and trading between weight classes. Some manufacturers are still lobbying the EU to adopt a similar system and European automakers are more in favour of extending the deadline to 2015 rather than 2012.

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[12] The EC proposed a voluntary code of conduct agreement. Under the terms of the agreement, automakers would be bound to focus less on the performance aspects of their vehicles. The advertising agreement is one of the measures the EC is considering to take emissions to the 120g/km limit from the 130g/km target from technology alone.

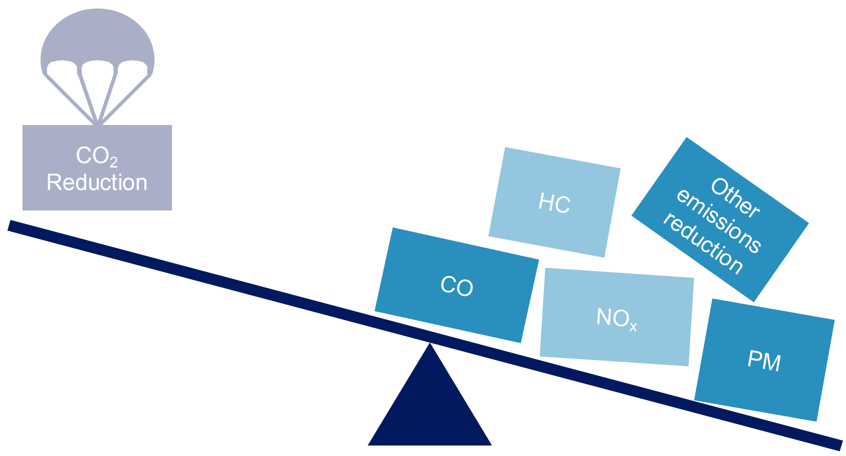
[13] For further information see chapter 4.1.4.

What about the US industry, which has often been criticised in the past for its predilection for producing inefficient vehicles? The US Congress and a group of federal agencies are developing separate proposals to address fuel economy. Likewise, Corporate Average Fuel Economy (CAFE) standards set by the National Highway Traffic and Safety Administration, require each manufacturer to meet specified fleet average fuel economy levels for any given model year, while the Environmental Protection Agency measures vehicle fuel efficiency. Presently, the US Senate is considering a bill for CAFE reform as rising fears over energy security and global warming take their toll. As a first step towards new fuel economy legislation, the new CAFE requirements stipulate that 50% of vehicles sold in the US must be alternative fuel vehicles (flex-fuel vehicles, hybrids, fuel cell vehicles and others) by 2015. Moreover, the average fuel economy standard for passenger cars manufactured after the 1984 model year remained at 27.5 mpg US (8.6 l/100 km or 11.6 km/l). Therefore, US passenger vehicle standards still lag behind Europe, Japan and other industrialised countries.

The California Air Resources Board (CARB), known as the 'clean air agency' of the state of California, issued fleet average GHG emission standards for new vehicles sold in the state. These regulations (California Code of Regulations 2004) apply to model year 2009 until 2016. Emissions of the various GHGs are weighted to take into account their differing impact on climate change, for example, a maximum of 323 g/mi is required by 2009 and 205 g/mi by 2016 for passenger vehicles. Achieving these standards means that California will continue to lead the way in the US with its vehicle emission regulations.

Besides Europe, US and Japan there is one rapidly growing country, namely, China, which has to be considered as well. As a result of Chinese dependence on foreign oil, minimum standards for every vehicle have been agreed. The new national standards established maximum values for fuel consumption according to weight categories. Moreover, the standards are to be implemented in two phases. The first one came into effect on 1 July 2005 for new vehicle models, and the second will be enforced during 2008 and 2009 (new models/continued models).

All these regulations are about reducing vehicle CO_2 emissions and establishing or revising fuel economy standards. But there are further regulations that set emission standards to reduce other pollutants contained in car exhaust gases. Relatively, a very small part of them consists of undesirable noxious or toxic substances, such as carbon monoxide (CO), hydrocarbons, nitrogen oxides (NO_x), and particulate matter, which will be controlled by these regulations. However, there is a trade-off between emission types: if you modify exhaust for NO_x or particulates, then fuel economy (CO_2 emissions) suffers slightly. A short summary of emission standards to reduce pollutants follows.

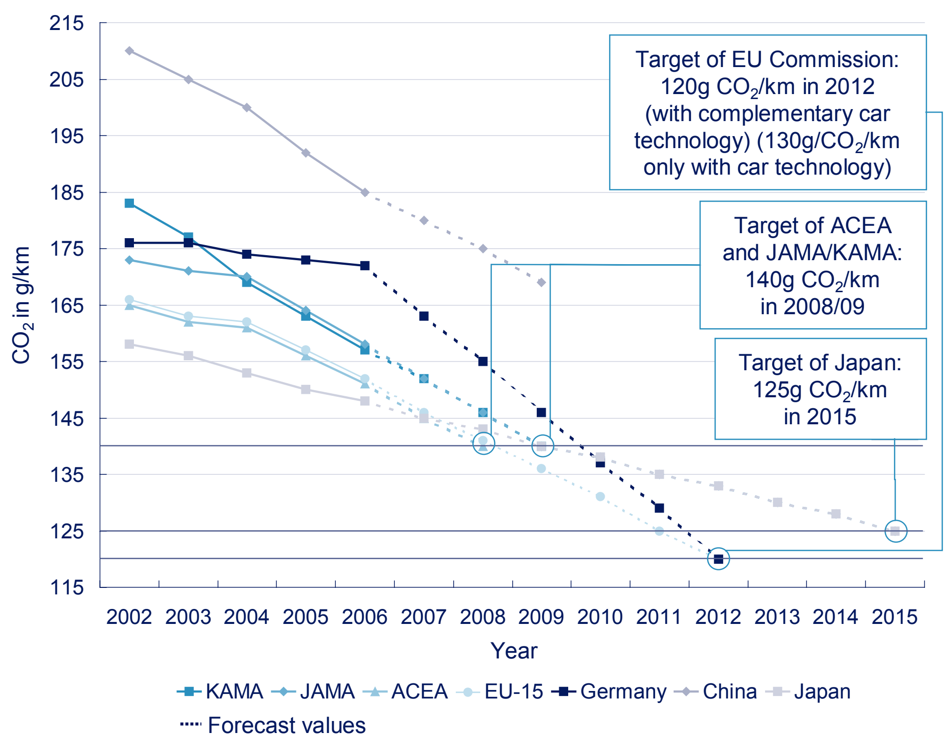


Source: PwC Automotive Institute

Fig. 17 Trade-off between CO_2 and other emissions reduction

For example, in the US, the Clean Air Act Amendments of 1990 introduced two standards: Tier 1 standards (from 1994 to 1997) and Tier 2 standards (from 2004 to 2009). Furthermore, Californian emission standards have been traditionally more stringent than the Environmental Protection Agency (EPA) requirements. The current LEV II standard (California Low Emission Vehicle legislation) adopted by the CARB was extended from the year 2004 until 2010 and is still in force. Under LEV II, NO_x and PM standards for all emission categories have been significantly tightened and both gasoline and diesel vehicles have been affected since 2001. Therefore, the emission standards can only be met by vehicles fitted with advanced emission control technologies, such as particulate filters and NO_x reduction catalysts. CARB is presently working on drafting LEV III in 2007 (likely to come into effect in 2010).

Moreover, emissions regulations in the EU do not just cover CO_2 for new vehicles – European emission standards define acceptable limits for exhaust emissions of new vehicles sold in EU member states. In the EU, standards are set for NO_x, hydrocarbon (HC), CO and PM. Currently, different standards have to be achieved for each vehicle type. Limits for exhaust emissions are defined in a series of EU directives – Euro 1 to Euro 6. The last directives Euro 5 and 6 were adopted by the member states in May 2007 and cover new European on-board diagnostic systems too. Euro 5 will come into force for all new car models in September 2009 (Euro 6: September 2014) and for all new vehicles in January 2011 (Euro 6: September 2015).



Source: ICCT

Fig. 18 Actual and protected GHG emissions for new passenger vehicles

In summary, the EU is working out specific regulations to achieve the objective of 120 g CO_2/km by 2012 through an 'integrated approach'; the US CAFE is still behind other industrialised countries; CARB standards are becoming more stringent annually; Japan improved its fuel economy standards to a respectively low level; and China, similar to Japan, has set weight-based fuel economy standards with a minimum level that must be achieved by every vehicle.

Even though the various standards will certainly contribute to the reduction of CO_2 emissions, their variety represents an additional challenge for automotive manufacturers as Thomas Kamla from Audi stated: *"The existing and expected standards vary from* *country to country. Such variance in legislation constitutes great challenges for automotive manufacturers which are, at least partly, not useful."*

2.2 EU and local approaches to reach CO_2 targets

"Defining the right policy is a long process and needs thorough assessment and consideration,"[14] said Sergio Marchionne, President of ACEA and CEO of Fiat. As outlined, the Commission will present a legislative framework for the first time, if possible in 2007 and at the latest by mid 2008, to force automotive manufacturers to cut CO_2 emissions to an average of 130 g/km CO_2 across the fleet by 2012 through improved vehicle technology. Complementary vehicle technology developments and an increased use of biofuels are expected to cut emissions by a further 10 g/km CO_2 to meet the overall target of 120 g/km by 2012.

Defining the 'right policy' or rather a policy that is accepted by all relevant and involved actors and is also fair to all stakeholders is very difficult, as Marchionne expressed. Therefore, before drafting a policy framework proposals can be submitted during 2007. Thus far, the EC has examined 46 proposals for implementation and have narrowed the proposals down to 8 that will be thoroughly examined for their impact.

Some quotes taken from our expert interviews may serve as an introduction to the variety of opinions and aspects to be taken into consideration:

"*Agreeing on a regulation which is based on the same average limits for all automotive manufacturers regardless of their vehicle portfolio would have a dramatic impact on German automotive manufacturers and the suppliers. Such regulation would create a strong competitive disadvantage for German manufacturers and would hurt the German economy significantly."* Dr Klaus Dräger, BMW AG.

"*We would expect legislation to be based on vehicle footprints at first, but there must be a process of alignment that shifts away from this to a standardised system for all automotive manufacturers in the long run."* Jos Dings, T&E European Federation for Transport and Environment.

"A meaningful legislation must have the objective to take everybody into duty. A homogeneous average emission target for every automotive manufacturer would have the consequence that volume oriented small-sized car manufacturer do not have to contribute to CO_2 reductions meanwhile premium manufacturers would be overstrained. Such kind of legislation cannot be in our interests. " Dr Thomas Schlick, VDA.

"A reliable, long-term and continuing tightening of the CO_2 emission limits would support the very successful German automotive industry in continuing to provide excellent and profitable cars 'Made in Germany' on a global basis." Professor Hans-Jörg Bullinger, Fraunhofer-Gesellschaft.

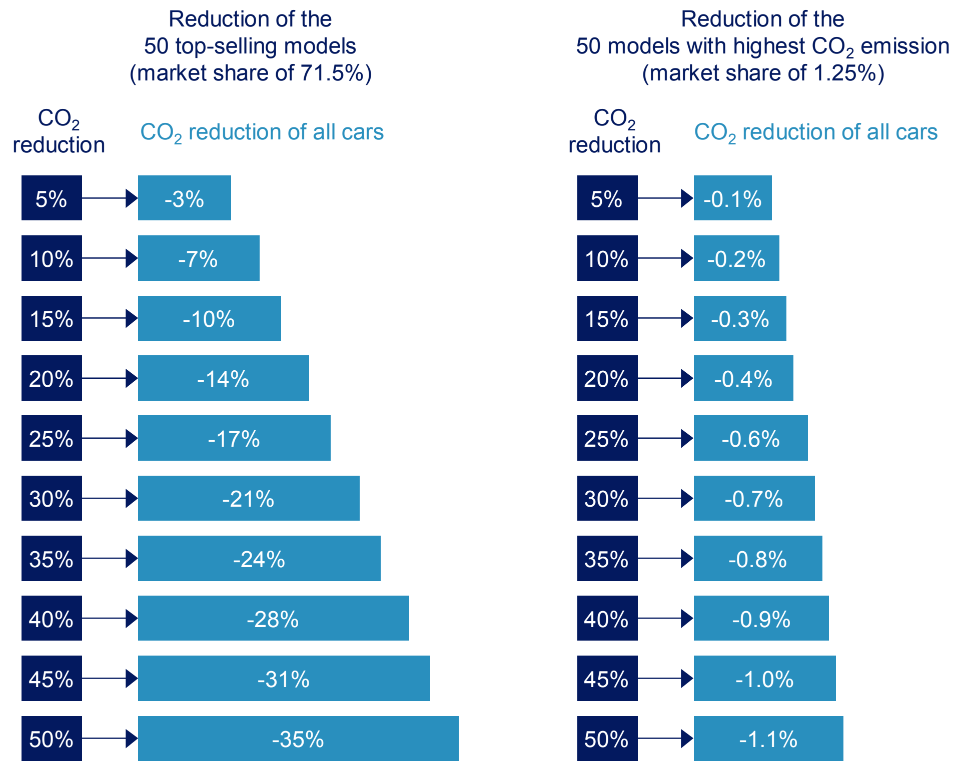
"*The legislation on the horizon is focusing on the vehicle emissions throughout the vehicle usage. Such legislation implies the risk of taking decisions which do not contribute to the CO_2 reduction from a lifecycle perspective due to high CO_2 emissions in the production phase or unfavourable recycling conditions. Politicians need to take that into consideration when coming up with legislation. Respective lifecycle studies have been performed and are available. "* Dr Henrik Adam, Thyssen Krupp Steel AG.

Depending on which proposal is selected, there are bound to be certain parties who will be far from happy with the impact. Thus far, there has been somewhat of a controversy over the proposed EU limit of 130 g/km of CO_2 for car emissions by 2012. The controversy has centred on how this objective will be translated – whether at regional, manufacturer or vehicle segment level.

[14] ACEA, European Automobile Industry United in Approach towards Further Reducing CO_2 Emissions from Cars, Venice 2007.

The ruling ‘130 g CO_2/km for an average fleet of new vehicles sold in 2012 in the EU’ has split the automotive manufacturers. On the one hand, it hurts Germany’s manufacturers of premium cars with high performance and on the other, it supports the French and Italian manufacturers with their smaller and more fuel-efficient models. German Environment Minister Sigmar Gabriel said that if the same targets were required of each fleet produced by each manufacturer, it could encourage carmakers to make acquisitions just to bring down the average emission levels of their fleets. Therefore, the burden of these reductions should be spread out between manufacturers of small and large models. Even Commissioner Verheugen said that the EU emission objective of 130 g CO_2/km *“must be differentiated between car makers”*[15].

Achieving the required 19.25% drop from 161 g/km of CO_2 in 2004 to 2012’s target of 130 g/km is complex, as demonstrated by the analysis below from the KBA and the VDA. As sales of high polluting cars are much lower, cutting their CO_2 output has far less benefit for total emissions than reducing emissions of the top 50 volume models. Taking the 50 models with the highest CO_2 emission and reducing their CO_2 emissions by 50% would only generate an overall CO_2 emission reduction of 1.1%. Even if all of these vehicles were prohibited, only 2.2% could be cut. The proportion of vehicles with high consumption is overrated generally. Significant CO_2 reduction can mostly be achieved in the segment of cars with CO_2emissions of between 120 g/km and 160 g/km – the top-selling cars on the market. Reducing their emissions by 25–30% would already lead to the total required reduction of 19.25%.



Source: KBA, VDA

Fig. 19 Comparison of CO_2 reduction of high emissions vs. top-selling vehicles

Even though this analysis shows the leverage available given the contribution of different segments to CO_2 emissions, it should be noted that, in our opinion, all segments still need to be challenged, including the upper premium segments with low sales and high CO_2 emissions per vehicle.

[15] Low carbon vehicle partnership: "EU emissions target 'must be differentiated between car makers' – Industry Commissioner", www.lowcvp.org.uk/news/700/searchsingle/, 13.08.2007

Axel Friedrich from the German Federal Environment Agency stated in a presentation made at the public hearing in Brussels on 11 July 2007 that the CO_2 emission limit should be per vehicle, based on vehicle segment. Additionally, he said that there would be no need to develop new vehicles as exchanging parts and other improvements would be sufficient to meet the 130 g/km target by 2012.

The EU Commission is considering a weight-based emission trading system with differentiated CO_2 limits, combining a midstream and bonus-malus system. In this way manufacturers who do not meet targets will be forced to pay penalties for non-compliance and those who go beyond their targets should be rewarded for doing so by the other manufacturers.

The German VDA and the ACEA prefer the weight-based approach in principle, but both are critical of the short timeframe proposed – 2012 vehicles are already on the manufacturers' drawing boards – and have been lobbying for the implementation date to be changed to 2015. Furthermore, they insist that the emphasis on vehicle technology is too strong, and that more than 10 g CO_2/km reduction should be achieved through alternative technologies and other improvements, such as eco-driving and infrastructure.

The reason for the unpopularity of calculations based on a blanket approach to manufacturers is shown in the following table, where manufacturers achieving a stronger reduction relatively and in absolute values still be penalised.

	Same proportional reduction		Varying reduction	
	Manufacturer 1	Manufacturer 2	Manufacturer 1	Manufacturer 2
Fleet average of CO_2 in 2006	175 g/km	145 g/km	175 g/km	145 g/km
Fleet average of CO_2 in 2012	149 g/km	123 g/km	131 g/km	123 g/km
Reduction of CO_2	26 g/km	22 g/km	44 g/km	22 g/km
Reduction of CO_2	15%	15%	25%	15%
Political assessment	Outside limit	Within limit	Outside limit	Within limit
Source: VDA				

Fig. 20 Impact of a uniform CO_2 limit

Another option being discussed is a differentiated manufacturer CO_2 limit. In this case, the car manufacturers would have to decrease CO_2 emissions each year compared to the previous year. This system, according to the VDA, would lead to the problem of determining which year actually should be the basis, what could result in unfair treatment of the different manufacturers. Early actions taken before the underlying year would be of no value to automotive manufacturers whereas carmakers who made no efforts in the past to reduce CO_2 emission would be rewarded.

Sectors of the European automotive industry are lobbying the EC to adopt elements of the Japanese approach (so-called 'top-runner system') to CO_2 emissions targeting, whereby the market is classified according to weight. Even this model is not without its drawbacks as the VDA has pointed out – there is a temptation for automakers to add weight to their vehicles so that they can move into the next category with higher CO_2 emission limits. In consideration of this, a linear function could be adopted to remove the incentive to produce bigger cars.

Incorporating the transport sector into the emission trading scheme (upstream model) would be, another meaningful alternative, according to several studies. However, this consideration has been discarded in favour of a proposal for more direct control of the automotive manufacturers. A further possibility is the so-called 'midstream model', whereby positive and negative deviations from the CO_2 emission targets can be traded among manufacturers. However, the VDA and ACEA are opposed to this model, as is the EC, because it would distort competition.

In summary, most premium automotive manufacturers, especially the German, express a preference for weight-based CO_2 emission standards, while the Italian and French manufacturers favour a fleet average threshold.

As has been demonstrated, there is no obvious solution and whatever is finally formulated will have a huge bearing on automakers' strategies in the next few years. As German Environment Minister Sigmar Gabriel remarked recently: *"The competition problem is a tough nut to crack"*[16].

Finally, the x-industry comparison with the energy sector may be of interest: The energy industry has gone through a similar process to what the automotive industry is now being faced with a voluntary commitment replaced by legal requirements. According to experts, the respective implications were and still are a considerable burden for the energy industry. However, the industry has learned to see the requirements as an opportunity in terms of image, technical know-how and technology transfer that they otherwise would never have had.

Excursion: Driving cycles – the myth and the reality

Different countries, agencies and other organisations generate driving cycles to estimate a vehicle's performance in various ways, such as fuel consumption and pollutants contained in exhaust gases from vehicles.

The public discussion on CO_2 made CO_2 emissions and consumption ratings a key factor that consumers take into consideration when planning to buy a new car. However, in reality many customers soon realise that the cars never meet the promised consumption figures as the testing conditions are often very different from real traffic situations. This is also causing difficulties for emission standards. Therefore, it is of utmost importance that the driving cycles under which emissions are measured reflect real driving conditions as much as possible.

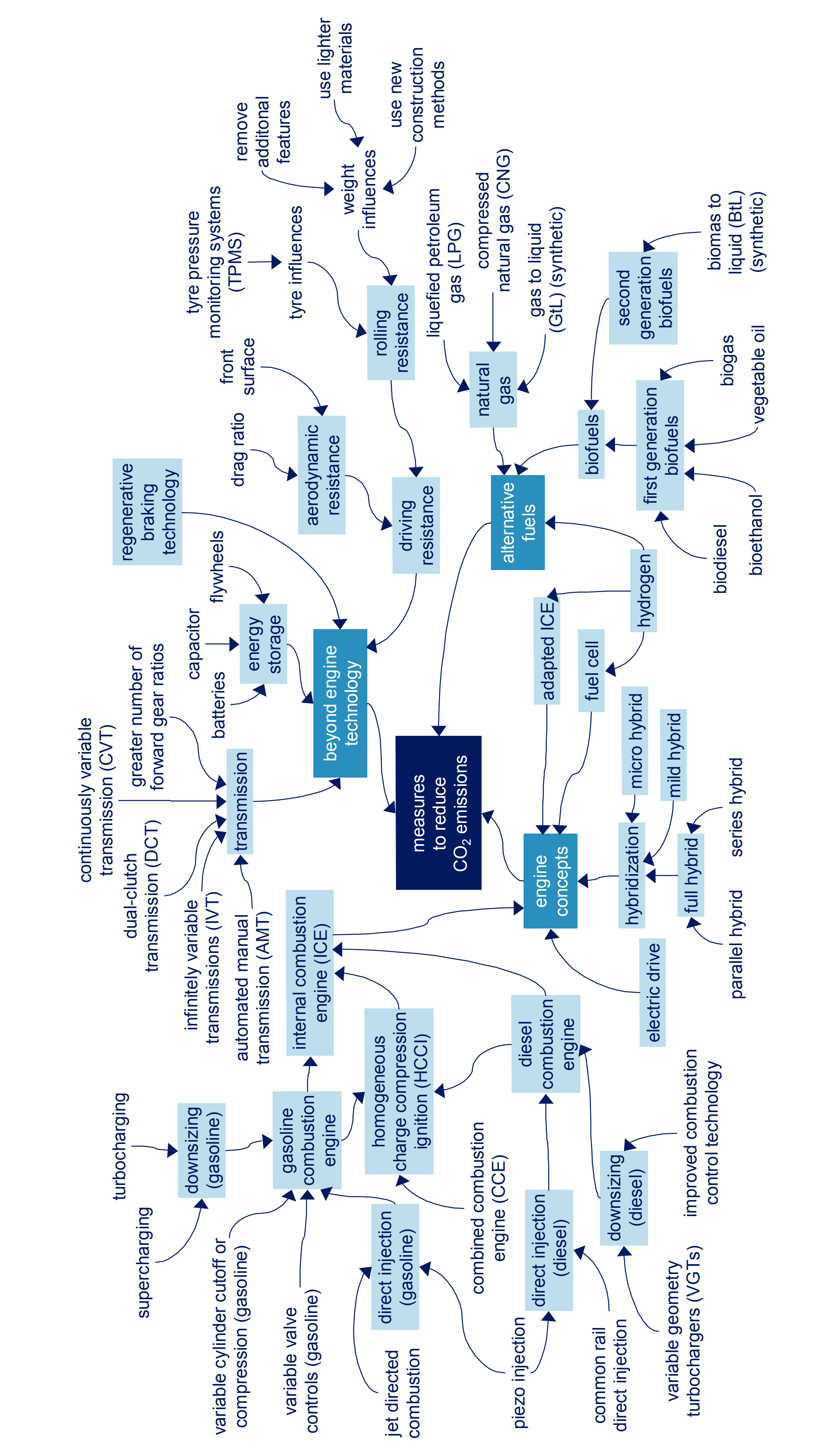
The biggest problems arise when manufacturers adapt their cars to achieve a better performance in the driving cycles only, while under actual driving conditions emissions are much higher.

Furthermore, especially in Germany, driving behaviour need to be considered. Especially for full-hybrids, long distance journeys on the Autobahn at top speeds probably cause the normally more efficient hybrid to perform worse than a diesel. This is not reflected in the driving cycles.

[16] Auto Motor Sport: "CO2: EU unklar über Lastenverteilung ", www.auto-motor-und-sport.de/news/politik_-_verkehr/hxcms_article_505077_14140.hbs, 28.06.2007.

C Supply-side approaches – providing clean vehicles

On the supply-side there are various approaches to limit and reduce CO_2 emissions. They can be divided into three main categories – alternative fuels, improved powertrain (engine and transmission) concepts, as well as other technologies designed to counteract vehicle inertia and rolling resistance.



Source: PwC Automotive Institute

Fig. 21 Measures to reduce CO_2 emission

1 Alternative fuels – CO_2 reduction without further ado?

1.1 Biofuels – renewable and clean

Besides the traditional fossil fuels, gasoline and diesel, the recent discussion is shifting towards renewable biofuels, which represent combustibles that can be used without major adjustments to the traditional Internal Combustion Engine (ICE). Biofuel is an all-encompassing term for fuels made from biological material. Sources of material vary: sugar cane, corn and rapeseed are the most common constituents of current biofuels.

In 2003, the EU ratified the EC's proposal aiming to promote the use of biofuels in transport. The strategy was:

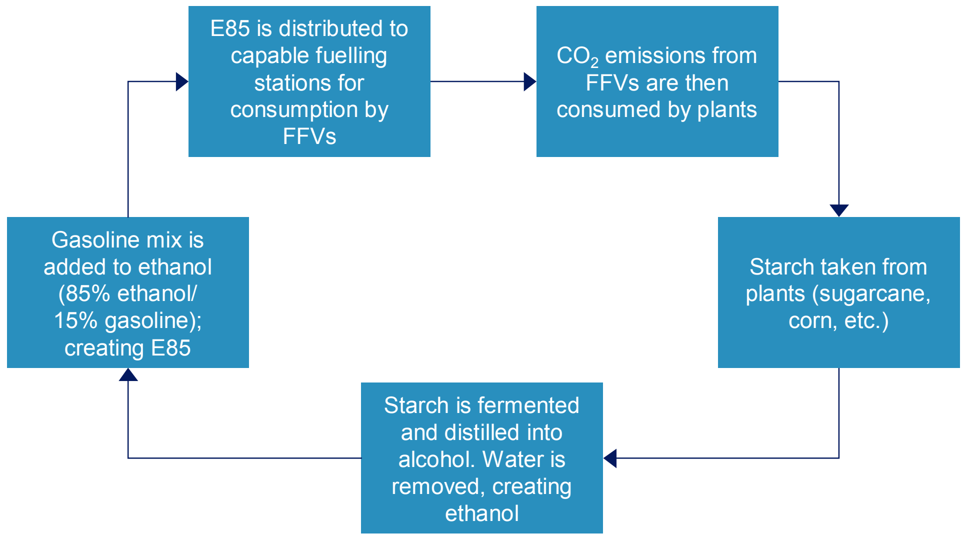
- to achieve low-level blends for existing gasoline and diesel,
- to support R&D for the next generation fuels and production efficiencies,
- to stimulate the demand for biofuels.

The goal was to reach a biofuel market share in the transport sector of 2% by 2005, which would grow annually by 0.75% to 5.75% in 2010. Even though the actual share in 2005 remained at 1.4%, the European Council has suggested setting a new target of 8% for 2015, envisioning a share of 25% by 2030.

The most important biofuels are ethanol, biodiesel, vegetable oil and biogas, which are often referred to as first generation biofuels as they are made from crops such as sugar beet and rapeseed. Second generation biofuels use biomass to liquid technologies. The importance of individual biofuels is dictated on a regional level by the local abundance of source materials: For example in Brazil ethanol derived from sugarcane is preferred, while in the US ethanol from corn is more common and in Europe diesel from rapeseed dominates.

Furthermore, regional demand for biofuels is also determined by the composition of the existing car park and continuing new vehicle demand. Therefore, diesel substitutes find favour in Europe while in other parts of the world fuels are popular that can be run in existing gasoline engines with only slight modifications.

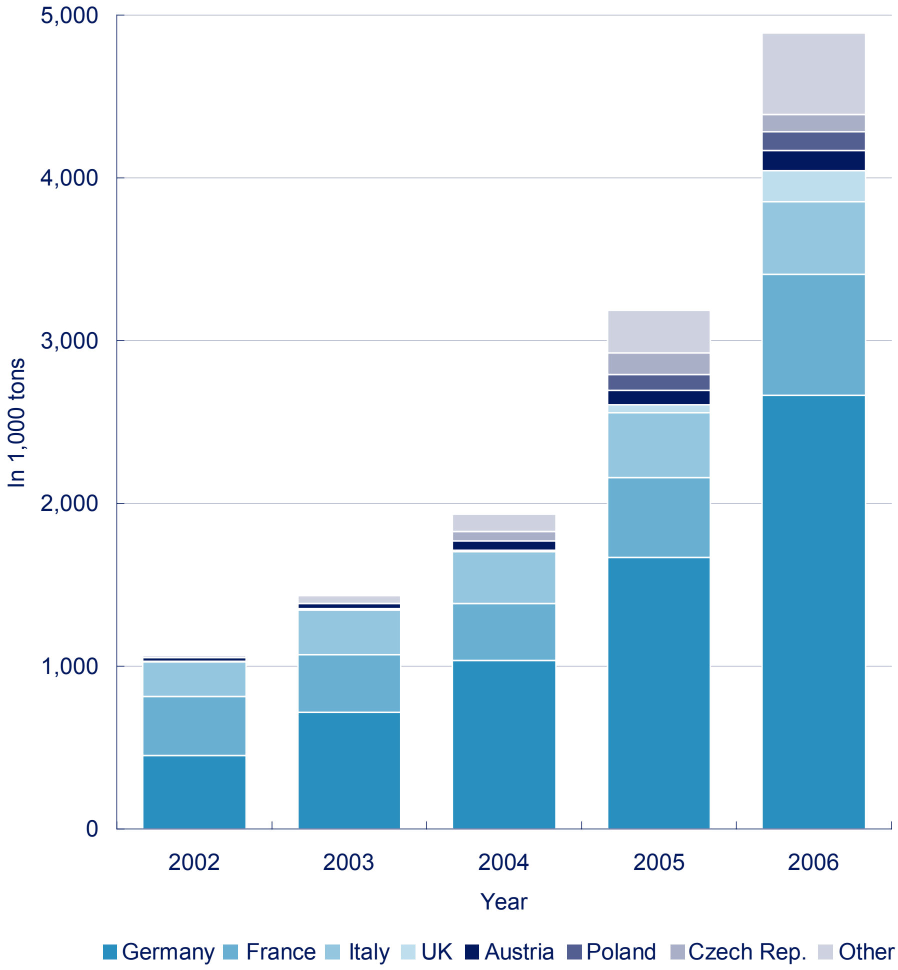
With respect to CO_2 reduction, biofuels are attracting attention because they recycle atmospheric CO_2, rather than releasing additional CO_2 as is the case with traditional fossil use. The carbon cycle with respect to 85% ethanol (E85) is shown below.



Source: PwC Automotive Institute

Fig. 22 Bioethanol (E85) cycle

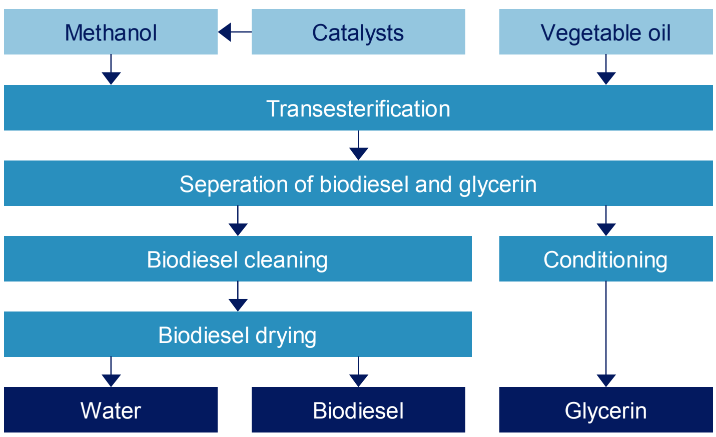
The EU is the biggest producer of biodiesel in the world with an output of approximately 4.9 million tons in 2006, which represents approximately 80% of EU biofuel production. The production of biodiesel more than doubled in the two years from 2004 to 2006 demonstrating the increased interest in biofuels.



Source: EBB

Fig. 23 EU-biodiesel production by country

Biodiesel is a replacement for diesel, either by complete substitution or blending. It is commonly known as 100% biodiesel (B100), 20% biodiesel (B20) or any other ratio, and is broadly compatible with modern diesel engines. Biodiesel is obtained from vegetable oils (rapeseed, soybean, or sunflower) or from waste fats through transesterification.

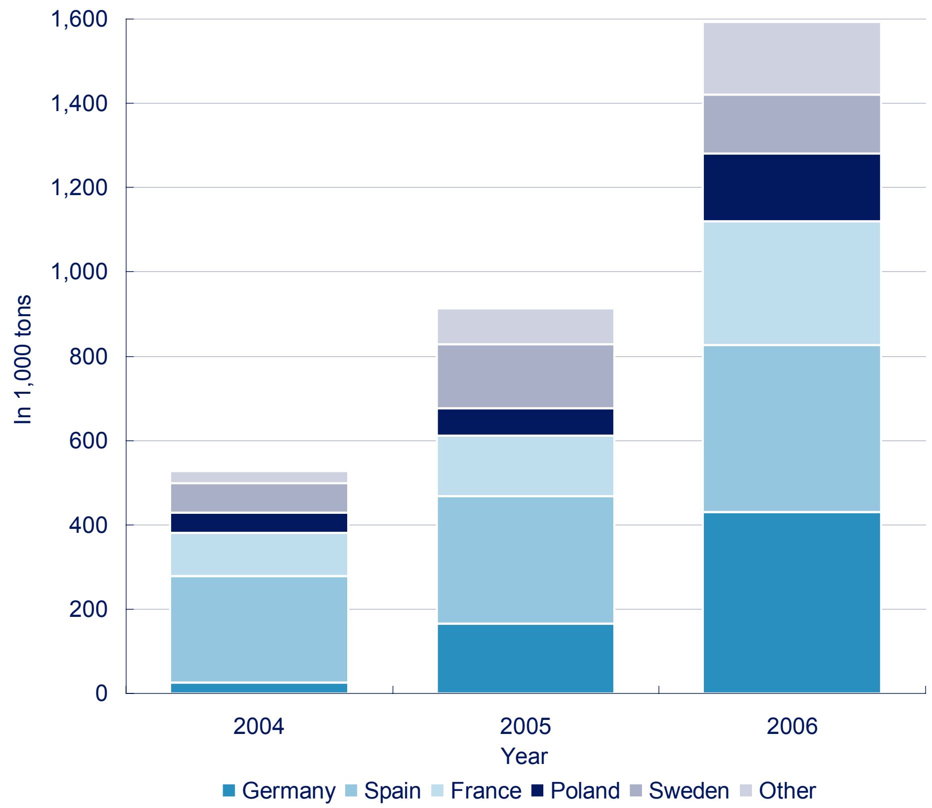


Source: Association of German Biofuel Industry

Fig. 24 Manufacturing process of biodiesel

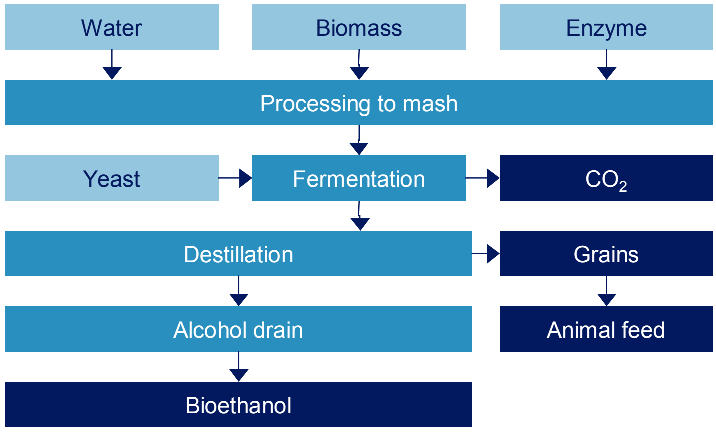
In Europe, biodiesel is predominantly made from rapeseeds (around 80%) and is, thus, named Raps-Methyl-Ester (RME). Generally, the characteristics of biodiesel are similar to fossil fuel, although the viscosity is lower. Problems arise with its solvent characteristics. Affected are plastic and rubber components, like gaskets and gasoline tubing. In cars approved by manufacturers special components are used which are solvent-resistant.

As with biodiesel for diesel, bioethanol is a replacement for gasoline fuel by complete substitution or blending. Bioethanol has achieved a share of around 20% of the biofuel market in the EU and thus represents the second most important biofuel. It is obtained through the fermentation of crops rich in sugar and starches, with cereal crops and sugar beets making up the biggest share in Europe.



Source: EBB

Fig. 25 EU-bioethanol production by country

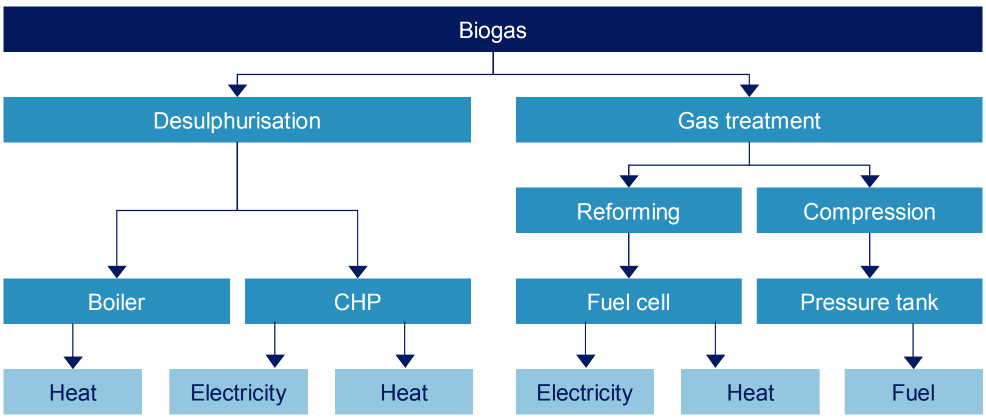


Source: Association of German Biofuel Industry

Fig. 26 Manufacturing process of bioethanol

Ethanol is commonly known as E100 or alcohol (100% ethanol), E85 (85% ethanol) or as a lower volume mix in standard gasoline (5–25%). It can be blended with gasoline in any proportion up to 5% in modern spark-ignition engines without any modification. Since ethanol is more corrosive than gasoline, stainless steel fuel tanks and Teflon fuel hoses are required to accommodate higher blends, such as E100, E85 or E25. Vehicles equipped with the necessary components are sold as Flexible Fuel Vehicles (FFV). Typically, an electric sensor within the vehicle is used to detect which fuel is being used, then adjusts engine and other parts accordingly, so that FFVs are able to use both regular gasoline and blends like E85. Usually these vehicles are offered at little or no additional cost to the consumer.

Biogas (also known as biomethane) can be used in a variety of applications and as fuel, due to its similar chemical constitution to natural gas. It can be used in natural gas vehicles without technical adaptation.



Source: IEA Bioenergy

Fig. 27 Biogas appliances

Up to now, biogas has only been used for demonstration and research in low quantities in Germany. However, the gas industry has set itself the target of mixing natural gas with 10% bio-methane by 2010 and 20% by 2020. Biogas as a fuel enjoys an advantageous tax position up to the end of 2015 and thereafter will be treated as natural gas used as fuel. There are two possible delivery methods available to the consumer: firstly, input via to the relevant natural gas grid or, secondly, via local biogas filling stations located next to biogas plants. Biogas consists of 40–75% methane. In order to use it as a road fuel the methane concentration has to be raised to 96%. The discharge of NO_x and hydrocarbons by biogas is, in comparison to petroleum and diesel fuels, up to 80% lower.

Biomass to Liquid (BtL), also known as synfuel, syndiesel or biofuel of the second generation, is a synthetic fuel made out of biomass. The technology to produce BtL is under development. First production sites have been established, for example, by Choren, however, there is still no industrial plant with the capacity to produce BtL fuel in significant quantities. It is estimated that the first industrial plant will soon be completed by Choren in Freiberg, Germany. The usage of BtL fuel is not subject to restrictions and is therefore adaptable to present engines. Appropriate biomasses to produce BtL fuel are timber, waste straw and other organic waste as well as special types of animal biomass. The characteristics of the BtL fuel can be specifically influenced and therefore adjusted to an optimised combustion process. *“Biofuels of the second generation will play an important role in the future. We expect them to cover 30–50% of the fuel demand in the long run. An open issue in this context is whether it’s more appropriate to use them in power stations or in vehicles. The displacement of subsistence agriculture has to be limited, especially in regard to imports from developing countries”.* Professor Hans-Jörg Bullinger, Fraunhofer Gesellschaft.

The Biofuel Conundrum

Availability of biofuels is not yet an issue, but needs to be considered with the expected growth in demand. Last year, less than 2% of European farmland was cultivated with crops for biofuels. The EU target of 5.75% would equal around 24 million tons of biofuel depending on the crops planted. According to the USDA Foreign Agricultural Service, this would require 15 to 18 million hectares of farmland, roughly 15–17% of the total arable land in the EU-25, assuming that bioethanol and biodiesel would each achieve a 50% share. As even the EC does not wish to use this amount of farmland only for fuel consumption in the transport sector, around half of the needed raw materials must be imported – which could cause other potential food or fuel issues in exporting countries.

Even if research on advanced technologies, efficiency gains and suitable crops could bring some relief, biofuels are not capable of replacing regular fossil fuels completely, nor could additional investments in production capacity make biofuels a sustainable alternative. *“Renewable energies will play an important role in the future but they alone won’t be able to cover the global energy demand”.* Professor Ulrich Seiffert, Technical University of Braunschweig. Presently, the price difference is not enough to persuade large numbers of consumers to make the switch to biofuels. Moreover, the distribution and infrastructure, hence, the availability for the consumer is still an issue. Up to now, there are less than 100 filling stations selling bioethanol in Germany. The biodiesel infrastructure is slightly better with 1900 stations across Germany offering B100.

Biofuels incentive

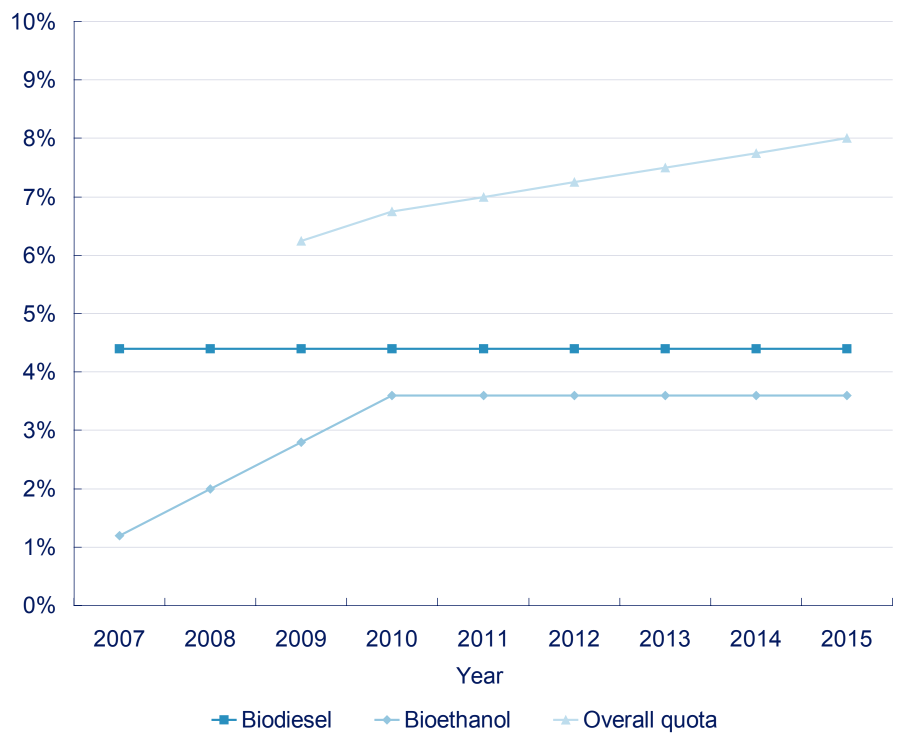
Governments generally have two instruments to increase the market share of biofuels. Firstly, they can influence the market through tax benefits or they can set mandatory quotas for biofuel. The EU provided the legal framework with two directives for a distinctive treatment of biofuels and fossil fuels in 2003. The directives cover the taxation of energy products and the promotion of the use of biofuels or other renewable fuels for transport. The latter provides voluntary targets for the market share of biofuels in 2005 (2%) and 2010 (5.75%). The EU released a report on the progress made in the use of biofuels and other renewable fuels in EU Member States early 2007. The report judges that the 2010 targets will not be achieved unless the current situation is altered. As a consequence, the EC included the proposal into its report to revise the biofuels directive including the objective to achieve a share of biofuels of 10% by 2020.

Given that the production of biofuels is still more expensive than that of conventional fuels, there is clearly a need for financial incentives in order to increase demand. Germany, for example, exempted biofuels from mineral oil tax since 2004, which also applies to the biofuel portion in blends. This is often seen as one major reason for the growth of biofuels in Germany. However, in 2006 the German government decided to gradually reduce the tax incentive for biofuels over the next few years. *“Energy from renewable sources will always appear to be less efficient than energy from fossil fuels since we usually make the mistake of not taking into account the energy which was needed to create the fossil fuel (e.g. prehistoric sunshine) in the first place”.* Peter Fröschle, DaimlerChrysler AG.

German taxation of biofuels	Taxation
Biodiesel (B100)	• Until 31 Dec 2007: 0.09 €/litre • 2008-12: incremental increase to 0.45 €/litre
Ethanol (E85) and BTL	• Until 2015: tax exemption
Biofuels as blend	• From 1 Jan 2007: Full taxation – Diesel: 0.47 €/litre, – Gasoline: 0.65 €/litre
Source: VDA	

Fig. 28 Taxation on biofuels in Germany

In order to avoid the reduction of the biofuels’ market share in Germany, the government introduced a new law with a mandatory quota for biofuels (BioKraftQuG). The following chart shows the quotas of different biofuels according to German law.



Source: BMU

Fig. 29 Biofuel quota in Germany

Overall, the original euphoria related to biofuel has cooled down lately. Nevertheless, biofuels will continue to play a part in the puzzle and assist CO_2 reduction by being blended in traditional fuels. Many vehicle manufacturers have already prepared their product portfolios in anticipation of a further increase in biofuel quotas.

Advantages	Disadvantages
• Immediate potential for CO_2 savings • Biofuels are relative easy to implement • Existing infrastructure can be used if biofuel is blended with conventional fuels • Mature, traditional combustion engines can be used • Usage of biofuel helps degreasing dependence on oil	• Shortage of arable crop and possible competition with food production • Changes to the engine system and changes within the fuel supply to the engine necessary if used in high blendings • Potential for corrosion in the fuel system • Profitability is questionable
Source: PwC Automotive Institute	

Fig. 30 Advantages and disadvantages of biofuels

1.2 Gas – the neglected fossil fuel

Although biofuels recently gained far more attention in the media, the leading fuel alternatives to diesel and gasoline are compressed natural gas (CNG) and liquefied petroleum gas (LPG). Other gas variants are synthetic fuels, known as gas-to-liquid (GtL), or synfuels. Fuel storage of gas is more complicated and space consuming compared to traditional fuels. LPG storage therefore takes place at a compression of 20 bar and CNG storage with 200–250 bar, to provide an adequate range for the vehicle.

Gas powered vehicles are already in production and are gaining market share in Europe. According to the European Natural Gas Vehicle Association, 43 automotive manufacturers around the world are manufacturing natural gas vehicles today. In Europe around 682,000 CNG vehicles and 5.5 million LPG powered vehicles are in use. Through economies of scale, the cost differential has narrowed in comparison with diesel and gasoline, making natural gas an even more attractive alternative. Looking at fuel prices, fuel for natural gas vehicles amounts to half of the cost of gasoline engines and are still 25–30% lower than the cost of diesel. This can be explained by the cost of natural gas on an energy equivalent basis and taxation. In Germany, natural gas benefits from tax incentives, which have recently been changed in favour of natural gas and now promote both CNG and LPG until 2018.

As with all alternative fuels, availability is crucial. The distribution network of filling stations is getting denser with more than 2105 CNG stations in Europe last year. In Germany, there are more than 750 filling stations for CNG, about 2800 public LPG filling stations and another 1200 used by industry.

In contrast to special filling stations, GtL can be delivered via the distribution network of conventional filling stations, because it has similar characteristics to diesel and gasoline. It is already used as a high quality diesel fuel-blending component, as it provides lower emissions than standard diesel. However, the GHG emissions are slightly higher as the fuel has less energy density than either diesel or gasoline. Additionally, the price of such blended fuels is also higher than common fuels and general supply capacity is limited.

The environmental impact of gas-powered vehicles is positive and with the given state of technology and the existing, rapidly expanding infrastructure, natural gas can provide a strong contribution to the reduction of CO_2 emissions. The usage of CNG reduces CO_2 emissions compared to conventional fuel by 20–25%. In this regard, Theodor Sams, manager of the R&D division at AVL List, stated: *"With the optimisation of current engines alone, we are able to increase the efficiency of natural gas operations by 5%. Currently, CNG direct fuel injection, which promises to increase efficiency by 20% and to reduce CO_2 emissions by up to 40%, is still in a experimental state"*[17]. The upcoming improvements of gas vehicles can thus help to reduce emissions even further. Moreover, natural gas vehicles hardly emit any particulates and emit less GHGs like CO, HC and NO_x.

The positive environmental impact and the availability of the technology and the fuel at a reasonable price led the EU to declare that 10% of all vehicles in member states should be powered with natural gas by 2020. The European Natural Gas Vehicle Association, which

[17] AVL List GmbH, Fuels for the Future, in: powertrain & drive focus, July 2007, p. 19

is not convinced that it will be possible to achieve the 10% target by 2010, sees a market share of 5–10% of the vehicle market by 2010 to be a major breakthrough and expects a market share of between 20–25% by 2025 to be possible. The advantages and disadvantages of gas can be summarised as follows:

Advantages	Disadvantages
• CO_2 advantages in comparison to gasoline and diesel engines today • Low cold-start emissions • Mature technology available and combination with traditional fuels possible • CNG is more evenly distributed over the world than oil • Cost effectiveness in the mass market possible	• Exhaustible energy source • No standardised gas solution across Europe (LPG vs CNG) • New infrastructure has to be built up parallel to the conventional one • Using gas as a fuel has general problems with storage and the costs of storage, the handling, the volume and the range • Customer resistance to drive gas driven vehicles
Source: PwC Automotive Institute	

Fig. 31 Advantages and disadvantages of CNG/LPG

2 Engine concepts for now and the future

2.1 Internal Combustion Engines – continuous improvement

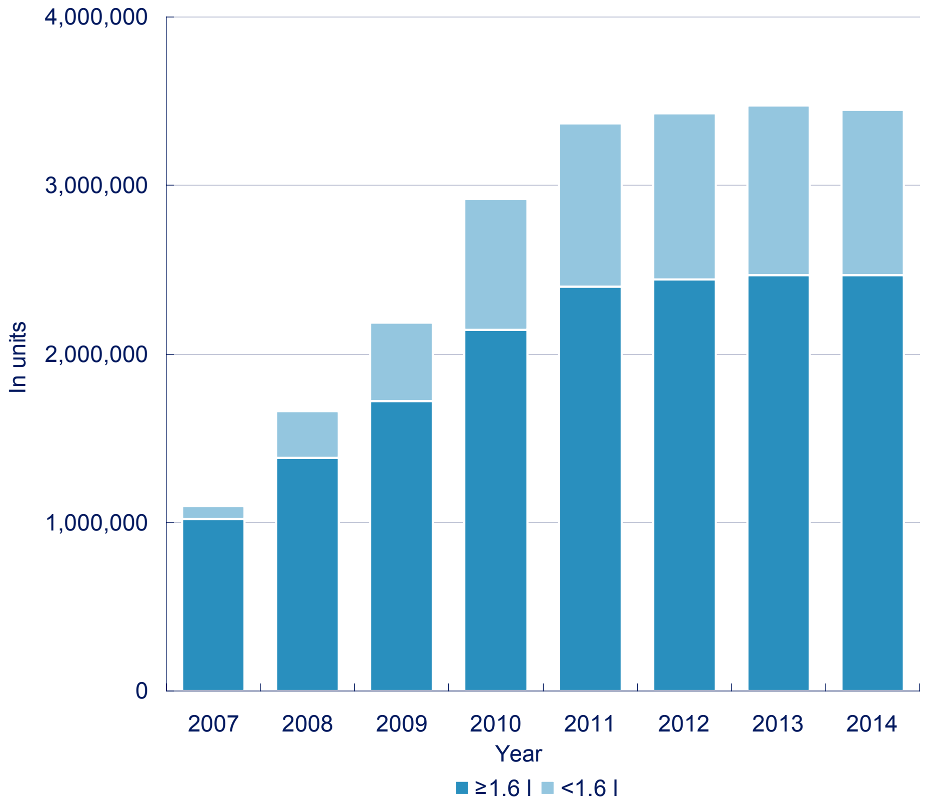
ICEs are an obvious starting point when it comes to technology improvements in reducing CO_2 emissions. ICEs are still the dominant technology to move a vehicle – and are expected by many to remain so. *“There is no real alternative to the combustion engine over the next 20 to 30 years.”* Dr Uwe Lahl, German Federal Ministry for the Environment. Even 120 years after Karl Benz developed the first automobile powered with an Otto cycle gasoline engine; there is still much room for efficiency gains.

Combustion engines were improved continuously over the last century with enhancements in power and fuel consumption. New engine management systems, improved injection systems, and an increased usage of sensors have changed engine characteristics in terms of performance and general emissions significantly. However, recently the focus has shifted from increasing power while maintaining fuel consumption, to maintaining power while significantly lowering fuel consumption (and therefore CO_2 emissions) and other emissions in general.

Otto engines

How much potential can still be tapped from traditional gasoline combustion engines? Engines are generally an inefficient means of converting the chemical energy from fuel, accounting for some 62% of the energy losses in a typical vehicle. It is however beyond the laws of thermodynamics to expect all of this energy loss to be recaptured. Notwithstanding this, there are technologies and strategies at hand to try to minimise these losses. A cost-efficient means to recapture some of these losses, on both the gasoline and diesel side of the ICE, is engine downsizing. With diesels, this process has largely been played out thanks to the advent of variable geometry turbochargers (VGTs) and improved combustion control technology. With gasoline engines, however, this process is only just beginning. The logic behind downsizing is that smaller engines need less fuel per se and engines have a lower degree of efficiency when running at partial load. Downsized engines have to work at a higher load to maintain motive power – so they work at their peak of efficiency more often – while for the peaks in power output some degree of forced induction is required, commonly turbocharging or supercharging, so that there is no requisite loss in power compared to that in larger displacement engines. It is no surprise that turbocharger manufacturers are counting on gasoline downsizing being a success. Honeywell, for example, sees five million turbocharged gasoline engines in use by 2010, more than doubling current levels. Together, Honeywell and BorgWarner anticipate that 25% of gasoline engines will be turbocharged by 2010, while VW estimates that 50% of German market VWs and Audis with gasoline engines will be turbocharged by

2010. All told, a downsized gasoline engine is estimated to be some 6% more economical with fuel than its traditional non-downsized counterpart. Downsizing in gasoline engines is expected to be most apparent in the sub 1.6 l category in the EU, as at the current 1.8–2.2 l range lays the bulk of European volume manufacturers' CO_2 emissions coming in above the 130 g/km threshold.



Source: PwC Automotive Institute

Fig. 32 EU turbocharged gasoline engine development

However, numerous stumbling blocks still hinder the expansion of downsizing. One element is the ongoing displacement culture which still prevails in Europe and is reinforced by consumers shifting upscale as overall wealth increases. Moreover, forced induction in the past has been marketed as a high-end option, which will require a further change in the consumer mindset. Another factor impeding the investments in downsizing is that fuel economy and CO_2 emissions are more easily met by diesel engines. Therefore, diesel as discussed in the following section has been the recent focus of competitive development – and is increasingly fixed in the European consumer's mindset as the fuel efficient option – instead of putting efforts into gasoline improvements.

However, with the increasing environmental pressure, gasoline downsizing is noticeably picking up momentum. Moreover, manufacturers can exploit greater synergies which are possible through downsizing as engine variants by displacement can be minimised and replaced by different tunings of single displacement engines by manufacturers.

Other areas for improvements of the Otto engine are direct injection, variable valve controls, cylinder deactivation and variable compression systems:

Gasoline direct injection

In comparison to a port fuel injection engine, in a gasoline direct injection engine the fuel charge is injected directly into the combustion chamber at high pressure. The key benefit of direct injection is greater fuel efficiency thanks to the control over the fuel/air ratio and injection timing. The loads under which the engine is operating determine the fuel/air ratio.

Under a partial load, the charge can be very lean – up to 40 parts fuel to one of air – compared with the stoichiometric (idealised operating condition) ratio of 14:1. As the lean burn mode operates so far away from the ideal, there can be problems with the complete combustion of the charge and the resulting NO_x emissions. This issue has largely been negated in modern gasoline direct injection systems thanks to combustion chamber and piston design which introduces swirl and tumble to the charge mixture and allows for more complete combustion thus reducing the inherently high NO_x emissions of standard lean burn systems. In terms of fuel savings, Mercedes estimates its M271 CGI engine is 10% more efficient than a comparable port fuel injection engine.

Variable Valve Controls (VVC)

There are numerous VVC systems on the market, some operating just on the intake valves, others just on the exhaust and others on both. In addition, the valves can be controlled for timing, duration or lift. While the permutations are many, all the various systems developed to date have one development goal in mind and that is to optimise the efficiency of the gasoline engine. Efficiency gains can be made in the fuel economy, power or emission control by varying the valve phases independently from engine speed, as it relates to camshaft rotation. The ultimate development in VVC is considered to be the camless engine, whereby valve actuation by way of independent hydraulic or electronic means gives infinite combinations of lift, timing and duration.

Cylinder deactivation

Cylinder deactivation or variable displacement is a technology that is gaining traction among larger displacement engines and in the US market in particular. Presently, Honda, GM, Chrysler and Mercedes-Benz are alone in using this technology. The principle is simple; under partial loads a vehicle does not need all its displacement for forward motion. Under partial load an engine typically only uses 30% of its available power – thus shutting off the fuel to unneeded engine cylinders, by closing the intake and exhaust valves brings a concomitant improvement in fuel efficiency and CO_2 emissions of around 20% on the highway.

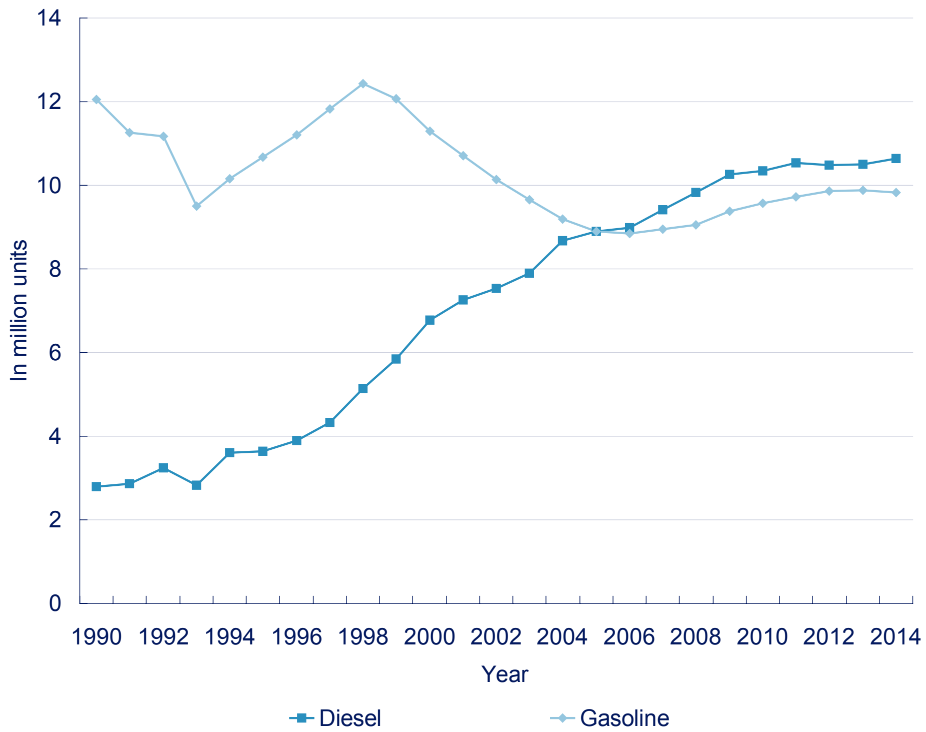
Variable compression systems

Engines with higher compression ratios operate more efficiently due to them being able to take a given fuel/air mixture and packing it into a smaller area between a piston's top dead centre and the cylinder head and getting more power per charge. This is one of the principle sources of efficiency with the diesel engine compared with the gasoline engine. In gasoline engines, high compression ratio engines bring attendant knocking (pre-ignition) problems under high load. The solution therefore is to vary the compression ratio according to engine loads. In the recent past this has been demonstrated in two ways: a hinged cylinder head (Saab system) or through varying the geometry of the conrod. The Atkinson cycle engine is a variant on this theme and has a partial varied compression ratio – it has a smaller compression ratio than expansion ratio – which brings greater fuel efficiency. Atkinson cycle engines are employed in the Toyota Prius ICE among others.

Diesel

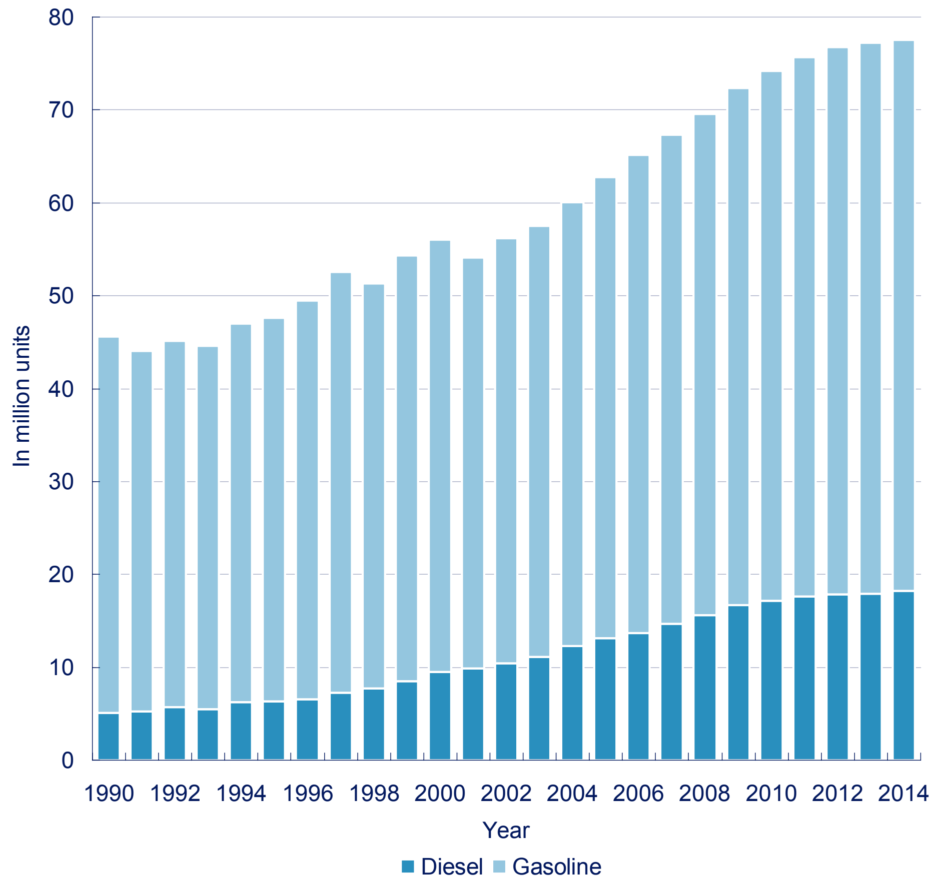
Diesel engines, by virtue of the higher energy density of diesel fuel when compared with that of gasoline, have better fuel economy per volumetric measure than gasoline and thereby emit less CO_2, somewhere in the order of 20–30%. Due to this significant factor, diesel engine development was the first focus of European manufacturers trying to accomplish the goals of the 1998 ACEA voluntary CO_2 reduction target and also of some European governments through favourable taxation regimes. Furthermore, up until the late 1980s – when the first direct injection diesel passenger car was introduced – and to the mid 1990s when common rail direct injection was introduced, diesel engines were relatively undeveloped and were something of a 'low hanging fruit' for powertrain development engineers.

These technological improvements, together with the widespread introduction of turbocharging, have largely overcome the acceptance hurdles (performance, response and emissions issues) that diesel had faced in the past. This has proved especially true in the European market where, due to availability and some benevolent taxation regimes towards diesel fuel, diesel penetration has increased from just over 10% in 1990 to over 50% by 2006.



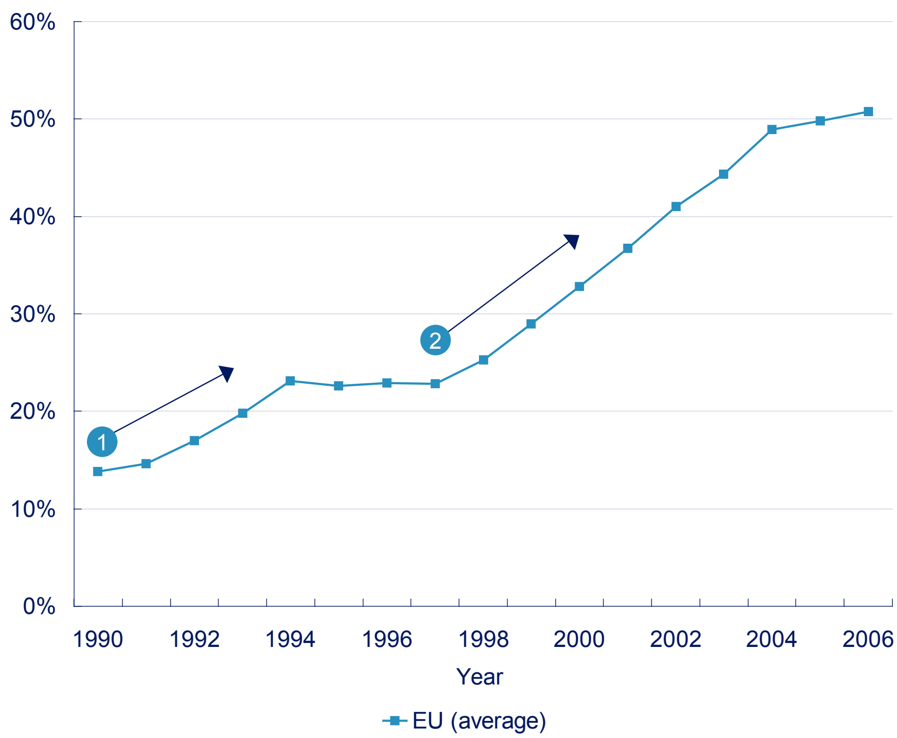
Source: PwC Automotive Institute

Fig. 33 Gasoline vs. diesel engine production in the EU



Source: PwC Automotive Institute

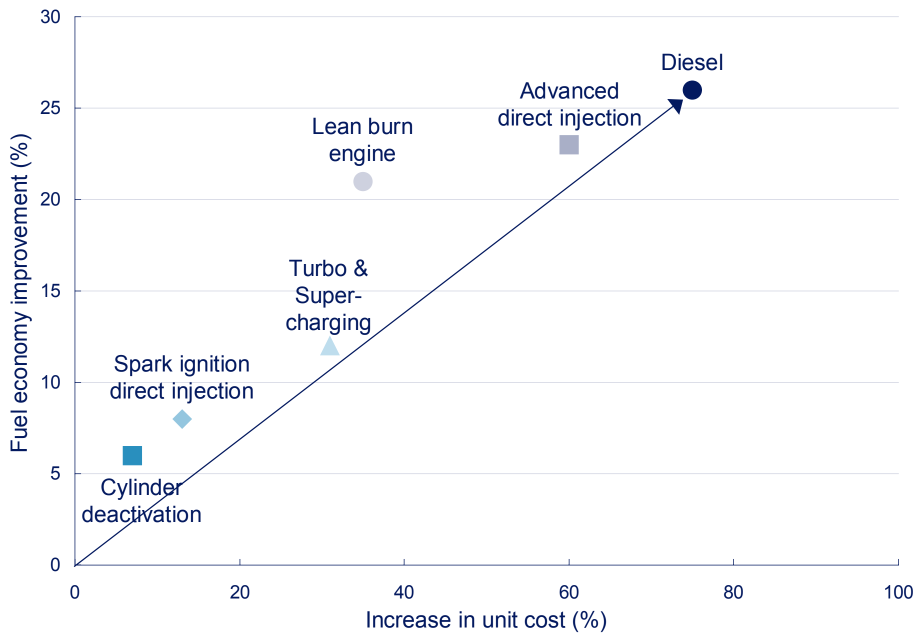
Fig. 34 Gasoline vs. diesel engine production globally



Source: ACEA; West Europe

Fig. 35 Diesel vehicle penetration in Europe

Diesel engines, today, are technologically advanced – the remaining technology targets are governed by emission regulations that require great control over NO_X emissions. Direct injection and turbocharging are well established in diesel engines and the potential for improvement is thus lower than in today's gasoline engines. Generally, ICE development goals can be summarised as a desire to make diesels as clean as gasoline engines and to make gasoline engines as fuel-efficient (as low in CO_2 emissions) as diesel engines.



Source: PwC Automotive Institute

Fig. 36 Trade-off between fuel economy and cost

Homogeneous Charge Compression Ignition (HCCI)

In light of the overriding ICE development goal – to combine the best characteristics of the diesel and gasoline engine – a promising concept is the HCCI engine. The engine takes the homogeneous charge (spark ignition) from the gasoline engine and mixes it with the stratified charge compression ignition of the diesel engine. Therefore, the fuel is mixed with air, but rather than relying on spark ignition the mixture is compressed until it auto-ignites. As the mixture needs to be extremely lean to avoid too high explosion pressure in the combustion chambers, the engine is as fuel efficient as a diesel engine. Furthermore, because combustion temperatures are lower than a spark-ignition engine there are virtually no NO_x emissions. On the debit side, HCCI engine concepts have always had control issues – whereby the parameters under which the mixture auto-ignites are not easily mapped. To eliminate this drawback most HCCI systems have to introduce a further control dimension, be it variable compression ratios, inducted gas at temperature, inducted gas at pressure, fuel/air mixture control, variable valve actuation or by varying the exhaust stroke. The other main drawback of HCCI engines has been a lack of power – and no simple way to improve power. In a typical gas engine, power is increased by changing the fuel/air mixture, while in diesel engines more fuel is injected into the combustion chamber to increase power. With HCCI, both methods change the combustion parameters once again and introduces more control issues. There are solutions to the problem: using different fuel mixes to change the heat release rates, thermally stratifying the charge so heat release is controlled, or just running the engine as HCCI under part load and switching to spark-ignition or compression-ignition mode under full load. VW is one manufacturer that has been at the forefront of recent developments with HCCI. In mid 2003, it announced plans for its own HCCI engine and in mid 2007 it revealed further details of its research. For diesel engines, it is planning a Combined Combustion System engine (similar to HCCI) designed to be optimised to work on biofuels and synthetics like

BtL and GtL. For gasoline engines, it revealed its Gasoline Compression Ignition concepts. The diesel engine could be available by the end of the decade. However, both engines do not seem to offer solutions to the lack of power from HCCI – the Combined Combustion System is limited to car speeds under 100 km/h, while the Gasoline Compression Ignition system only works at part loads. Mercedes-Benz also demonstrated its HCCI concept in 2007 under the name of DiesOtto.

2.2 Hybridisation – A smooth transition from add-on to alternative systems

Hybridisation is often communicated as an entirely new technology revolutionising the automotive industry and seems to be *en vogue*. Clever marketing campaigns, for example, by Toyota and the promotion through the media and by politicians like Renate Künast who recently stated: “Folks, buy hybrid vehicles from Toyota”[18] have contributed to this impression. *“The hype around hybrids is to a large extent the result of clever marketing.”* Dr Klaus Draeger, BMW AG.

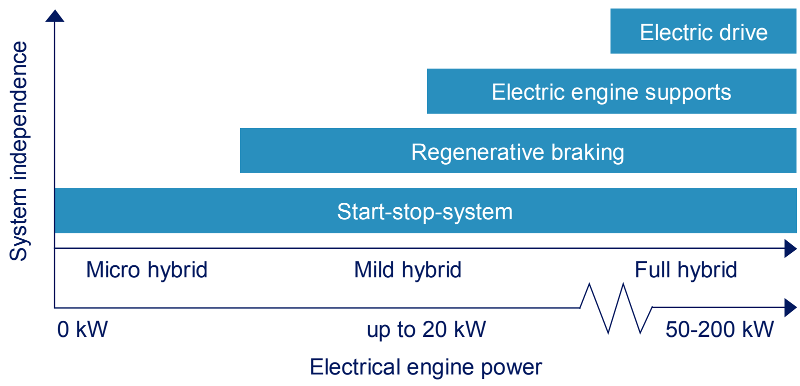
“Toyota’s fleet has, on average, higher CO_2 emissions than Volkswagen’s. However, due to clever marketing, customer perception is certainly the other way round.” Professor Ulrich Seiffert, Technical University of Braunschweig.

Fact is that the first hybrid car was already built in 1899 in Barcelona (Spain). The vehicle was equipped with an electric engine and an additional small-sized combustion engine. That it was not revolutionary does not lessen its importance for the automotive industry. To some extent, hybrid vehicles are simply an improvement of traditional ICE vehicles and as such are an effective way of contributing to more efficiency. In this regard, hybridisation is a very important development for the future of the auto and the automotive industry.

Hybrids are actually a group of technologies based on the principle of combining electric with combustion engines. The United Nations formulated a definition of the hybrid vehicle in 2003, as ‘a vehicle with at least two different energy converters and two different energy storage systems (onboard the vehicle) for the purpose of vehicle propulsion’. This definition covers a significant variety of concepts but has largely been focused within the automotive sector on supplementing a conventional internal combustion engine with an electric motor or motors and suitable energy storage systems (such as batteries or ultra capacitors).

Hybrids can be distinguished by the power output of the electric engine. Start-stop systems, in which a small electrical engine allows the engines to be shut down at a traffic light to eliminate wasteful idling, can be seen as the first step towards the hybridisation of a vehicle. Such vehicles are called micro hybrids. The next level of hybridisation, mostly known as mild hybrid vehicles, are additionally equipped with regenerative braking technology and a stronger electrical engine which offers some support and can boost the combustion engine upon demand. Full hybrids, sometimes also called strong hybrids, allow (limited) driving with the electrical engine only.

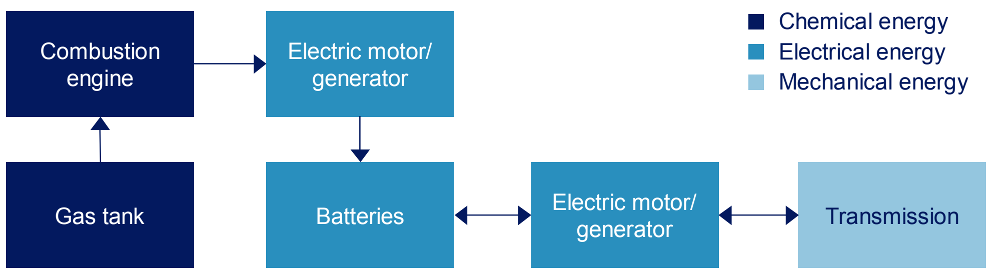
[18] Tartler J., Merkel fordert Entwicklung von Spar-Autos, in: Financial Times Deutschland, 12.02.2007



Source: Bosch Kraftfahrzeugtechnisches Taschenbuch

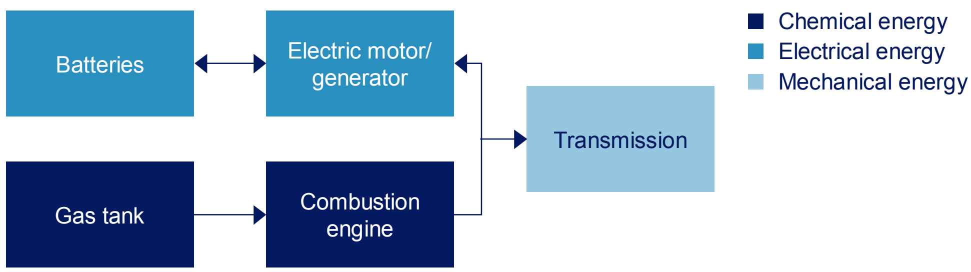
Fig. 37 Types of hybrids by degree of hybridisation

Hybrids can be constructed as parallel hybrids or series hybrids. Parallel hybrids, the most common concept today, have an electrical and a combustion engine each directly linked to the transmission. In a series hybrid, the combustion engine powers an electric generator that propels the vehicle. As the combustion engine is not directly moving the wheels, series hybrids do not need transmissions. Furthermore, in a series hybrid system the saving potential is higher than in a parallel hybrid as the engine can continuously run in its most efficient mode, while the electric motor is providing the required level of energy for the vehicle drive. In addition to these two pure architectures, automotive manufacturers are working with combined hybrids, using elements from both series and parallel hybrids.



Source: PwC Automotive Institute

Fig. 38 Structure of a series hybrid



Source: PwC Automotive Institute

Fig. 39 Structure of a parallel hybrid

Full hybrids (e.g. the Toyota Prius) can run on just the engine, just the batteries, or a combination of both. In order to provide sufficient energy, a large, high-capacity battery pack is needed, which today is still a hurdle for these vehicles, as current batteries are not capable to equip an average vehicle with sufficient range in the zero emission battery-only mode.

Excursion: Batteries – energy storage for vehicles

Batteries have the ability to convert electrical energy immediately to chemical energy and to save it in such way. Furthermore, they provide the energy on demand. Years ago, the extent of electrical equipment in vehicles consisted of only a few units. Nowadays, there is a trend to substitute mechanical with electrical units, for instance break-by-wire and steering systems, because electric powered components reach a higher efficiency. Besides new hybrid and electric vehicle propulsion, this new level of energy demand is the reason for increasing requirements for batteries.

The key requirements for hybrid batteries are a voltage range from 100 to 300 V and the ability to absorb higher quantities of electricity in short periods. Further important criterions are also weight, durability, the necessary peak power, capacity and energetic efficiency. There are technical approaches for every one of the criterions; however maximising all of them at the same time is not feasible due to a negative correlation of some of the objectives. To assure high durability for instance, the state of charge should lie between 30–70% of the maximum capacity of the battery. This makes it necessary to increase the battery size and hence its weight accordingly or to accept a shorter operating distance. Another good example is the customers' requirement for a fast charge. This is correlated with the development of heat, which significantly reduces the ecological efficiency as well as the batteries durability.

Looking at batteries available today we still face problems with regard to power, energy density and their weight. Therefore, the range of electrical vehicles is still limited. For instance, the Lexus LS 600h is theoretically able to reach up to 6 km with a speed of 45 km/h. In practice, however, the combustion engine is working after 3 km, due to the many electrical loads. To reach appropriate distances for an electrical vehicle, 150 to 200 Wh/kg would be necessary; current batteries are mostly in the range of 40 to 100 Wh/kg only.

The table below gives an overview about the prevailing types of batteries and their characteristics.

Type of battery		Power density (W/kg)	Energy density (Wh/kg)		Durability (years)		Costs (€/kWh)	
		2006	2006	2015	2006	2015	2006	2015
Lead acid	Pb	< 250	35	40	2-3	< 3	100	100
Nickel-cadmium	Ni-Cd	400	40-60	< 60	6	6	350	350
Nickel-metal-hydrid	Ni-MeH	400	60-80	100	5	5	500	300
Sodium-nickelchloride	$Na\text{-}NiCl_2$	200	100	n/a	5	n/a	300	n/a
Lithium-ionic	Li-Ion	400	140	180	5	10	750	300

Source: According to Dr A. Jossen expert for batteries at 'Zentrum für Sonnenenergie und Wasserstoff-Forschung in BW' (2006) in 'Automobilität und Innovation' of 'Wissenschaftszentrum Berlin für Sozialforschung gGmbH (WZB)'

Fig. 40 Development status and future prospects of batteries

At present full hybrid vehicles are mostly equipped with Ni-MH batteries, but it is likely that they will be replaced by Li-Ion batteries over the next few years once the final reliability problems are resolved. For example, Toyota was widely expected to use Li-Ion batteries on its next generation Prius from 2008, but it now appears the changeover has been delayed for at least a couple of years due to a need for ongoing development of the Li-Ion battery's reliability and safety.

The current R&D activities invested into batteries are mostly related to co-operations between automotive and electronic companies. For instance, Toyota is co-operating with Panasonic EV and Sanyo with the VW group. General Motors will co-develop Li-Ion battery cells with A123 Systems and is planning to use the batteries in its E-Flex electric drive system of the new Chevrolet Volt in the early 2010. Overall, battery development is and will be an important competitive factor. *"The topic 'battery' merited more attention. Being good at batteries might well represent an important competitive advantage in the future."* Thomas Kamla, Audi AG.

Today, batteries are still a limiting factor but we do expect further significant progress in the next years. However, some of the experts we interviewed raised the concern that physical boundaries might prevent the development to reach a stage e.g. necessary for an electrical vehicle.

"In the long term electro vehicles and fuel cells will compete for the dominant position. This, however, requires adequate batteries. Today, we see that Germany is far behind with its battery research. Physical boundaries are limiting the maximum energy density of batteries, so that the electro vehicle might still be at disadvantage even if durability, load-time and other obstacles would be eliminated. Overall, we perceive batteries to be an interesting field of research in which the Fraunhofer Gesellschaft should also put some effort." Professor Hans-Jörg Bullinger, Fraunhofer Gesellschaft.

Hybrid vehicles offer a variety of benefits, ranging from the avoidance of engine idling to regenerative braking and increased engine efficiency through optimal load and further downsizing potential. On the other hand hybrids increase complexity and the weight of the vehicle, reducing the (fuel) savings potential and leading to additional costs. Furthermore, lifecycle aspects such as production input and recycling costs need to be taken into consideration when judging the overall ecology and economy of a hybrid vehicle. Overall, most experts state that there is a technical point of hybridisation where the marginal utility is overcompensated by the marginal cost. This point is mostly seen between mild hybrids and full hybrids.

Finally, hybrids strongly depend on the driving behaviour and the type of usage. Long-distance journeys at higher speeds lead to higher consumption in comparison with pure ICEs, while hybrids provide advantages in inner cities. Determining the true savings potential under real driving conditions is still difficult and intensely discussed among experts.

Advantages	Disadvantages
• More favourable degree of efficiency and lower fuel consumption result in lower vehicle emissions compared to conventional internal combustion engines (degree depending on vehicle usage) • Hybrids can combine the benefits of internal combustion engines (e.g. sportiness) with electronically engines due to combining large ranges with the emission free driving option in burdened areas • Still improvement potential in the technology	• High development and production cost for manufacturers • Higher purchase price for consumers, lower expected resale value and decreased fuel efficiency advantage outside urban areas lead hybrids to a weak competitive position in terms of overall cost per km driven • Energy storage (i.e. batteries) is still a limiting factor • The introduction of hybrids requires new skills for maintenance staff and electrical technicians

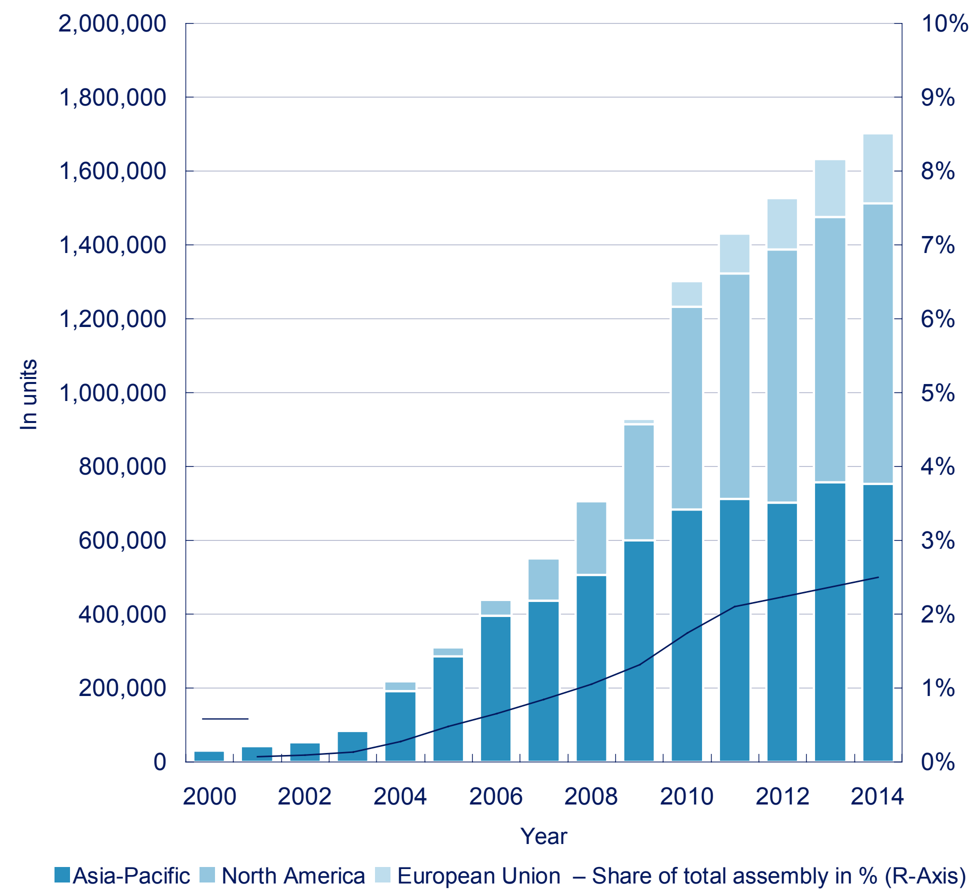
Source: PwC Automotive Institute

Fig. 41 Advantages and disadvantages of full hybrids

What is certain is the significant potential for further innovation and efficiency gains in a variety of applications for different hybrid systems. Especially the mild and micro hybrids, including a power assist unit for the vehicle and an improvement of traditional ICE, will penetrate the European market across segments in the next few years since they are not only capable of increasing the ecology of a vehicle but also the ‘fun aspect’ through providing additional peak power upon demand. *“The trend to electrification will continue in the next couple of years.”* Thomas Kamla, Audi AG.

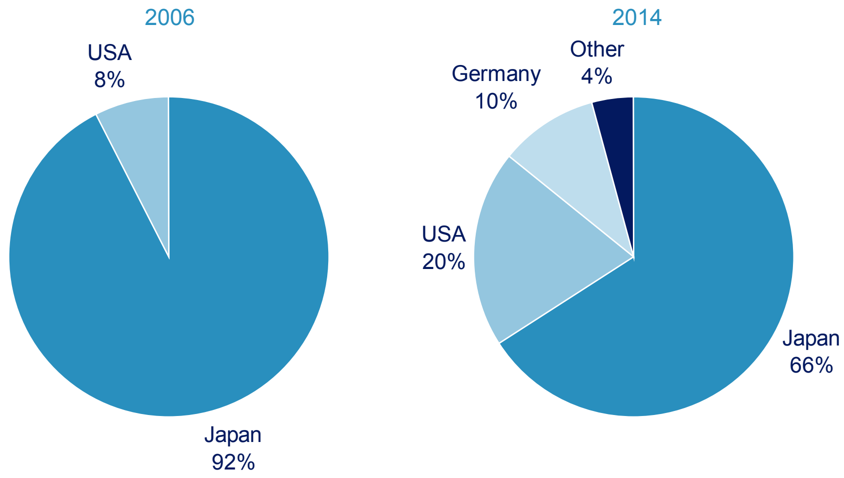
“The hybridisation of vehicles will not only continue due to ecological reasons, fun to drive might also play an important role.” Dr Thomas Schlick, The German Association of the Automotive Industry (VDA). Micro hybrids are set to become ubiquitous within the EU by 2012 and when the 130 g/km CO_2 target is implemented. Already in the past six months, we have seen micro hybrids introduced on a range of BMW vehicles and it seems certain that other manufacturers will add micro hybrids to their vehicles as a relatively cost efficient way of improving fuel economy.

Looking at full hybrids, PwC expects that the market share will remain relatively low, despite the fact that hybrids garner plenty of media and public attention. However, customers will have the final say. PwC therefore considers it important for all automotive manufacturers to have mild as well as full hybrids in their strategic portfolio. Taking the high research and development costs into consideration, cooperation in that area as, for example, DaimlerChrysler, BMW and GM are already doing, seems to be a valuable option for automotive manufacturers. *”Overall hybrid technology demands high investments which can only partly be passed on to the customer. The ‘Hybrid-Alliance’ with DaimlerChrysler and GM allows us to share these R&D investments and also enables us to gain synergies from economies of scale.”* Dr Klaus Draeger, BMW AG.



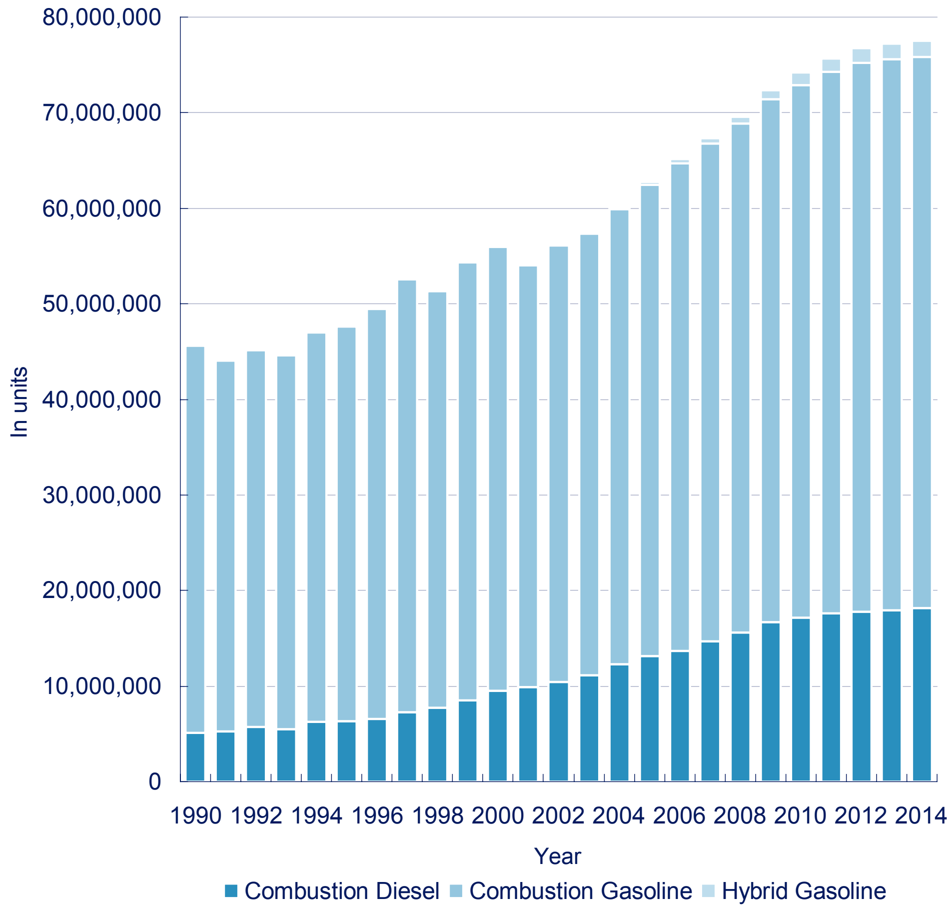
Source: PwC Automotive Institute

Fig. 42 Global full hybrid assembly by region



Source: PwC Automotive Institute

Fig. 43 Hybrid production by country of brand origin 2006 and 2014



Source: PwC Automotive Institute

Fig. 44 Development of global powertrain production

There is another aspect of hybrids that is worth looking at. Within the hybrid development, especially full hybrid development, components such as high voltage cables, electric engines or batteries have been developed that work efficiently in battery-only mode, as found in electric and fuel cell vehicles. The maturity of these components will be significantly improved through their application in hybrid technology. At the same time, the economies of scale accompanied by mass production lower the cost dramatically compared to prototyping. Hybridisation may, therefore, well turn out to be a bridging technology, preparing the ground for electric and especially fuel cell vehicles.

2.3 Hydrogen – the future of automobile propulsion?

Hydrogen is widely regarded as the future of automobile propulsion. As a fuel it conjures the images of quiet and efficient vehicles without any emissions other than water. Used in fuel cell vehicles, hydrogen allows not only a higher degree of energy efficiency compared to combustion engines but also avoids the combustion engines side effects like noise, vibration and harshness. Therefore, hydrogen seems to hold much promise for the future. However, the reality is complex and the introduction of mass market hydrogen powered vehicles will take at least another decade before becoming reality.

Hydrogen

First, hydrogen does not occur naturally in pure form, as do crude oil and gas. In order to generate hydrogen an energy input is needed, which splits up the bond structures in which hydrogen exists. Examples of hydrogen compounds are manifold. Most prominent is water (H_2O), but natural gas and fossil fuels also have bonded hydrogen in their atomic structure. The energy input to extract hydrogen from its compound can stem from a variety of energy sources, like fossil fuels, wind power, solar energy and water power. The three basic means of hydrogen production are chemical (steam reformation of natural gas), electrolysis (using electrical currents to split H_2O) and biological (using photosynthetic algae or hydrogen rich enzymes). Of the three, the most widespread process is steam reformation. Electrolysis offers the potential to bring zero CO_2 emissions if the electricity used is generated from renewable energy. For determining the real ecological impact of hydrogen a holistic approach is therefore needed which takes all aspects from 'well to wheel' into consideration. Overall hydrogen will develop its real ecological power only if gained from renewable energies. Most experts, however, agree that a temporary production out of natural gas may still be an option since the overall energy efficiency is still higher compared to gasoline and diesel. *"Hydrogen production out of natural gas exclusively doesn't make sense in the long-term-run, temporarily, however, it might well be an option since it's still more efficient than using gasoline"* Dr Joachim Wolf, Linde AG, Linde Gas Division.

"The clean fuel we use requires refineries to use huge amounts of hydrogen throughout the cleaning process. A shift to using hydrogen as fuel would therefore already have positive economic impact if gained from natural gas." Peter Fröschle, DaimlerChrysler AG.

Hydrogen infrastructure

Depending on the source and type of production, hydrogen has to be transported over a shorter or longer distance to the filling station. Since hydrogen is at room temperature a volatile gas, the hydrogen needs either to be compressed or cooled to liquid. The cooling process to –253 degrees Celsius requires about 30% of the energy contained in the hydrogen. This appears to be highly inefficient at first sight, but this is not actually the case. The alternative of compressing the hydrogen to 700 bar appears to be more attractive as only 18% of the energy in hydrogen is used in the process; however, the energy density of compressed hydrogen is much lower than that of liquid hydrogen, leading to additional transport costs that eliminate the efficiency advantage of compressed hydrogen.

One solution for the transport is a pipeline network. Such a network would be very costly to implement, which decreases the likelihood of such a network being implemented in the near future, excepting significant government subsidy or hydrogen demand reaching a critical mass. Transport via containers on the contrary, used to some extent to transport diesel and gasoline today, encounters the problem that, even in liquid form, you need several times as much volume as for conventional fuels due to the lower energy density of hydrogen. The result would be an increase in fuel consumption and emissions, stemming from the container transport system. Even in a perfect world with zero emission vehicles (on a Tank-to-Wheel measure), traffic would increase significantly if container transport was chosen as the distribution means. *"The volumetric energy density of hydrogen is much lower compared to gasoline or diesel. You will need 2.5–3.0 trucks to transport the equal amount of energy through liquid hydrogen compared to gasoline or diesel. Large distances and large amounts should therefore be covered by pipelines. For shorter distances, especially for the supply of fuelling stations, transportation and delivery of Liquid Hydrogen will be the only viable option. Having standardised global regulatory requirements would help the industry a lot in developing an appropriate hydrogen infrastructure."* Dr Joachim Wolf, Linde AG, Linde Gas Division. In this regard, it will be interesting to monitor the oil industry's response. On the one hand, pushing hydrogen development forward is undermining the oil industry's current business model, on the other hand, leading the way also protects the oil industry's future. If the industry shifts its focus to hydrogen in the long-run, it might well be perceived as the logical evolution of their current business model.

Hydrogen storage

A further major challenge for hydrogen is the storage on board the vehicle. Due to its low energy density the hydrogen either needs to be compressed at pressures of up to 70 Mpa (700 bar), stored in the liquefied form or use metal hydride systems in order to store a reasonable quantity of hydrogen in a very confined space in a vehicle. Another solution is indirect hydrogen, although it is now falling out of favour with some manufacturers. This alternative extracts the hydrogen from another liquid fuel, like methanol, gasoline or even diesel via an on-board reformer. This solution avoids the necessity of a hydrogen refuelling infrastructure, but is less efficient and increases GHG emissions.

Liter of hydrogen under standard conditions[1]	Physical condition	Comment
1	Gaseous	1 bar
500	Gaseous	Compressed, 700 bar
700	Liquid	–253°C
1300	Solid	Metal hydride

[1] Amount of hydrogen covered by one liter of tank volume

Source: GKSS

Fig. 45 Comparison of tank storage capacity

While distribution of liquid hydrogen would appear superior in terms of transport and energy efficiency measures, there are problems associated with storing liquid hydrogen over extended periods. If cooled to –253 degrees Celsius gradual losses of the liquefied hydrogen (‘boil-off effect’) can hardly be avoided over time since hydrogen is a volatile gas. It is technically feasible to seal and isolate a tank in such a way that no hydrogen can leak out; the gas’s attributes, however, lead to an increasing pressure in the tank over time. In order to keep pressure at acceptable levels, hydrogen has to be removed from the tank after a certain period of time – either through consumption or by deflating the pressure and hence the amount of hydrogen. Current technology is able to avoid boil-off effects of up to two weeks without moving the car. Furthermore, on-board control of the liquid storage environment, particularly temperature, has to be controlled very carefully. Achieving that adds costs and consumes energy.

Given this, many automotive manufacturers therefore consider compressed hydrogen as the superior solution for vehicle tanks; although this avoids the boil-off effect, it presents other challenges. Firstly, compression requires a strong frame, which needs space and adds weight to the vehicle. Additionally, the lower energy density compared to the liquid form either limits the driving distance or requires bigger tanks. Finally, there are also safety issues with compressed hydrogen – as there are with any compressed gas.

Consequently, there is also much research being carried out into solid-state metal hydrides as a source for hydrogen fuel – the hurdle with this technology being the required size and weight of the fuel tank, which is typically three-times larger and four-times heavier than a gasoline tank holding the same energy. Even though compression is currently favoured by most manufacturers, given all the conflicting pros and cons regarding the right solution, the last word regarding the right technology has surely not yet been spoken.

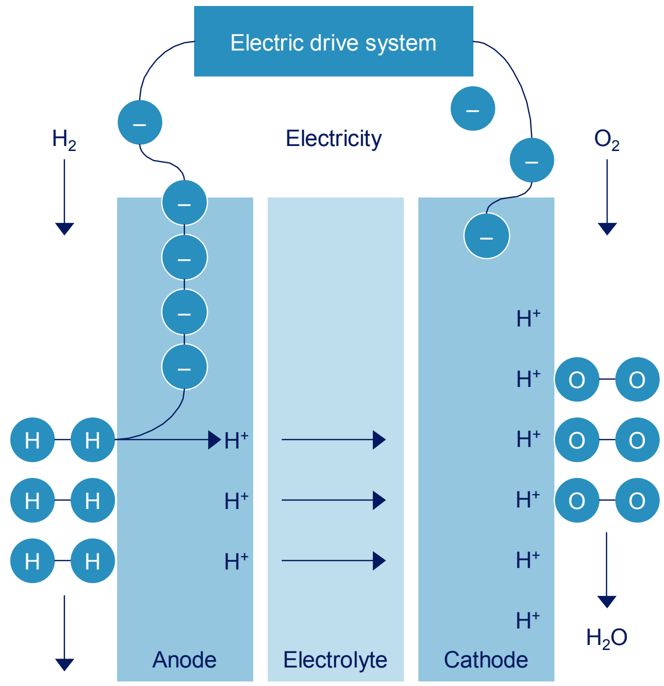
Electric vehicles

One way of bypassing the ‘tank’ hurdle would be to produce the electricity needed to drive the vehicle not onboard but offboard, transferring the electricity to the vehicle afterwards. Pure electrical vehicles, however, have to save the electricity in batteries chemically. As explained in the previous chapter developing such powerful batteries might fail due to physical boundaries, so hydrogen onboard must be considered the more promising path that is likely to limit electrical vehicles to a niche role in the future.

Hydrogen in ICEs and fuel cells

There are two general ways of using hydrogen on board of a vehicle: in an adapted ICE, as is the case in the current BMW 7 series (Hydrogen), or it can be used in combination with a fuel cell. Within an ICE, hydrogen is burnt like any other fuel, while the fuel cell uses it to produce electric power through the chemical reaction of hydrogen and oxygen. Hydrogen ICEs are expected to reach maximum energy efficiency similar to diesel engines; fuel cells on the other hand are much more efficient in converting energy – about twice as effective as the ICE. Fuel cells represent chemical converters that use hydrogen and ambient air to produce electricity, heat and water, without any emissions. The fuel cell can therefore be seen as the most promising technology in terms of efficiency and tank-to-wheel (TtW) emission avoidance. Due to the development of hybrid vehicles, most electrical components needed for fuel cell vehicles have already been developed, the only real new components left for fuel cell vehicles are the hydrogen tank and the fuel cell itself.

In principle, a fuel cell consists of two electrodes positioned around an electrolyte. Oxygen passes over one electrode and hydrogen over the other, generating electricity, water and heat.



Source: University of Bayreuth

Fig. 46 Operating mode of a fuel cell

Hydrogen fuel is brought into the anode chamber of the fuel cell. Oxygen, from standard air, enters the fuel cell through the cathode. Enriched with a catalyst the hydrogen atom splits into a proton and an electron: the proton passes through the electrolyte, while the electrons create a separate current that can be utilized before they return to the cathode. There they are reunited with the hydrogen and oxygen in a molecule of water.

Outlook

According to Dr. Peter Fröschle from DaimlerChrysler, there are still many technical steps to take until the fuel cell vehicle is ready for a mass market launch but there is no technical hurdle left where technical solutions are not in sight. Most experts do expect the first mass marketed fuel cells to be launched around 2015. *"When it comes to fuel cell development we see that the projections of what happens when, have become much more reliable recently. At the same time the error rate decreased significantly. There is now a realistic plan in place until market introduction which I expect to take place around 2012-2017."* Dr Joachim Wolf, Linde AG, Linde Gas Division.

"We are well on track with the fuel cell development. There is a real push from management to make things happen. If all goes well we will meet our objective to launch the first mass fuel cell product between 2012 and 2015." Peter Fröschle, DaimlerChrysler AG.

Market acceptance of fuel cell vehicles is difficult to judge. *"Projecting the market penetration of fuel cells is nearly impossible. However, the steps towards enabling future* *penetration are clear: today we demonstrate the technical capability; in 2009 to 2010 we expect to have a mature system with which we intend to convince the customers. The remaining years until market launch, planned for 2012 to 2015, will mainly focus on cost reduction."* Peter Fröschle, DaimlerChrysler AG. However, there are also critical comments e.g. Dr Klaus Draeger from BMW states that: *"Based on our current technological know-how we expect the combustion engine to remain the dominant powertrain concept over the next decades, the fuel cell is currently not judged as a real alternative in the foreseeable future".*

Based on our consumer research offering a new technology at competitive prices compared to combustion engines will be critical for success, a huge price premium will not be enforceable. The automotive industry therefore needs to put the focus not only on developing the technology but also to get the cost down to a competitive level. Overall it might take several decades until fuel cell vehicles are really competing with combustion engines and they certainly will not help automotive manufacturers to reach 2012 emission limits but they will most likely eventually be the dominant technology so any automotive manufacturer and supplier should perceive it as an important field of R&D.

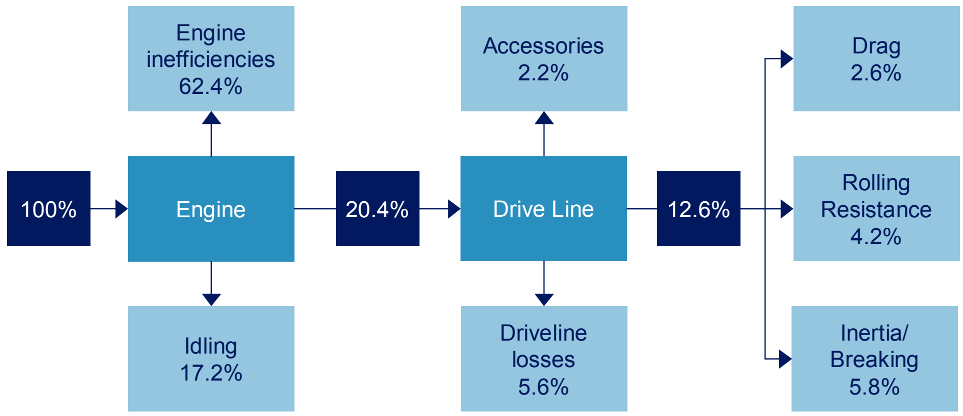
Advantages	Disadvantages
• Possibility of zero emission vehicle, real potential however is only evolved if hydrogen is gained from renewable energies • Higher degree of efficiency compared to conventional technology • Universal energy carrier of every primary resource • Considered technology of the future	• Maturity of development and high cost do not allow technology to be introduced to the mass market within the next years • New infrastructure has to be built up parallel to the conventional one • Remaining technical challenges with hydrogen storage (liquid, compressed and solid state), batteries and fuel cell
Source: PwC Automotive Institute	

Fig. 47 Advantages and disadvantages of hydrogen fuel cell

3 Beyond engine technology – further potential in the periphery

Given that the ICE is responsible for some 80% of the chemical energy lost when the fuel source is converted into mechanical power, much of the technology to enable more fuel-efficient vehicles has focussed on reducing these losses. So far we have seen that technology has focussed on making both the combustion process more efficient and reducing the amount of time the engine is idling (through micro hybrids). However, once the source of mechanical power reaches full optimisation it still leaves room to address the remaining 20% of losses. *"We need to focus on reducing CO_2 on the basis of a holistic approach through managing the energy flux within the vehicle as intelligently and economically as possible."* Dr. Klaus Draeger, BMW AG.

Of the remaining losses, those attributable to the transmission and a vehicle's inertia (i.e. mass) are the most significant. Therefore, this section looks at developments in both these areas in detail while also considering rolling resistance and aerodynamics.



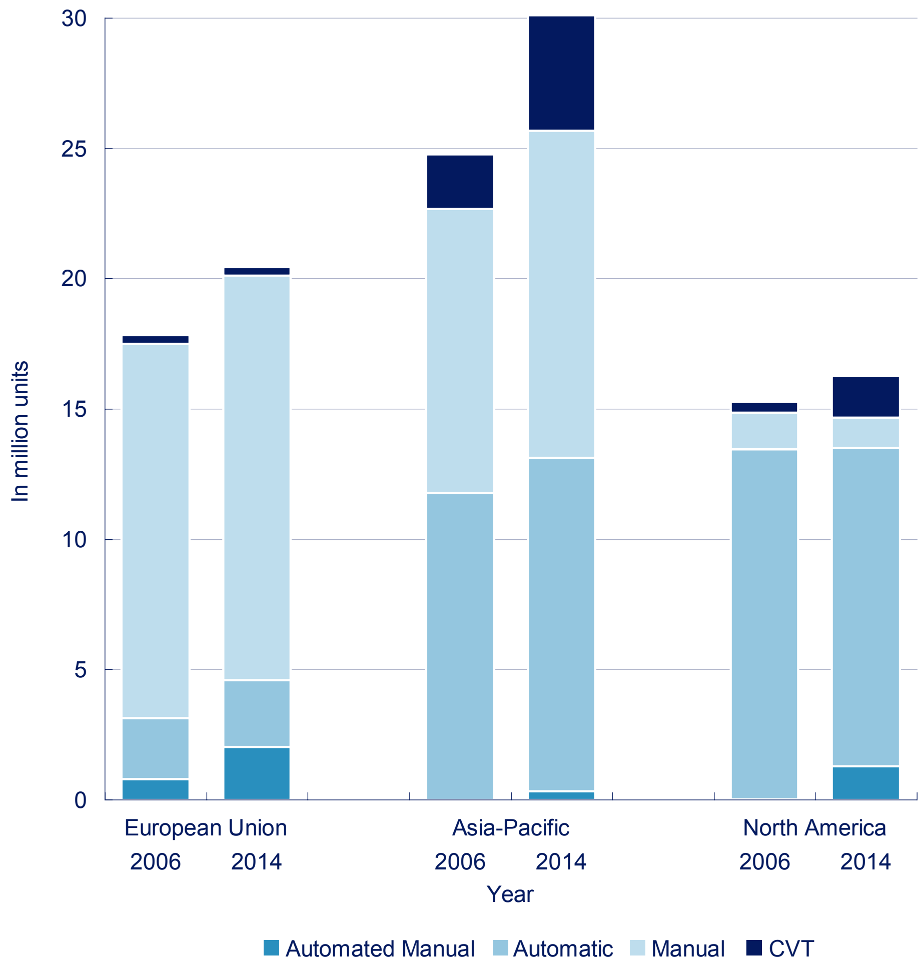
Source: EPA

Fig. 48 Where the energy goes

Transmission

The need to reduce driveline losses is resulting in one of the most dynamic periods for the transmission market since the GM Hydramatic automatic transmission was introduced to the market in 1939. While manual and automatic transmissions have dominated the market for decades, the consumption and emission requirements have led to a rethinking for the developers.

Conventionally, manual transmissions are more fuel-efficient than torque converter automatic transmissions, due to the efficiency losses suffered by the torque converter. However, manufacturers' test-driving cycle results are more likely to be reproduced in real world applications when the transmission is automated – thus obviating inefficient individual driving styles. This need, coupled with increasing urban congestion promoting demand for greater user comfort, is leading to the development and production of multifarious automatic transmission concepts. This change in the transmission market is most noticeable in the European market, which has traditionally been a bastion of the manual transmission.



Source: PwC Automotive Institute

Fig. 49 Development of transmission types by region

Choosing the most efficient transmission concept is by no means straightforward. Existing regional preferences and infrastructures require consideration in addition to a more perfunctory cost-benefit analysis. For example, automated manual transmissions (AMT) are most relevant for the European market not because they are the best means of obtaining control over gear changes, but because they make best usage of Europe's existing highly developed manual transmission manufacturing capacity and are therefore a cost-efficient means for the European industry to automate gear changes.

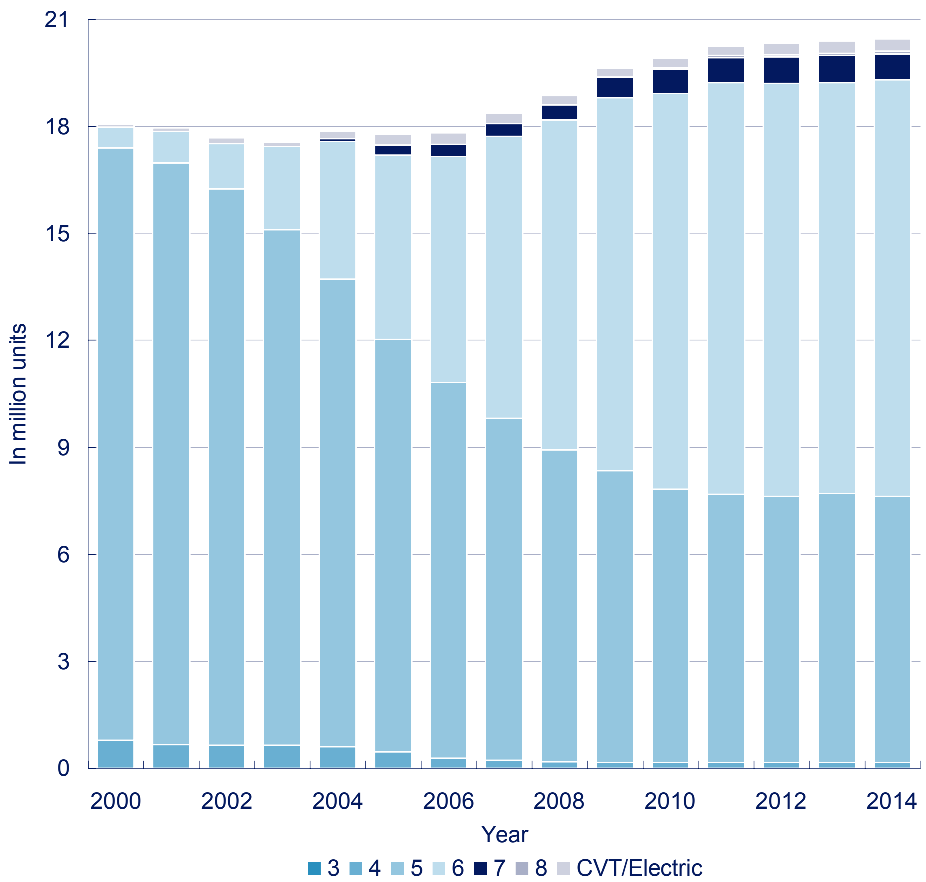
The subjective analysis of the various transmission concepts below is typical of the technology assessments automakers have to carry out as they consider the optimum transmission technology to meet their needs going forward. Below, we see that from BMW's perspective, automatic and dual-clutch transmissions are the best solutions for automation in their vehicles. The chart also helps us understand why other transmission forms are increasingly preferred in different markets and by different automakers. For example, in the Japanese market there is a high degree of urban congestion, which increases the relative importance of comfort in the market and leads to higher adoption of continuously variable transmissions (CVTs) in the market there. Furthermore, costs in the market are reduced by the significant manufacturing capacity held by JATCO for CVTs, while sportiness is not a prominent attribute for those stuck in Tokyo rush-hour traffic jams. Likewise, the dual-clutch transmission (DCT) transmission will find more favour in the European market because it is an adaptation of the existing manual transmission makes good use of extant manufacturing capacity and has natural manual control functions that appeal to European customers.

Potential	MT	AMT	CVT	AT	DCT
Cost	+++	++	–	+	–
Weight/Package	+++	++	+/–	+/–	–
Technology	+/–	+/–	+	++	+++
Comfort	+/–	+/–	+++	++	++
Sportiness	+	+	–	+/–	++
Fuel efficiency	+/–	++	+	+	++
Market	–	+	–	+	++
Source: ATZ					

Fig. 50 BMW's evaluation of transmission systems

The fuel efficiency driver has more weight than ever before and transmission development will simply not stand still. Therefore, the solutions that seem optimal now may be regarded as obsolete in 20 years' time as technology develops. Presently, as well as in the field of DCTs, there is considerable development work being carried out on infinitely variable transmissions (IVTs), with Torotrak at the forefront of these developments, which are regarded by some as the optimum fuel-efficient solution (at 12% fuel saving when compared with 6-speed automated transmission ATs). Additionally, some companies, notably Zeroshift, are working hard to eliminate the inherent drawbacks (torque interrupt and poor shift quality) of the standard AMTs. If successful these new type AMTs could prove most appealing to European automakers as they will require much less investment in new manufacturing capability than other solutions that are being touted.

While there is little apparent global agreement on the optimal type of transmission due to differences in regional vehicle types, infrastructure, and consumer preferences, etc. one area for transmission development that has global consensus is the increasing number of forward ratios. This development is demonstrated in Figure 50, with global change tempered to a degree by growth in emerging markets, where simplicity is the order of the day.



Source: PwC Automotive Institute

Fig. 51 Development of gear ratios in the EU

Put simply, a greater number of forward gear ratios allows for a better spread of gearing, which in turn gets better efficiency from the engine through the transmission. The addition of more forward ratios has seen most manufacturers opt to give more overdrive gears – as many as three in some cases. Overdrive refers to the transmission giving a higher output speed than is input from the engine – thereby allowing the engine to operate at a lower rpm, thus boosting fuel efficiency for a given road speed. Thus, more and higher overdrive gears boost fuel efficiency.

It is thought likely that there are increasing prospects for greater penetration of more forward gear ratios thanks to developments in engine downsizing. Broadly, downsized turbocharged engines have a lower operating engine revolution range than traditional gasoline engines. This therefore increases the requirement for the transmission to have a greater spread range. Analogous to this, diesel engines also operate at a narrower speed range than gasoline engines. Diesel engine popularity in Europe has contributed to the increasing number of forward ratios on transmissions.

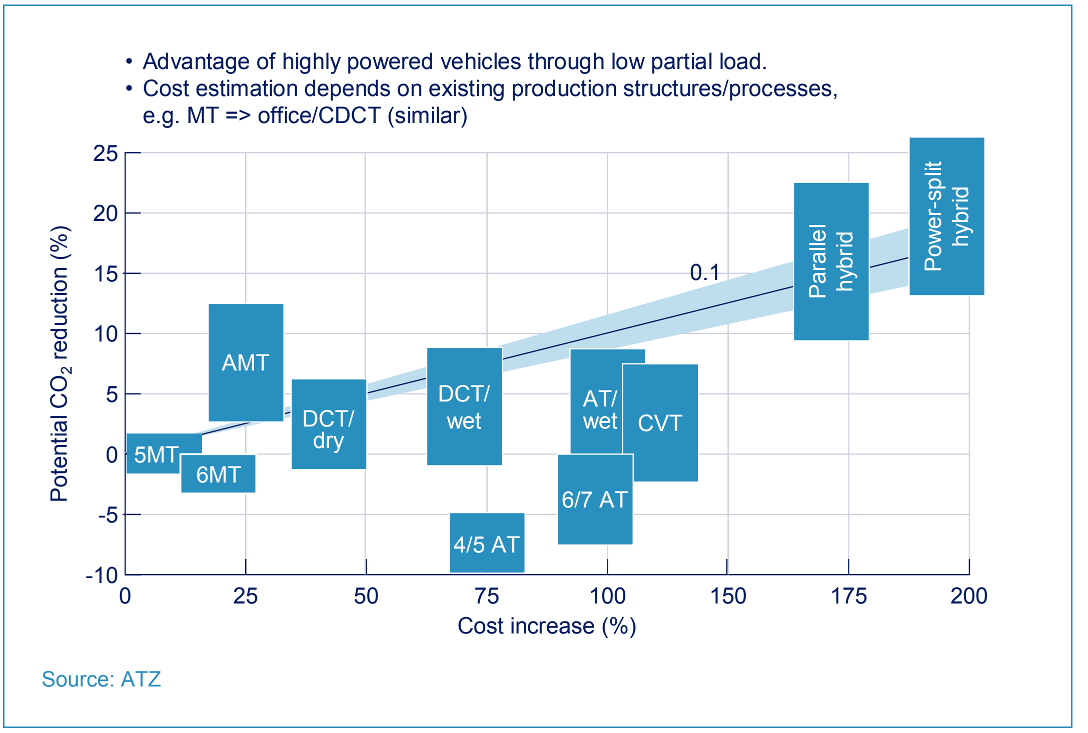
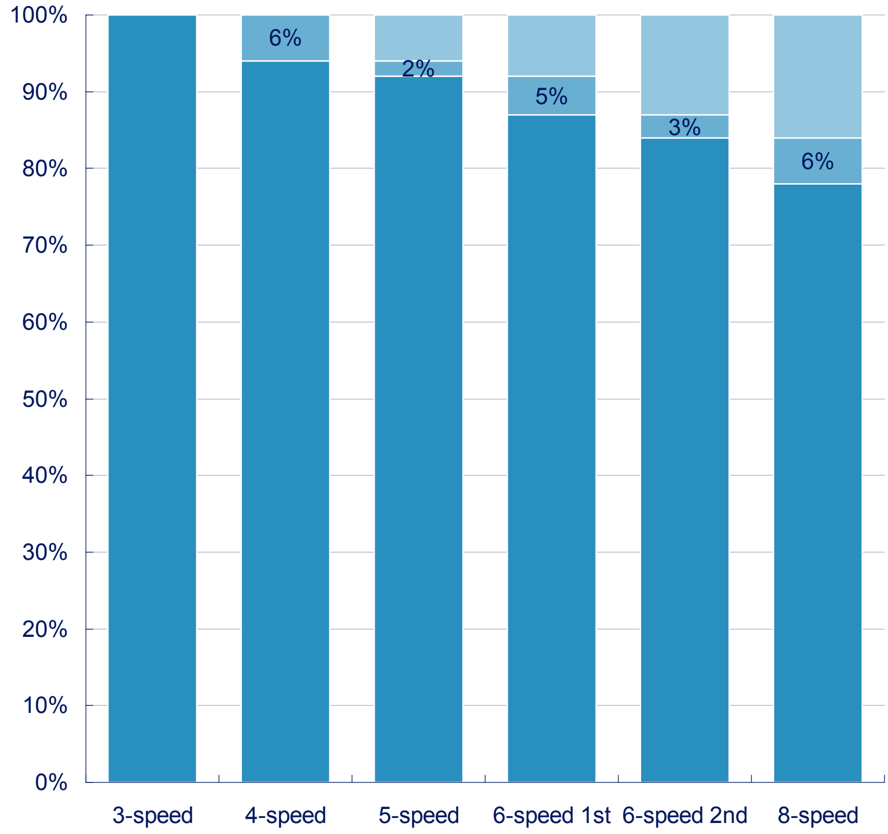


Fig. 52 CO_2 reduction of current and future transmissions

Until recently, 6-speed automatic transmissions were considered the optimum solution in terms of cost-benefit analysis. This analysis was largely based on the prevailing Lepelletier gear set – anything more than six speeds was considered marketing bravado with no real-world efficiency benefit. However, competitive pressure from DCTs and the existence of successfully applied 7- and 8-speed automatic transmissions has forced a re-evaluation of this viewpoint and it is considered that 8-speed automatic transmissions will become the future benchmark for automatics. The fuel-saving benefits achieved by the new ZF 8-speed automatics compared to their predecessors are shown in Figure 53.



Source: ZF Group

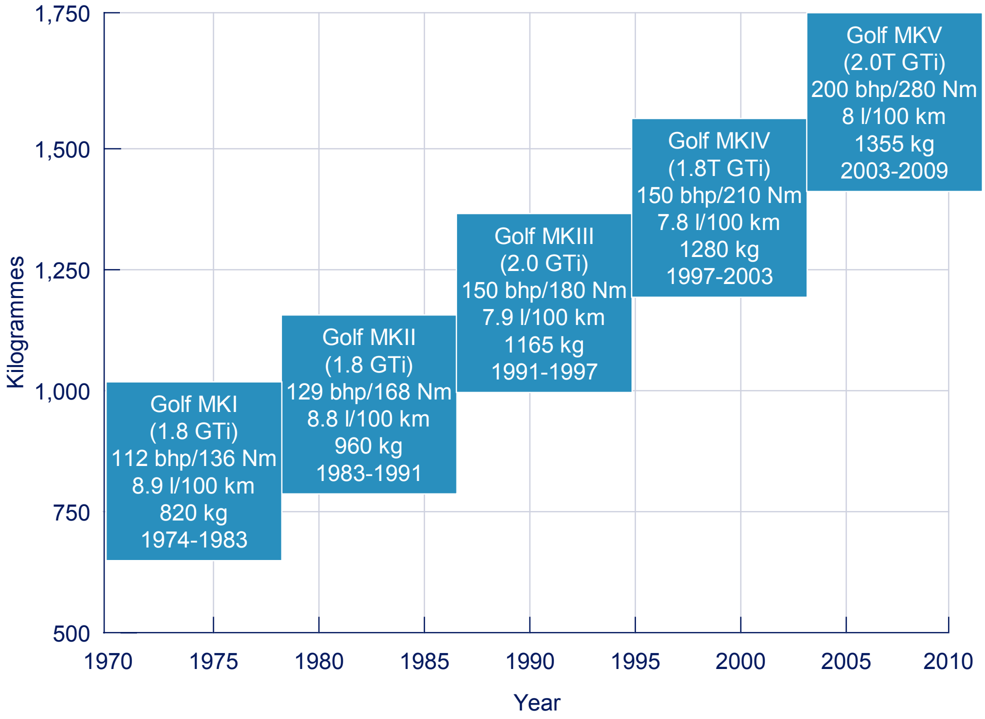
Fig. 53 Fuel consumption reduction 3- to 8-speed automatic

In theory, given the benefits that multiple ratios provide for fuel economy, it should follow that the ultimate transmission for fuel economy is the continuous variable transmission (CVT). Here, the transmission ratio can vary continuously and thus constantly operate in the engine's most economic and efficient way. However, there have been many false starts for the CVT over the years and it remains uncertain whether CVT will penetrate the market in the medium term.

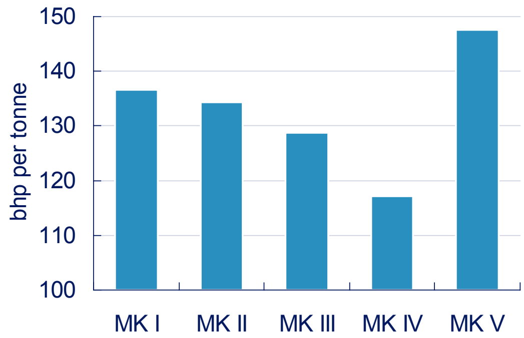
Besides overall powertrain (engine and transmission) efficiency, the second most important area for consideration is reduction of driving resistance losses. Driving resistance losses are related to the energy required to move the vehicle forwards. Driving resistance can be further categorised into inertia losses (and resulting braking losses), rolling resistance (weight and tyre influences) and aerodynamic resistance.

Reducing weight

The direct source of inertia is weight. In recent years, due to generational increases in vehicles, increasing demand for additional equipment, growth in the premium car segment, the need for greater vehicle safety and the increasing popularity of SUVs, vehicle weight has increased almost exponentially. The figure below shows the increase in weight of the VW Golf GTi from generation to generation and the scale of the engine developments that have been necessary to keep pace with this weight gain.



Overall change MKI – MKV	
Power	79%
Fuel economy	11%
Acceleration	25%
Max. speed	36%
Weight	65%



Source: PwC Automotive Institute

Fig. 54 Evolution of the VW Golf GTI

There is a wide range of opportunity to reduce weight in vehicles. This can be done by simply removing additional features which are not necessary, using lighter materials, like aluminium, magnesium or composites, and using new construction methods, like laser-welded tailored blanks.

Aluminium for example has gained a lot of attention and has become one of the most used materials by vehicle manufacturers. Aluminium has gained popularity mainly due to its light weight and strength. Compared with steel, on a volume basis, aluminium is three times lighter, but for most automotive applications the basic rule is that one kilogram of aluminium can replace about two kilograms of steel or iron.

Region	1990	2000	2006
North America	165 lbs/vehicle	258 lbs/vehicle	319 lbs/vehicle
Europe	112 lbs/vehicle	196 lbs/vehicle	259 lbs/vehicle
Japan	135 lbs/vehicle	212 lbs/vehicle	251 lbs/vehicle

Source: Ducker Research via Aluminum Association

Fig. 55 LV Aluminum Content by region/country

While aluminium has advantages for CO_2 reduction on a superficial basis – through reduced inertia losses – if a whole life cycle analysis is carried out there are some problems associated with using aluminium, as it requires significant energy input for its extraction and manufacture. Using aluminium selectively is therefore adding value; however, completely replacing steel with aluminium does not seem to be a viable option. Consequently, the automotive steel industry has demonstrated a number of weight-saving concepts over the last decade through its Ultra Light Steel Automotive Body (ULSAB) and associated initiatives. Technologies used to demonstrate weight-saving potential have included hydroforming of tubing and extrusions and laser-welded tailored blanks. *"Looking at the entire product life cycle and assuming realistic scenarios, aluminium auto bodies have, compared to light steel auto bodies like a ULSAB-AVC structure, no potential to contribute to CO_2 reduction. Steel is, in contrast to aluminium, a highly alterable material. This opens up many prospects for steel in the future. Through optimising molecule alignment or e.g. reducing the cut-off quantity we expect further significant improvements in terms of quantity, weight, safety and ultimately CO_2 emissions for the future."* Dr. Henrik Adam & Oliver Hoffmann, Thyssen Krupp Steel AG.

With regard to overall weight saving, the Wuppertal Institut estimated the potential in the different parts of an average upper medium size car to be between 25 and 50%. This would lead to fuel savings of approximately 0.9–1.8 litres per 100 km, based on an assumed saving ratio of 0.0025 l/kg and 100 km.

Component	Conventional weight (in kg)	Actual weight reduction potential (in %)	Resulting fuel saving (l/100km)
Body	514	50	0.6
Powertrain	499	10-50	0.1-0.6
Chassis	394	10-50	0.1-0.5
Other	62	55	0.1
Total	1470	25-50	0.9-1.8

Powertrain reduction includes saving without affecting performance and adjustment to performance
Chassis savings include the technological potential
Source: Wuppertal Institut

Fig. 56 Weight saving potential within the vehicle

As has already been mentioned, weight savings in vehicles should not just be limited to a discussion of material choice, a fact that the 2007 Mazda2 ably demonstrates. The 2007 Mazda2 (demo in Japan) is some 100 kg lighter than its predecessor model, without widespread use of any radical new materials. The Mazda2 demonstrates that weight reduction in vehicles can be achieved by taking a holistic approach to vehicle design and execution, with the resulting small incremental improvements adding up to considerable progress. Some 60% of the weight savings was achieved through engineering solutions, including the use of high and ultra-high tensile steels for a lower-weight body, with a further 20% reduction achieved through optional feature adjustment and the remaining 20% achieved through reducing the vehicle's length by 40 mm and the height by 55 mm. Other engineering measures included shortening the design of the rear suspension, reducing the length of the wiring harness and changing the door-mounted speaker magnet material to neodymium, which is a more powerful magnetic material than traditional magnets relative to its mass.

Recuperating braking losses

While energy is lost through inertia, the same energy – transformed into kinetic energy – that is used to move the vehicle is then lost every time the brakes are applied, when heat energy dissipates into the air. Regenerative braking technology is increasingly applied in automobiles to try to recover the wasted heat energy and put it to use in powering the vehicle. Currently, the applications on the market use the converted kinetic energy to charge the battery pack, but its use has also been investigated for charging a capacitor for electric launch assist, storing hydraulic power or for powering flywheels. In the case of flywheels, Kinetic Energy Recovery Systems (KERS) are being looked at seriously by manufacturers and suppliers. The potential for application of the technology in passenger vehicles is set to get a boost with the technology becoming mandatory on F1 cars from the 2009 season onwards.

Reducing rolling resistance

After inertia losses and braking losses, the next most significant category of energy loss in motor vehicles is rolling resistance, which accounts for some 4% of the overall energy loss. Rolling resistance losses increase with load and velocity and are exacerbated by incorrect tyre pressures. On account of this, tyre pressure monitoring systems (TPMS) are increasingly becoming mandatory. In the US, the Transportation Recall Enhancement Accountability and Documentation (TREAD) Act of 2000 mandated that 50% of model year (MY) 2006 light vehicles would be fitted with TPMS, increasing to 90% for the 2007 MY and 100% thereafter. In Europe, the EC has recommended that TPMS become compulsory as part of the legislative framework the EC is formulating for the 2012 emission reduction requirement. To illustrate why TPMS are garnering such legislative attention, consider that a tyre pressure reduction of 0.6 bar could increase fuel consumption by up to 4%, while reducing the lifetime by up to 50%. Furthermore, the EC is also in the process of formulating maximum tyre rolling resistance parameters for the EU. Rolling resistance and TPMS form one part of a package of measures that the EC is to implement to enable an extra 10 g/km CO_2 reduction to reach 120 g/km, which will not emanate from the vehicle manufacturers alone.

Reducing aerodynamic resistance

With aerodynamic drag accounting for over 2.5% of energy losses in the typical vehicle there is an increasing focus on aerodynamic improvements to try to reduce losses. The improvement in fuel consumption depends mainly on the speed of the vehicle, the drag ratio and the front surface. The last variable is currently particularly pertinent in Europe, where pedestrian safety legislation means that car manufacturers largely have to design vehicles with less aerodynamically efficient front ends. An improvement in the aerodynamics of a vehicle amounting to a drag coefficient change of just 0.001 has the same effect as a weight reduction of 2–3 kg, even at a low average speed of around 33.4 km/h. Figure 57 demonstrates how small changes in the car affect the drag coefficient and consequently the CO_2 emissions from a vehicle.

	Drag ratio	Aerodynamic resistance in kW middle value A= 2m^2 at different speeds			
	c_w	40 km/h	80 km/h	120 km/h	160 km/h
Convertible (open)	0.33-0.5	0.7	5.3	18	42
Offroad vehicle	0.35-0.5	0.71	5.5	19	44
Sedan	0.26-0.35	0.50	3.8	13	31
Station-Wagon	0.30-0.34	0.52	4.1	14	33
Source: Bosch Kraftfahrzeugtechnisches Taschenbuch					

Fig. 57 Aerodynamic resistance of different vehicle categories

Summary: driving resistance

So what do all these peripheral measures have the potential to achieve? As a rule of thumb the following fuel efficiencies might be achievable:

- 10% weight reduction – 6% fuel savings
- 10% improvement in aerodynamics – 3% fuel savings
- 10% decrease in rolling resistance – 2% fuel savings

	Fuel saving potential up to …
Piezo Injection	20%
Auto Start Stop Function	9%
Electric Power Steering	3-5%
Low Rolling Resistance Tyres	3%
Gear Shift Indicator	1.5%
Total	15-17%
Source: DAT	

Fig. 58 Fuel saving potential of different components

Case study: BMW Efficient Dynamics

	New models	Old models
	BMW 120i • Combined fuel consumption: 6.4 l/100 km • Combined CO_2 emissions: 152 g/km	BMW 120i • Combined fuel consumption: 7.4 l/100 km • Combined CO_2 emissions: 178 g/km
	BMW 120d • Combined fuel consumption: 4.9 l/100 km • Combined CO_2 emissions: 129 g/km	BMW 120d • Combined fuel consumption: 5.7 l/100 km • Combined CO_2 emissions: 152 g/km
Source: BMW, DAT		

Fig. 59 BMW Efficient Dynamics

Behind BMW Efficient Dynamics lies a package of technological features that considerably reduces CO_2 emissions, but not at the expense of performance. The new BMW 1-Series comprises a package of features that push the current technological envelope and demonstrate what is possible as outlined above. These features include:

- High precision injection – Piezo injectors on both the diesel and gasoline engines make the combustion process more controlled
- Auto start stop – ‘micro’ hybrid as standard
- Brake energy regeneration
- Electric Power Steering
- Air vent control
- Gear shift indicator
- Reduced rolling resistance tyres

Case study: VW Polo Blue Motion

	VW Polo 1,4 TDI DPF BlueMotion	VW 1,4 TDI DPF
	• Combined fuel consumption: 3.8–4.0 l/100 km • Combined CO_2 emissions: 99–104 g/km	• Combined fuel consumption: 4.5 l/100 km • Combined CO_2 emissions: 119 g/km

Source: VW, DAT

Fig. 60 VW Blue Motion

Unlike the 1-Series, the Polo BlueMotion does not make any great technological leap forward. Instead, it demonstrates the fuel efficiency savings that can be made by optimisation of peripheral elements, although omissions such as air-conditioning may compromise market acceptability.

The VW Polo 1.4 Turbodiesel Direct Injection (TDI) with particulate filter was already a vehicle emitting CO_2 below 120 g/km, but with a series of measures aimed at optimising fuel efficiency VW has managed to shave a further 9.2% off emissions with the BlueMotion package, giving it the lowest emissions in its class and less than the Toyota Prius.

The BlueMotion package incorporates:

- 1.4L TDI improvements
  - VGT, improved exhaust and catalytic converter
- 5-speed manual gearbox with longer ratios
- Aerodynamics
  - Revised front-end contributing to improved aerodynamics with lower air resistance (c_w=0.30)
  - Rear spoiler to smooth airflow
  - Smaller door mirrors
- Miscellaneous weight savings and energy measures
  - Light alloy wheels fitted with low roll-resistance tyres as standard
  - Not included: air conditioning, electric door mirrors, remote central locking

D Demand-side (re)action – the key to CO_2 reduction

"It would not surprise me if at one point in time driving a huge CO_2 critical vehicle such as a SUV will socially be as problematic as wearing a fur coat nowadays". Dr. Henrik Adam & Oliver Hoffmann, Thyssen Krupp Steel AG.

"The public discussion certainly helps us in bringing forward the theme; however it would be helpful if the discussion would be based even more on facts than is currently the case." Dr. Thomas Schlick, VDA – Verband der Automobilindustrie.

1 Changing the demand side – the real challenge

Even with the EC's new supply-side mandate, announced February 2007, the market alone lacks the required impetus for CO_2 reduction. For any tangible results to be achieved by the supply-side mandate, clear demand-side changes have to be instigated. Until now, CO_2 reduction has been tacked on to the bottom of a list of needs and desires (e.g. safety, End of Life Vehicle (ELV), NO_X, etc.) that often conflict with the goal of reducing CO_2 emissions. What help the market has received has been sporadic and inconsistent and not a sufficient incentive for consumers to change purchasing habits.

"The recent discussions surrounding CO_2 led to a strong customer uncertainty, which we can observe in the show rooms. The Federal Ministry of the Environment therefore actively supports an initiative for 'labelling' the energy efficiency of vehicles – a small step towards recovering the lost consumer confidence." Dr. Uwe Lahl, Bundesumweltministerium (Federal Ministry of the Environment).

Holistic planning is required and regulatory goals, supply-side opportunities and the needs of the customer have to be aligned so that various outcome dependencies do not subvert the initial starting goal. This means that supply and demand need to be looked in unison to move away from the current approach, which Sergio Marchionne, ACEA president and Fiat CEO sums up: *"The ideas put forward today by the EC focus too much on vehicle technology…"*[19]

1.1 The customer mindset – a barrier to low emission vehicle acceptance in the past

The key to success for any kind of ecological strategy is successfully promoting acceptance of environmentally friendly products and thus adjusting consumer demand. In the recent past this has been one of the main hurdles that environmentally friendly cars have failed to negotiate. Dieter Zetsche, CEO of DaimlerChrysler AG has stated in this regard: *"We must influence the market, not simply supply it with vehicles that people don't want to buy."*[20]

[19] ACEA Press Release, Proposed CO2 emission targets are arbitrary and too severe, Brussels, 7 February 2007

[20] Hutton, R., Emissions row divides carmakers: Europe's motor industry can't decide how to deal with tough new limits on carbon emissions, in: The Sunday Times, 18 March 2007

Opel Corsa Eco

- 115 g/km car. Same price as standard Corsa 1.0 l
- Low sales due to trans., tyres and performance

Renault Electric Vehicles

- Succession of low-selling electric vehicles
- 2002 electric Kangoo only sold 151 units.

VW Golf CityStromer

- Pure electric MK III Golf
- High cost and lower performance vs standard Golf saw < 150 sold.

Audi Duo

- Plug-in parallel hybrid introduced 1997
- 60 units sold

VW Lupo 3L

- High-tech weight and fuel saving technology
- Positive initial response, but ultimate market limited

Fiat Seicento Elettra

- 1998 electric Seicento
- Only 294 made over a four year period.

Source: ACEA

Fig. 61 Low emission vehicles in the past

If there is lacklustre demand for environmentally friendly vehicles, even if financial incentives are offered, it will be virtually impossible to meet the future CO_2 targets: thus, creating demand for efficient vehicles is key to success.

Taxation, discussed in this chapter, is a powerful tool as it creates a monetary incentive for consumers to switch to more fuel-efficient vehicles. However, this is only part of the equation, and it is of equal importance to change the image of these types of vehicles. With the public debate on climate change escalating, together with some causal links for recent meteorological occurrences being established, the task of changing the perception of environmentally-friendly vehicles is not as thankless as perhaps it has been in the past. On the other hand, it's certainly not a self-seller as the following quotations indicate: *"In Germany the attribute 'ecological' is still a secondary purchase criterion."* Thomas Kamla, Audi AG.

"Customers do want cars with low CO_2 emissions. Ten years ago the emotional focus was on power, cylinder and valves – this has changed dramatically." Professor Ulrich Seiffert, Technical University of Braunschweig.

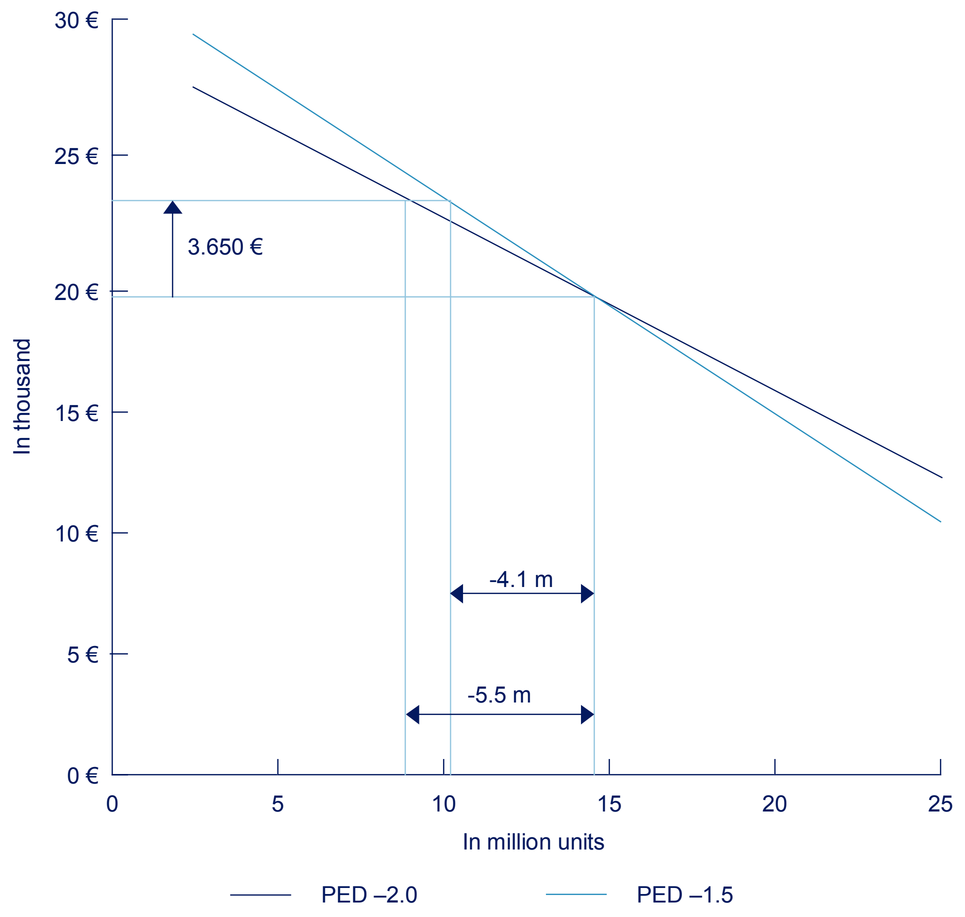
Furthermore, the increased interest in environmentally friendly vehicles, together with mounting legislation is leading to a shift in the marketing strategies of the automotive manufacturers. While technical features and prestige were the focus in the past, clean vehicles are increasingly becoming an important sales segment. Recent marketing and advertisement campaigns of the major automakers seem to acknowledge that.

Marketing is also considered in the EC proposal to take emissions to the 120 g/km limit from the 130 g/km target from technology alone, as car manufacturers shall be asked to sign an EU code of good practice on car marketing and advertising to promote more sustainable consumption patterns. Under the terms of the agreement, automakers will be bound to focus less on the performance aspects of their vehicles.

1.2 Cost – are automakers overstating the negative impact of the CO_2 measures?

Market perception and emotional aspects are not the only change elements to be considered when analysing the potential for demand shifts. Price is another key factor which strongly influences the demand, especially in price-sensitive saturated markets, and automakers have voiced their concerns that the cost of implementing the CO_2 technology could have a severe negative impact on the European market.

The EU-15 market is essentially a stagnant market. Since peaking in 1999 at 15.1 million units, the market has fluctuated between 14.2 million units and 14.8 million units, even though prices for new vehicles decreased. In this environment, Renault's VP Patrick Pelata stated that his company estimates that a 10% increase in prices will result in 15–20% fall in sales. Assuming that the related costs are transferred to the customers one to one and taking an average transaction price of 20,000 euros per vehicle in the EU, the cost of the CO_2 mandate could mean a sales loss of between 4.1 and 5.5 million units, given that ACEA estimates that the 130 g/km CO_2 limit for 2012 will cost on average 3,650 euros per car.



Source: ACEA

Fig. 62 Price elasticity of demand for new cars

This illustration provides only a rough estimate, as demand in the EU market is much more complicated. Not all vehicles have the same Price Elasticity of Demand (PED), so that an extra 3,650 euros per vehicle has less impact where demand is more inelastic, as in the case of luxury or sports vehicles. Pelata's statement seems to focus on B and C segment vehicles, where Renault's competitive efforts are focussed.

Another issue is that the additional costs to implement the new limits, currently estimated at 3,650 euros per vehicle by ACEA, are likely to be lower by 2012 as further potential for efficiency gains will be tapped and scale economies will have a bearing. This factor has been observed in the past for technologies such as catalytic converters and Antilock Braking System (ABS) brakes. Finally, the implementation costs will greatly depend on the vehicle, so that not all vehicles or manufacturers will incur the same costs. In addition, it is likely that some automakers will look to absorb the extra costs in order to protect sales rather than pass the whole cost through to the customers.

"The average customer only pays a price premium if he gets a tangible and direct value in return." Dr. Thomas Schlick, VDA – Verband der Automobilindustrie.

Additionally, increasing running costs brought by high fuel prices are focussing consumer minds on fuel efficiency. A break-even for more expensive technologies offering lower fuel consumption/CO_2 emissions will be reached earlier in an era of high fuel prices.

1.3 Steering consumer demand – the role of taxation

Taxation is a very strong instrument to control and direct behaviour. Environmental tax, petroleum tax, and the motor vehicle tax can be summarized as Pigovian taxes, all intended to change people's behaviour in order to reduce negative environmental effects. Of course, taxation can always fulfil fiscal objectives for governments as well, but in this case focuses on its Pigovian objectives.

Fair ecological taxation would make the originator pay the price for the environmental damage that is affecting the entire society, as well as the overall economy, as the 'Stern Review' outlined. However, any taxation must be regarded in the light of social acceptability.

The question is how such a tax system needs to be structured in order to fulfil the purpose of environmental protection. ACEA, for example, *"is in favour of replacing registration taxes with a system that increasingly reflects environmental priorities. Car taxation should be more directly based on the use (rather than ownership) of a vehicle and on its environmental performance."*[21] The EC has introduced a proposal for a directive regarding passenger car taxation and which is linked to CO_2 emissions, but it is not yet agreed. Even though most member states agree that indeed the level of CO_2 emissions should decrease significantly and that car taxation is the policy instrument to do so, critics argue that changing the taxation in the way that the EC has proposed is not socially acceptable. It would seriously affect the poorest European citizens, who are not able to buy the latest CO_2 efficient cars. With respect to the average age of the European car fleet, in the 'new' member states the average vehicle is more than ten years old, these arguments need to be considered carefully.

However, the biggest challenge in Europe is to align the different tax regimes and to take into account the different objectives and financial needs of the member states, as taxation is still a national issue. *"We expect a shift of car taxation towards CO_2 emissions. Looking at the best existing car taxation systems in the EU there is no country that does a perfect job, but for example the UK's company car tax system and the Dutch registration tax system are examples of current best practices."* Jos Dings, T&E European Federation for Transport and Environment.

"We expect a change towards a CO_2 emission-based taxation system. Middle-average fuel consumption might serve as an appropriate calculation basis. In order to develop a noticeable allocation function, the taxation needs to be noticeable for all drivers including company car owners; overall taxation needs to be considerably higher than today." Professor Hans-Jörg Bullinger, Fraunhofer Gesellschaft.

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[21] ACEA: "Car Taxation – Towards coordination and environmental focus", 23.04.2007, www.acea.be/car_taxation_towards_coordination_and_environmental_focus.

	France	Germany	Italy	The Netherlands	UK
Acquisition	VAT (19.6%), registration tax (by region (> € 46) and CO_2 banding)	VAT (16%), registration tax (€ 25.6)	VAT (20%), registration tax (flat fee) € 150, registration fee € 70	VAT (19%), registration tax (45,2% of the pre-tax list-price (-€ 1,540 gaso-line/+€ 328 diesel), with discount/bonus system based on fuel efficiency bands)	VAT (17.5%), first registration fee € 56
Ownership	Company car tax based on CO_2 emissions – € 2-19 per gram CO_2	Engine size and fuel type (gaso-line from € 6.75/ diesel from € 15.44 per 100 cc engine size)	Ownership tax (by output) € 2.58/kW	By weight, fuel type and province (e.g. Utrecht region @ 1500 kg – gaso-line = € 664/ diesel = € 1,224)	CO_2 ratings € 0-440
Usage	Fuel taxes • Gasoline 63.8% • Diesel 55.9% (pump prices)	Fuel taxes • Gasoline 63% • Diesel 69% (pump prices)	Fuel taxes • Gasoline 61% • Diesel 52% (pump prices)	Fuel taxes • Gasoline 65% • Diesel 53% (pump prices)	Fuel taxes • Gasoline 68.5% • Diesel 65.9% (pump prices)

Source: PwC/ACEA

Fig. 63 Taxation in selected EU countries

Given the different political interests, a common taxation regime for Europe seems almost impossible, although there are approaches in all member states to link environmental considerations to taxation.

Furthermore, as they stand the existing various taxation regimes provide not insignificant tax revenues to EU member state governments and any harmonised regime would have to be constructed so as not to detrimentally affect government revenues.

Countries with CO_2 tax elements in place	Sales & registration	Annual ownership	Other[1]	Total (€ billion)
Austria	0.440	1.40	8.46	10.3
Belgium	0.317	1.43	9.85	11.6
Denmark (DKK)	16.799	8.33	18.5	5.9
Germany	–	7.74	69.6	77.4
Spain	1.289	2.05	22.5	25.9
France	1.309	1.16	56.0	58.5
Greece	0.928	0.69	2.38	4
Ireland	0.807	0.68	2.51	4
Italy	2.067	5.50	57	64.6
Netherlands	2.874	2.11	8	13
Portugal	1.211	0.14	4.54	5.9
Finland	1.310	0.51	5.78	7.6
Sweden (SEK)	n.a.	10.2	66.3	8.2
United Kingdom (£)	n.a.	4.45	38.5	62.3
Total	–	–	–	359

[1] Incl. VAT, servicing, insurances, customs duties, spares.

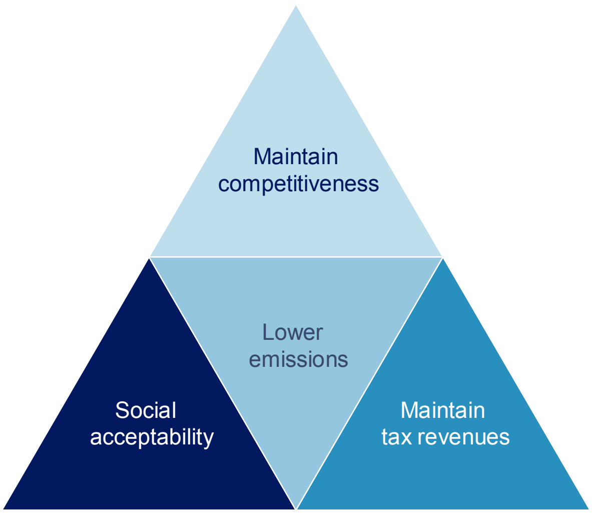
Source: EU Road Federation 2006

Fig. 64 Motor vehicle tax revenues in EU-15 countries

The table shows the motor vehicle tax revenues in the EU-15 countries in 2004. If the governments followed ACEA and adopted a more integrated approach to taxation with *"…a focus on increasing demand through taxation measures…"*[22] where all existing EU member car taxes and fees should be replaced by a circulation tax based primarily on CO_2

[22] ACEA, Integrated Approach: Beyond 2008: reversing weak demand through taxation..., www.acea.be/integrated_approach

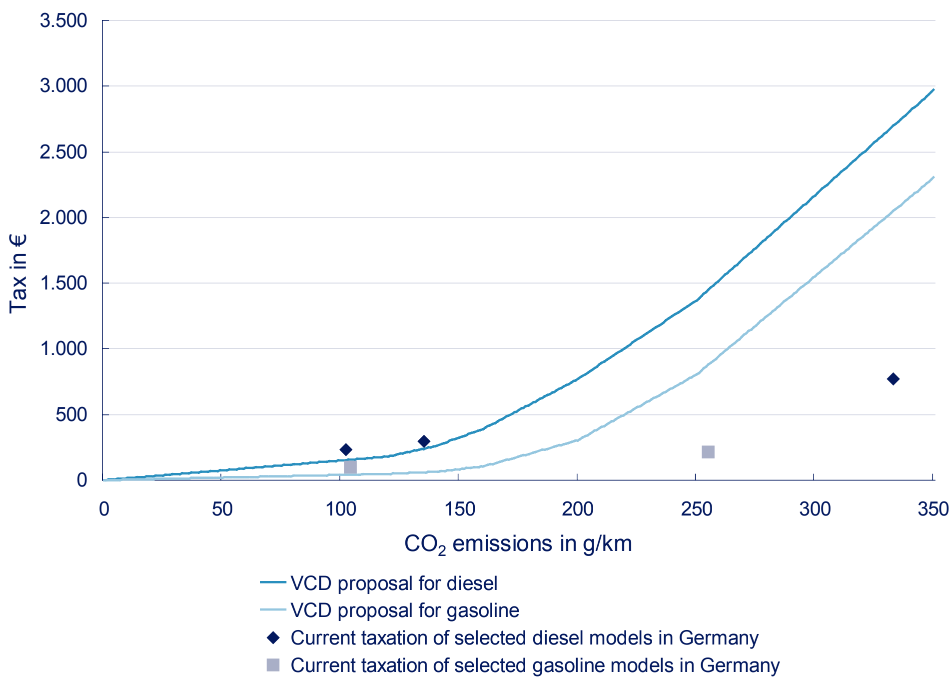
emissions, then the overall tax revenues could decline by 30% – roughly 1% of the EU's total GDP. The challenge is therefore to balance inducements while maintaining income and ensuring continuing competitiveness – all in a socially acceptable package.



Source: PwC Automotive Institute

Fig. 65 Requirements for a new tax system

In Germany, several concepts are in discussion. The VCD suggests a taxation that replaces the German engine displacement-based tax with a CO_2 emissions-based tax.



Source: VCD

Fig. 66 The VCD taxation model

Case study: UK market – tax system starting to send signals

The UK's system is structured in two ways: through the annual road tax, payable by all vehicles, and through the company car system.

- On the face of it, the differentials in annual road tax based upon CO_2 emissions are not significant – ranging from 35 to 300 pounds – and presently not great enough to result in a noticeable shift in buying behaviour. However, there are likely to be ripples through to the second-hand market – negatively influencing residual values for high-polluting vehicles and thereby indirectly effecting first-use demand.

- However, the announced increase to 400 pounds for band G from 2008 sends out a clear signal to the market that further increases are likely and the tax liability of the most polluting vehicles will continue to increase.

- Perhaps of more significance in affecting buying behaviour at present is the company car tax system, which is based upon the level of pollution of a vehicle, the list price and the marginal tax band of the user. With around 50% of new car sales going to company users, the generally lower emissions and tax liability of diesel cars means the UK company car taxation system has been instrumental in promoting the growth of diesel sales and the reduction in CO_2 emissions of the new car fleet.

Excursion: Spotlight Q&A on CO_2 tax implications in Europe with PwC's Bart Vanham, Director, Leader Indirect Tax Automotive Practice

Can you summarise the type of taxation proposals that the EC has tabled for CO_2?

On 5 July 2005, the EC proposed a Council Directive on passenger car related taxes. This proposal, which is not yet agreed upon by the member states, consists of three main measures. Firstly, the EC is looking to abolish the registration tax (RT) on vehicles. It further wants to organise a refund system for the RT and the annual circulation tax (ACT) according to the use of the car in the member state concerned. Finally and most importantly, the Commission would like to restructure the tax base of the RT and the ACT in such a way that by 2008 at least 25% of the total tax revenue from RT and ACT respectively should originate in the CO_2-based element of each of these. By December 2010 this should reach 50%.

Will EU member states be able to agree collectively on CO_2 taxation? Members with high registration taxes will surely fight the proposals?

It will indeed be difficult to collectively agree on the measures proposed by the Commission (unanimity is required). Naturally, countries like Denmark and The Netherlands, with high RT, are not very satisfied with the proposal. However not only the countries with a high RT are reacting, CEE countries are reacting too, arguing the unsocial character of the proposal. Today, it looks like the proposal will not be adopted in its current condition. It is likely the EC will work further on the proposal although it does seem very likely that the CO_2 measures are going to be enforced via a new legislative framework expected in 2008.

How do the CO_2 taxation initiatives fit with the principle of subsidiarity in the EU? How will they be implemented, will boundaries be set by the EU?

The proposal only aims to restructure passenger car related taxes. Nevertheless, the EC feels that the commitments taken under the Kyoto Protocol, such as the reduction of CO_2 emissions, cannot be sufficiently achieved by the individual member states and, therefore, due to the scale or effects of the action, can be better achieved at Community level. Thus, the EC argues that the subsidiarity principle is fully complied with and they will indeed set the standards that should be reached by the member states.

Do you think that member countries will seek to claw back taxation revenues in other ways, after all, the current system delivers around 360 billion euros in revenue?

In principle the proposal from the EC should be revenue neutral. The loss in RT could be compensated by an increase in the revenue from ACT. This would result in a car taxation that is more directly based on the use of the car. EU member states will look for a compensation of any loss of revenue that results, but on the other hand, should realise that the beneficial environmental effects do not come without a price. Needless to say that there will be a tension between the objective of (changing) the taxation, i.e. more 'green' cars, and the lack of tax revenues if successful.

Is it not the case that many EU member countries already tax for fuel efficiency in the level of duty imposed on fuel?

Member state do differentiate the duty imposed on fuel but not always related to fuel efficiency or environmental reasons. Most Member States impose relative low levels of duty on bio-fuels to compensate for increased production costs. Nevertheless, excise duties on fuel can be one of the most efficient and easy to implement kilometre charges and therefore measures to take to tax the use and not the possession of a car.

The US Supreme Court ruling that CO_2 is admissible as a pollutant is leaving many to speculate there that fuel duties will be raised in the US. Does the EU situation show that fuel duties are not an effective taxation lever for CO_2 reduction/fuel efficiency?

It is hard to estimate the effect of rising excise duties on fuel in the long term. However the high oil prices of last year and correspondingly high fuel prices in Belgium showed us that during that period fuel consumption dropped by 6%.

With respect to the forthcoming CO_2 tax initiative, what advice would PwC give to key automotive stakeholders?

PwC is monitoring the different car taxes closely and is informing its clients accordingly. A direct impact can be found already in the car leasing sector. The taxation proposals will have a significant influence on the residual value of today's cars in two or three years. Therefore, car leasing companies, already today, have to consider the coming legislation when calculating the residual value of the leasing cars.

The car industry together with the governments should also be well informed/prepared about the impact of any measure taken in order to avoid any 'wild', politically driven, initiative. Many different CO_2 related systems or parts thereof have been implemented in an increasing amount of member states, some of these systems with a proven track record others with estimated impact. PwC has studied the impact or expected of these best practices and can use these in financial models to calculate the potential impact of any of those measures based on a given starting point. These best practices could be a step to a uniform European approach that would be transparent, and most manageable for the car industry.

1.4 Eco-driving – a signpost from consumers

Eco-driving is a way to reduce CO_2 emissions while saving money. It is a piece of the puzzle which can greatly contribute to CO_2 reduction without major investments. The preceding sections focussed on the responsibilities of the industry and governments but without individual responsibility, wider environmental targets will not be met. Anybody can buy a car with a good environmental profile, but without responsible usage – where eco-driving comes in – the vehicle will not help the environment in the manner envisaged.

Eco-driving is often misunderstood. People see eco-driving as the opposite of dynamic, fast driving, which is not necessarily the case, even though a certain trade-off is inevitable. More information and education of drivers will definitely lead to drivers becoming more aware of the environmental and financial implications of not driving economically. Besides saving fuel and reducing emissions, eco-driving reduces vehicle wear and increases traffic safety, giving drivers the opportunity to help minimise many of the problems in today's traffic.

The basic tenets of eco-driving are driving at low revolutions per minute, changing gears early, anticipating changes in traffic conditions and avoiding idling the engine unnecessarily. In addition, the right tyre pressure, limited weight on board and the reduction of aerodynamic drag, all discussed in section C 3.5, are central elements of eco-driving. The driver is responsible for checking the tyre pressure on a frequent basis, taking off weight of unnecessary equipment and freight and removing unnecessary exterior parts like roof boxes. A factor that should not be ignored is the use of air-conditioning or other technical aggregates like hi-fi units. Air-conditioning can impair fuel economy by up to 20% and should therefore only be used deliberately.

The overall consumption reduction of eco-driving is assumed at as much as 25%, although in the long run it levels off at a lower rate in most of the studies. Other positive side effects, like the reduction of accidents, increased comfort for driver and passenger and reduced cost through lower consumption and less cost for repair and maintenance, promote eco-driving as a viable concept regardless of the supply-side initiatives.

However, how can eco-driving be promoted further? The EC is recommending the mandatory deployment of TPMS, gearshift indicators, low rolling resistance tyres and implementation of more fuel efficient air conditioning systems on new cars as a means of the overall 2012 target of 120 g/km per vehicle being achieved. However, driver education and training has a significant role to play too. It has been suggested that the tenets of eco-driving should be embedded into driving lessons and the driving test. Furthermore, fuel taxes and the public discussion have an indirect impact on eco-driving, as cost and ecological awareness can convince the public. The industry and the government could additionally offer affordable training and other incentives for current drivers to propagate eco-driving.

Having heard much about theory, expert opinions and technique, we will now focus on the feedback we received from consumers in our customer research.

2 Feedback from the consumer

Current challenges from the consumer perspective – environmental problems play a subordinate role

Current problems related to driving

In response to the initial open-ended question, what problems can be generally associated with driving today, 27% of those surveyed answered that there were no problems at all. Three critical topics emerged from the answers of the remaining respondents: gasoline prices, high traffic congestion and interpersonal difficulties between different road users.

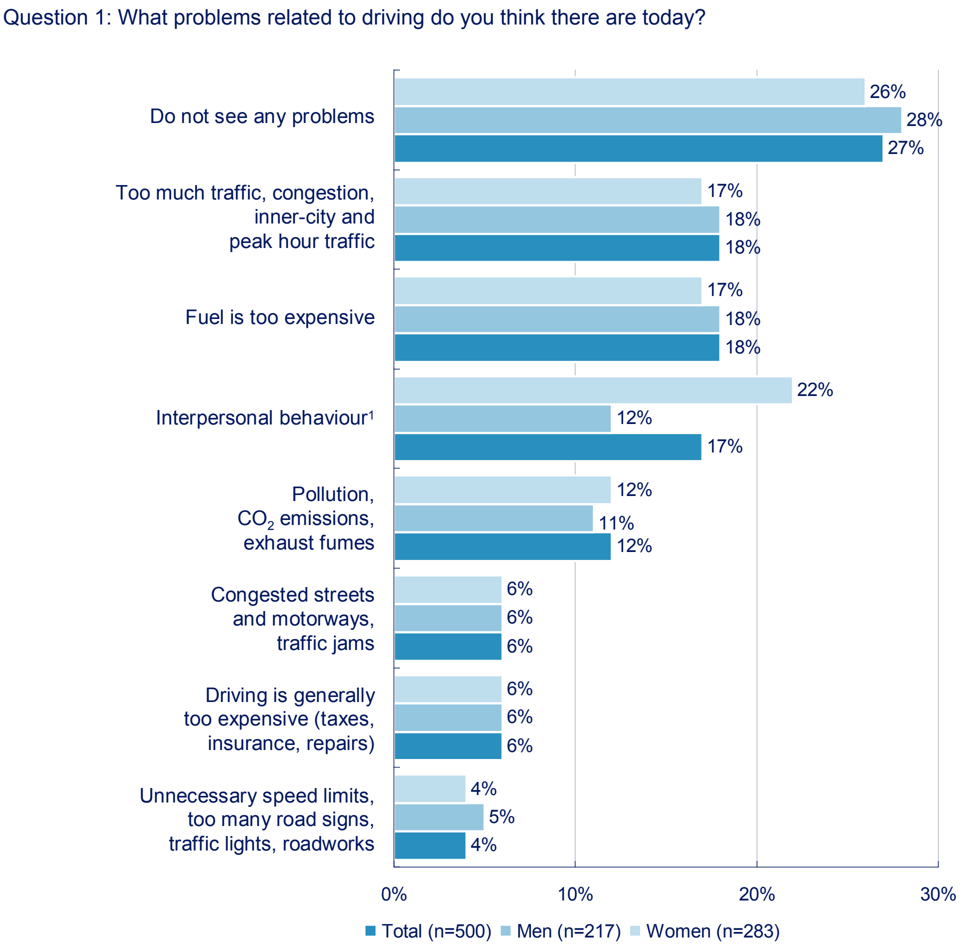
The driving-related problems mentioned most often were (too) expensive gasoline and (too) high levels of congestion with too much traffic, as well as too much city and peak hour traffic, each of which were mentioned by 18% of all respondents. Seventeen percent of the comments on today's road traffic problems were critical of the driving style of other road users. These could be divided into the following three categories:

- Inconsiderate, stubborn, impolite driving behaviour, not keeping enough distance, bad drivers (9% of all answers),

- Driving too fast, speeding, and aggressive drivers (7% of all answers),

- Specific groups were perceived as particularly disruptive, such as: young drivers, elderly drivers, cyclists, motorcyclists (4% of all answers)

The aggregation of these three given aspects reveals that female drivers especially regard the behaviour of other drivers to be a problem. Twenty-two percent of women surveyed described the behaviour of many drivers as problematic (inconsiderate, aggressive, etc.) whereas only 12% of men are disturbed by how others drive.



[1] Interpersonal behaviour: Careless, stubborn, inconsiderate driving, not keeping a distance, bad drivers/ driving too fast, speeding, aggressive drivers/certain annoying groups (young drivers, elderly drivers, cyclists, motorcyclists)

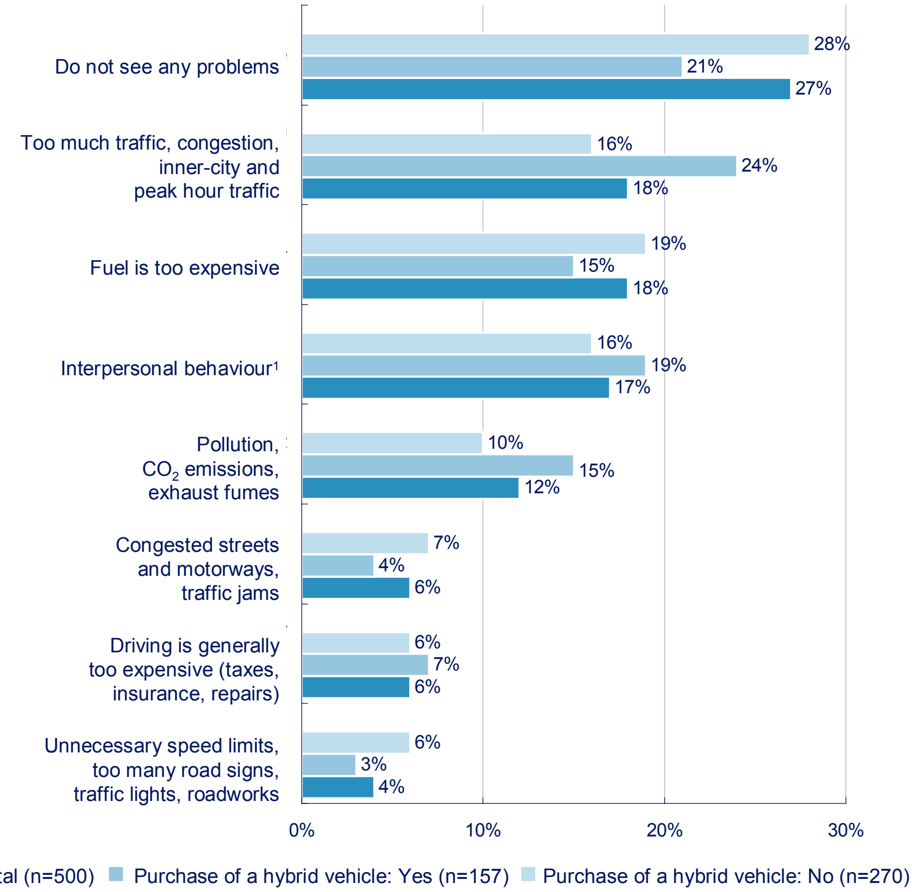
Source: PwC survey

Fig. 67 Problems related to driving – by gender

Environmental issues such as pollution, CO_2 emissions and exhaust fumes were mentioned by 12% of respondents. Six percent of respondents are bothered by traffic jams, congested streets and motorways, and a further 6% finds driving to be generally too expensive today. With values of less than 5%, other unaided responses covered aspects such as unnecessary speed limits, too many road signs, traffic lights and road works. Also mentioned were too many or disruptive trucks, too few parking spaces, streets in poor condition, too few economical cars and generally too much stress when driving.

Overall, people who would consider buying a hybrid car appear to be generally more aware of problems and more sensitive to the environment than respondents who would not consider buying a hybrid. When describing problems, respondents who were interested in hybrids were more likely to mention ecological and interactive aspects related to road traffic. Twenty-four percent believed that high traffic congestion was a current problem whereas only 16% of those with no interest in hybrid cars said it was. For this latter group the price of gasoline tended to play a greater role and 28% said they saw no problems at all related to driving.

Question 1: What problems related to driving do you think there are today?



[1] Interpersonal behaviour: Careless, stubborn, inconsiderate driving, not keeping a distance, bad drivers/ driving too fast, speeding, aggressive drivers/certain annoying groups (young drivers, elderly drivers, cyclists, motorcyclists)

Source: PwC survey

Fig. 68 Problems related to driving – by attitude

Of those respondents who had not changed their driving behaviour over the last years, a considerable 32% said they saw no problems at all related to driving today. On the other hand, only every fifth respondent who said they had changed their driving style gave this answer.

Reported changes in driving behaviour

Forty-two percent of motorists surveyed said that they had changed their driving behaviour over the last few years. Thirty-eight percent of women drivers mentioned changes in their own behaviour compared to 48% of men. Respondents from smaller localities reported more often than city dwellers that they had changed their driving style. Only 39% of respondents from cities with at least 100,000 inhabitants reported a change in comparison to 50% of respondents from towns with a population of less than 5,000.

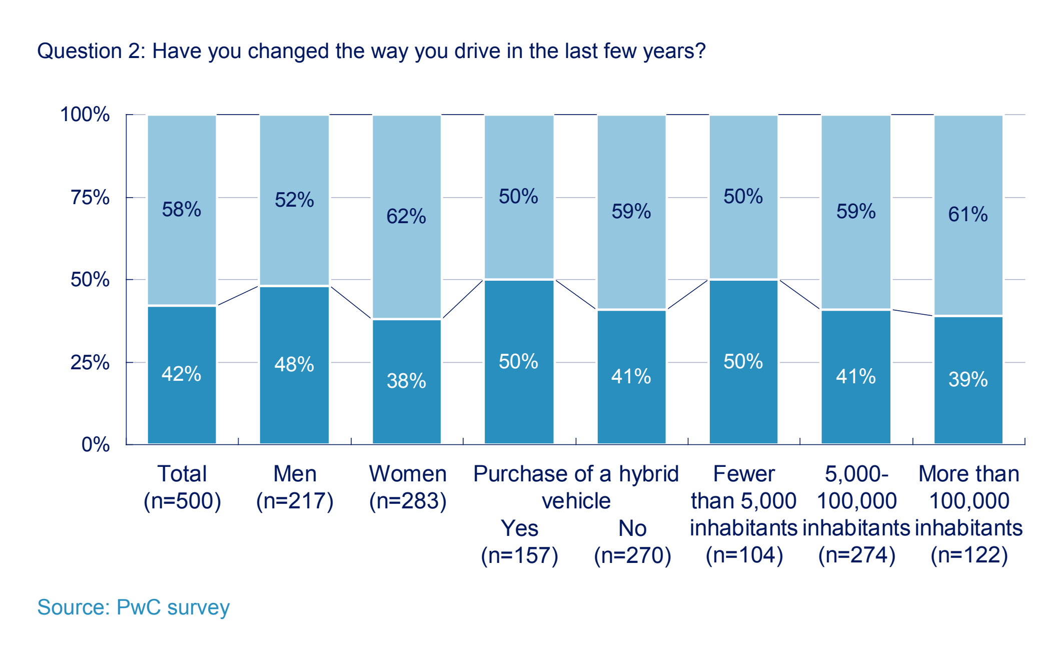
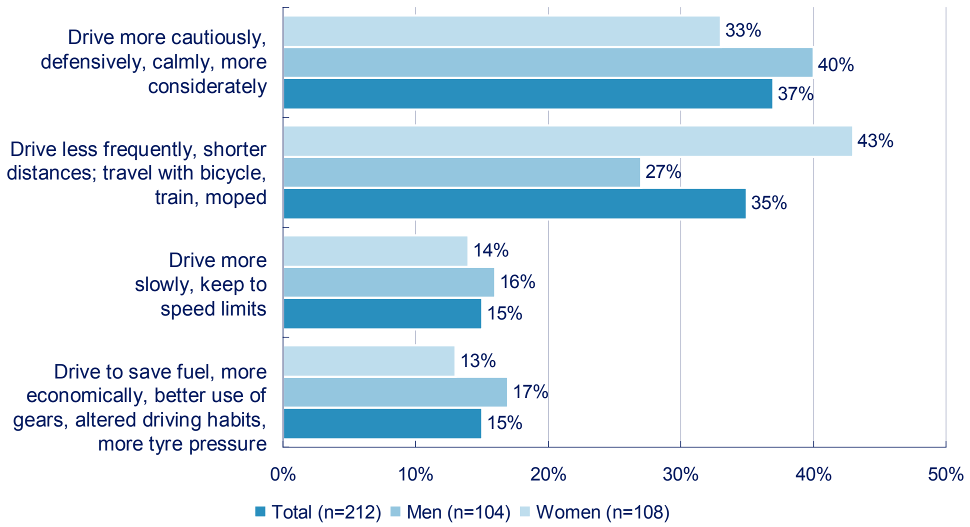


Fig. 69 Recent change of driving behaviour – overview

In response to the open question on how respondents had changed their driving behaviour, 37% of those who had actually altered their behaviour said that they now drive more cautiously, defensively, calmer and with more consideration. Thirty-five percent claimed that they drive less frequently and are more likely to take the train, drive a moped or cycle. This was particularly notable among women with 43% (men: 27%). Fifteen percent of those who changed their driving behaviour said that they now drive more slowly and keep to the speed limits. Fifteen percent also reported that they drive more economically to save fuel by making better use of the gears, altering their driving style and paying better attention to tyre pressure.

Just a tiny minority (6% of 42 percent, in absolute figures 13 of the 500 respondents) explicitly mentioned the changes to driving habits in an ecological context: these 13 motorists described more environmentally conscious behaviour through an environmentally friendly car or environmentally friendly fuel. Although the main changes that were mentioned (more cautious, less frequent, slower and more economical) can certainly be said to have positive effects on the ecology, in essence these changes do not appear to have been ecologically motivated. They imply positive side effects but are primarily answers to perceived stress factors and burdens caused by traffic congestion and the increase in fuel prices.

Question 2a: In what way? (if 'yes' to question 2, responses above 10%)

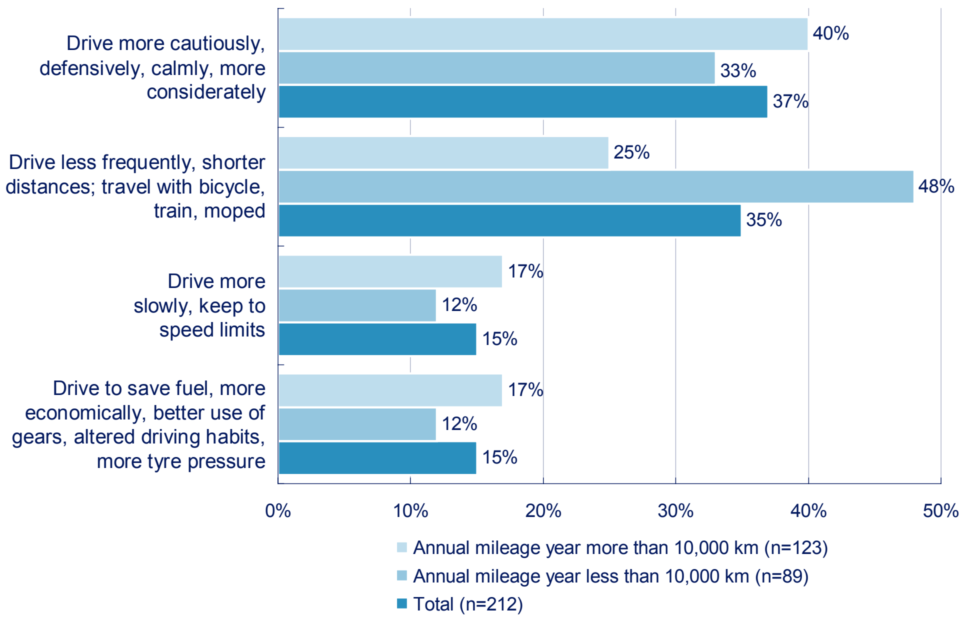


Source: PwC survey

Fig. 70 Recent change of driving behaviour – by gender

Of the respondents who currently drive less than 10,000 kilometres per year, every second said that they now drove less often than before and were using other forms of transport instead. What remains unclear, however, is whether these drivers actually drove a lot before or not.

Question 2a: In what way? (if 'yes' to question 2, responses above 10%)



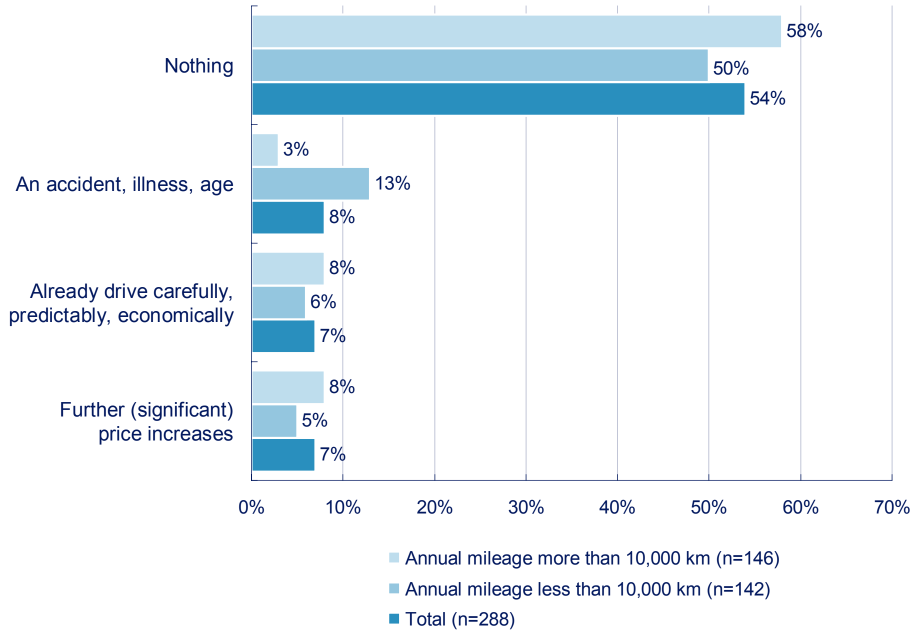
Source: PwC survey

Fig. 71 Recent change of driving behaviour – by km driven

Fifty-eight percent of motorists surveyed said that they had not changed their driving behaviour over the last few years and the majority of these could not imagine anything that would make them change their driving behaviour in the future. This was particularly true of respondents from small towns with less than 5,000 inhabitants: 63% of this group said they would not change their driving behaviour in comparison to just 49% of respondents from cities.

Eight percent said, unaided, that they would only change their behaviour in the case of a major occurrence such as a car accident, illness or age. Seven percent would change their driving behaviour as a result of further cost increases and another 7% of respondents claimed that they already drove carefully, predictably and economically. Environmental issues did not play a role at all in the answers to this open-ended question.

Question 2b: What would make you change your driving behaviour? (if 'no' to question 2, responses above 7%)



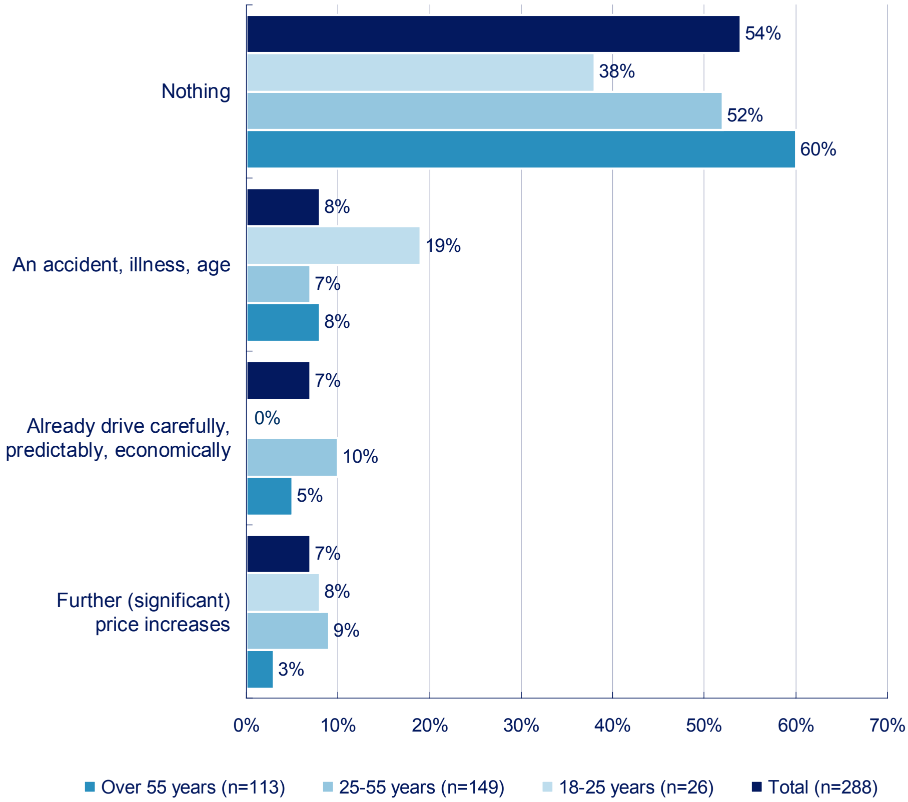
Source: PwC survey

Fig. 72 Events leading to a change of driving behaviour – by km driven

The declared readiness to change behaviour varies somewhat between age groups too. In contrast with the older age groups, a larger number of young drivers felt that a major occurrence would cause them to change their behaviour. Once again, environmental issues did not play a role here, rather car accidents, age, or illness. Whereas 19% of the 18 to 25 age group were of the opinion that such experiences would influence their driving behaviour only 7% of older drivers agreed. Drivers with an annual mileage of less than 10,000 kilometres (13%) were also more inclined than frequent drivers (only 3%) to believe that such occurrences would affect their driving behaviour.

On the whole, this means that about three out of every ten drivers cannot be moved to change their behaviour, at least, not with abstract argumentation, communicated values or even growing economic pressure. The reasons given for behavioural changes tended to be private (car accident, illness, age) or the drivers were satisfied with their own driving style and therefore saw no need to change. Frequent drivers and inhabitants of sparsely populated areas and smaller localities seemed least inclined to want to change and were less likely than infrequent drivers and city dwellers to consider practical alternatives to the car or to have access to such facilities.

Question 2b: What would make you change your driving behaviour? (if 'no' to question 2, responses above 7%)



Source: PwC survey

Fig. 73 Events leading to a change of driving behaviour – by age

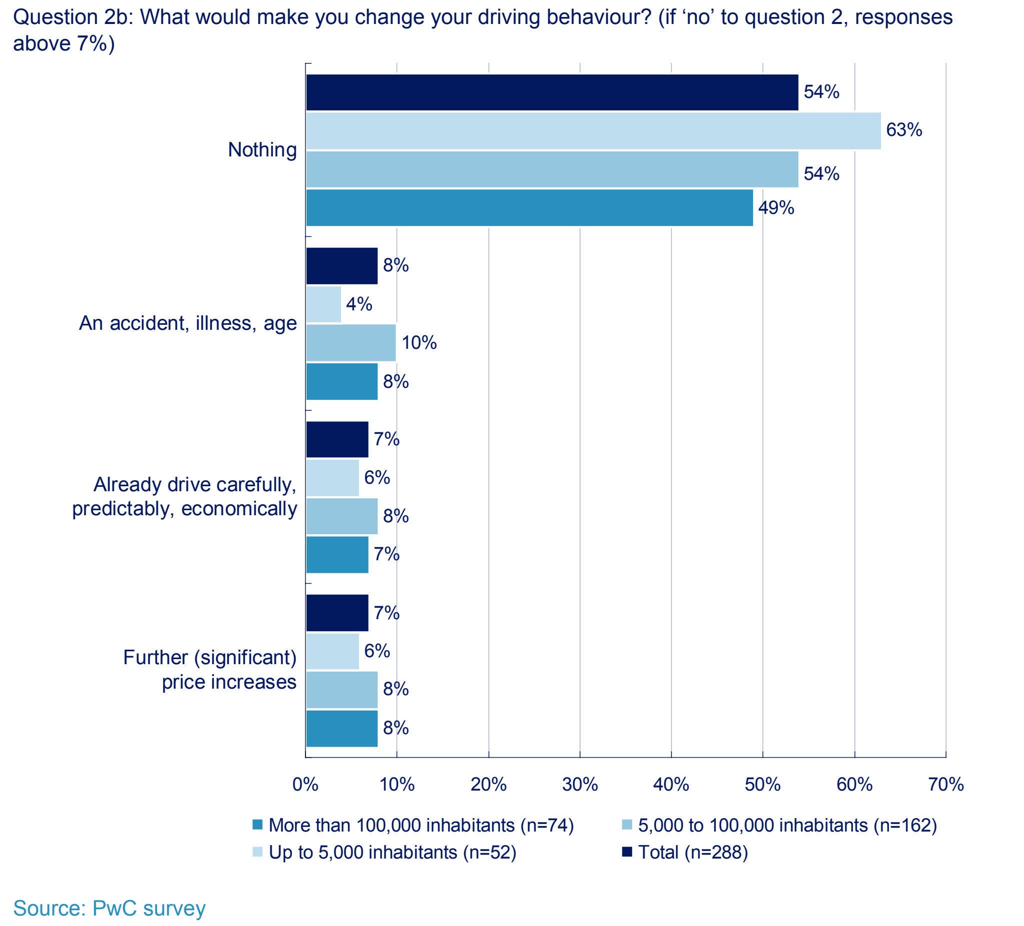
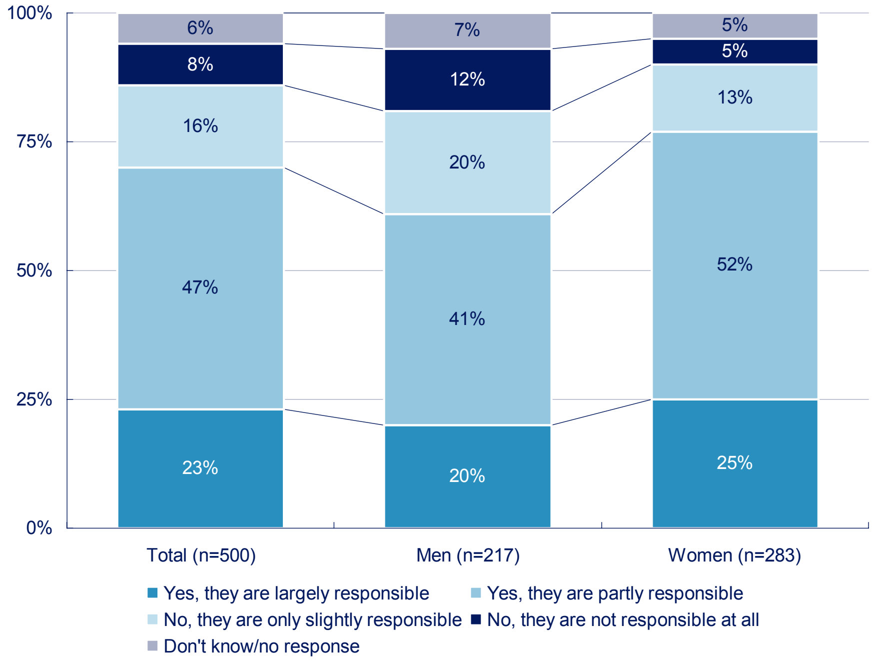


Fig. 74 Events leading to a change of driving behaviour – by size of city

The role of greenhouse gases in global warming

When initial contact was made with the drivers surveyed they were given no indication that the interviews were about environmental issues. In the answers to the open-ended questions on problems related to driving and motives behind changes in driving behaviour, environmental issues and climate change were of little or of no significance at all. The picture changes completely when the questions no longer target the driver's own behaviour but refer to abstract causes and responsibilities. A total of 70% of respondents said they believed that greenhouse gases were responsible for global warming. Agreement was especially high among women drivers (77%), whereas only 61% of men accepted the statement. Every third male respondent assumed that greenhouse gases had little or nothing at all to do with global warming.

Question 3: In your opinion, are greenhouse gases responsible for global warming?

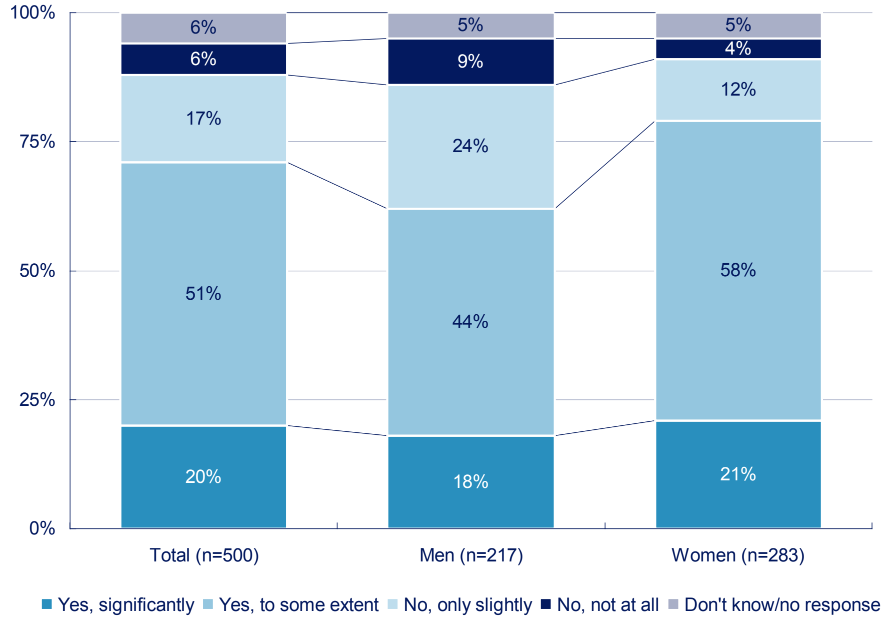


Source: PwC survey

Fig. 75 Relationship between GHG and global warming – by gender

In answer to the question whether CO_2 emitted by cars contributed to global warming, 71% of motorists actually agreed, although the majority selected the statement that CO_2 emissions were 'partly' responsible. Once again, more women drivers (79%) felt that carbon dioxide emissions from cars had a considerable effect on global warming. In contrast, only 62% of men were of the same opinion, and every third man was convinced that CO_2 in car fumes were only slightly or not at all responsible for global warming. The difference between responses given by men and women is not very surprising and reflects again the phenomenon recognised in sociology of answers typically appropriated to each gender. In general, women are more likely to weigh up all options, their answers are more reflective, and when in doubt they tend to be more cautious and hesitant than men and give answers closer to what thought to be the social norm. Whilst men tend to explore their own and technological possibilities, women are inclined to speculate on the consequences and to describe risks and limits.

Question 4: In your opinion, do CO_2 emissions, i.e. the carbon dioxide that is emitted when driving, contribute significantly to global warming?

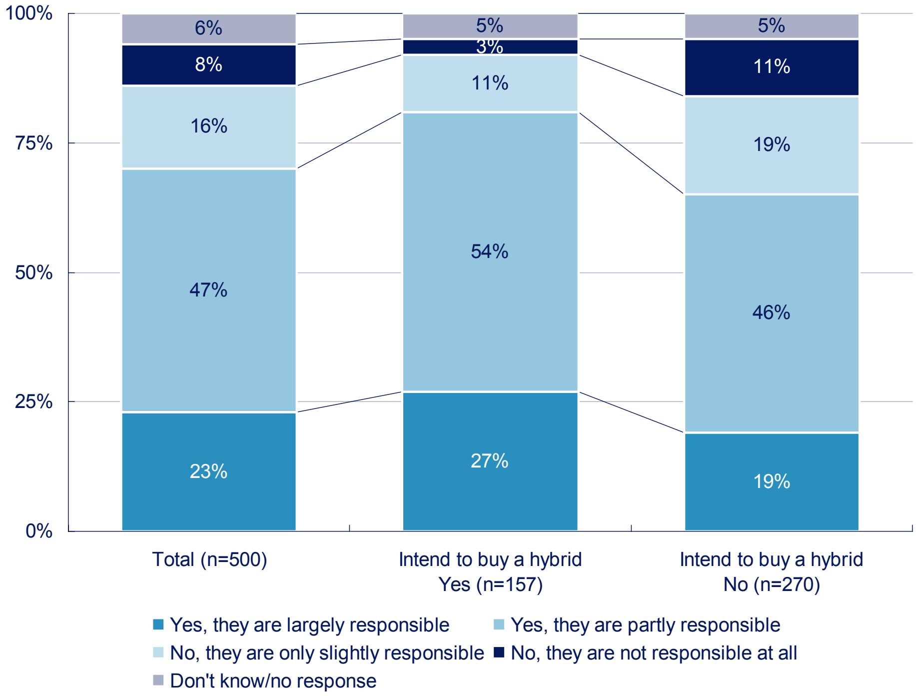


Source: PwC survey

Fig. 76 Contribution of vehicle CO_2 emission to global warming

Taking both genders into account, what was the response from those men **and** women who expressed interest in new technology such as hybrid cars?

Question 3: In your opinion, are greenhouse gases responsible for global warming?

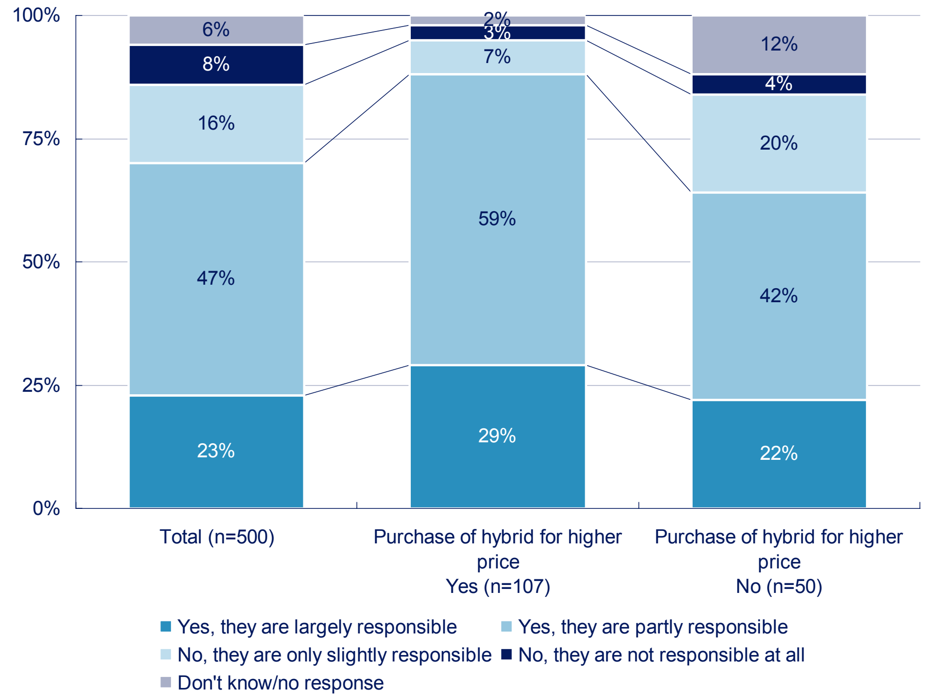


Source: PwC survey

Fig. 77 Relationship between GHG and global warming – by attitude (1/2)

Out of the group of male **and** female respondents interested in buying a hybrid, 81% agreed that greenhouse gases were responsible for global warming. By filtering the group down to those that were prepared to pay a higher price for a hybrid, agreement rises to 88%. In contrast, only 65% of those with no interest in hybrid cars agreed, indicating a clear link between interest in alternative environmentally friendly technology and the degree of sensitivity to climate and environmental issues. At the same time, it also becomes clear that even if someone agrees with the statement that cars (partly) cause climate change, they do not necessarily see driving a car as problematic or become interested in buying a hybrid. Stress and tension experienced in the midst of congested traffic as well as burdens such as rising fuel prices are more likely to affect change in driving behaviour than abstract causal theories.

Question 3: In your opinion, are greenhouse gases responsible for global warming?

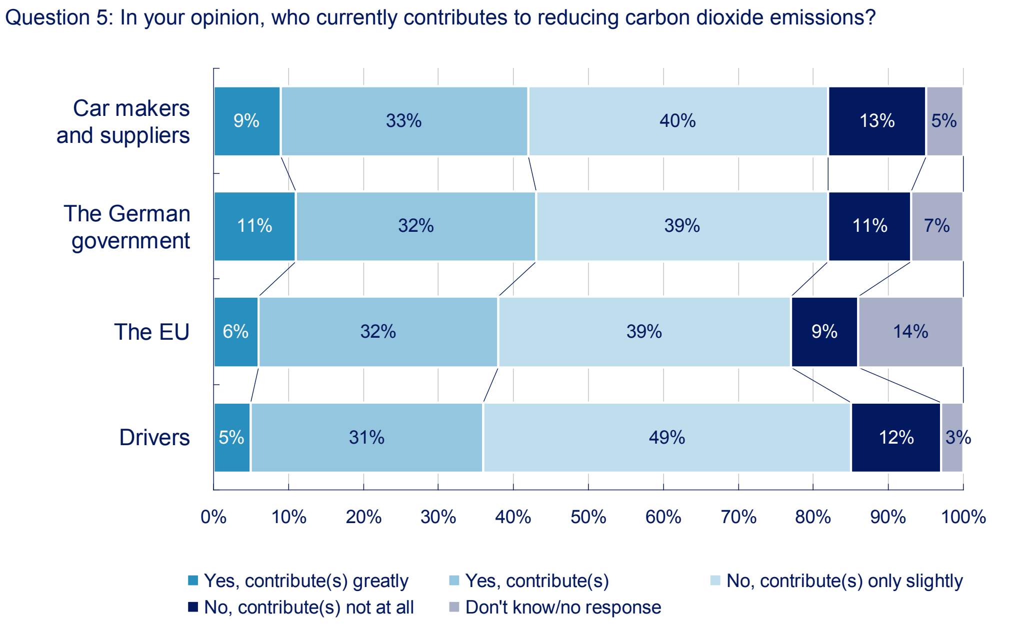


Source: PwC survey

Fig. 78 Relationship between GHG and global warming – by attitude (2/2)

Finding the solution – the competencies of the principal actors. Who is responsible for what?

None of the social groups listed in the questionnaire are accredited with having made a particularly high contribution to the reduction of CO_2 emissions. Government, industry and consumers are all rated similarly. A majority 43% of respondents believed that the German government did the most to reduce emissions (the climate summit in Heiligendamm was, however, still dominating the media at the time of the survey). Forty-two percent acknowledged carmakers and suppliers. The role of the EU in this issue seemed to be unclear to respondents as 14% were not able to give an answer. The group that contributes the least to carbon dioxide reduction was judged to be the drivers themselves with the support of just 36% of all answers.

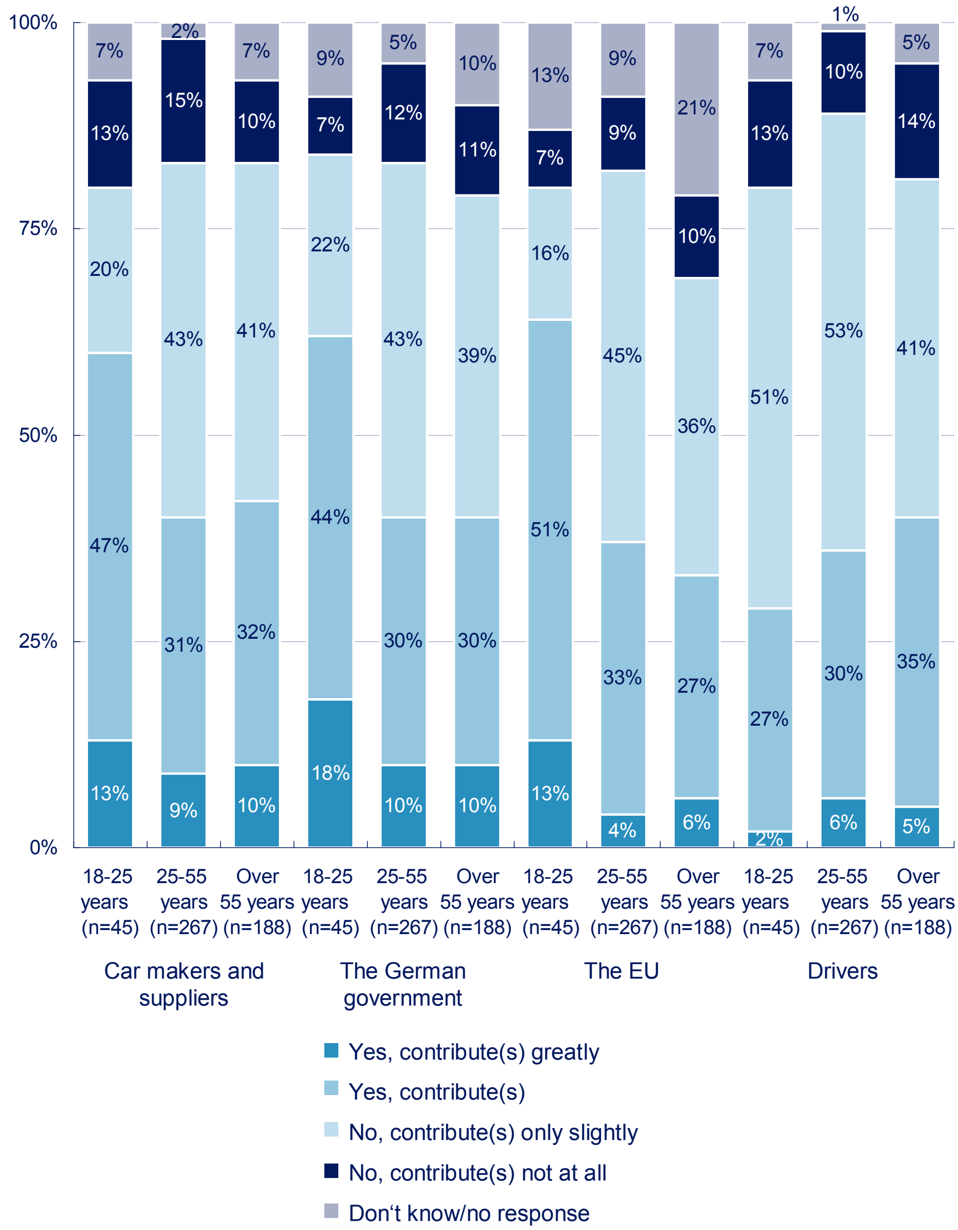


Source: PwC survey

Fig. 79 Comparison of emission originators

Interestingly, young drivers under the age of 25, in particular, believe that various political groups and industry contribute to the reduction of CO_2 emissions. According to 64% of younger respondents, the EU also plays a role, while 62% chose the German government and 60% carmakers and suppliers. Drivers once again bring up the rear: only 29% of the younger respondents are of the opinion that today's motorists contribute to the reduction of CO_2.

Question 5: In your opinion, who currently contributes to reducing carbon dioxide emissions?



Source: PwC survey

Fig. 80 Contribution of emission originators to CO_2 reduction

Opinions on different measures to reduce CO_2 emissions

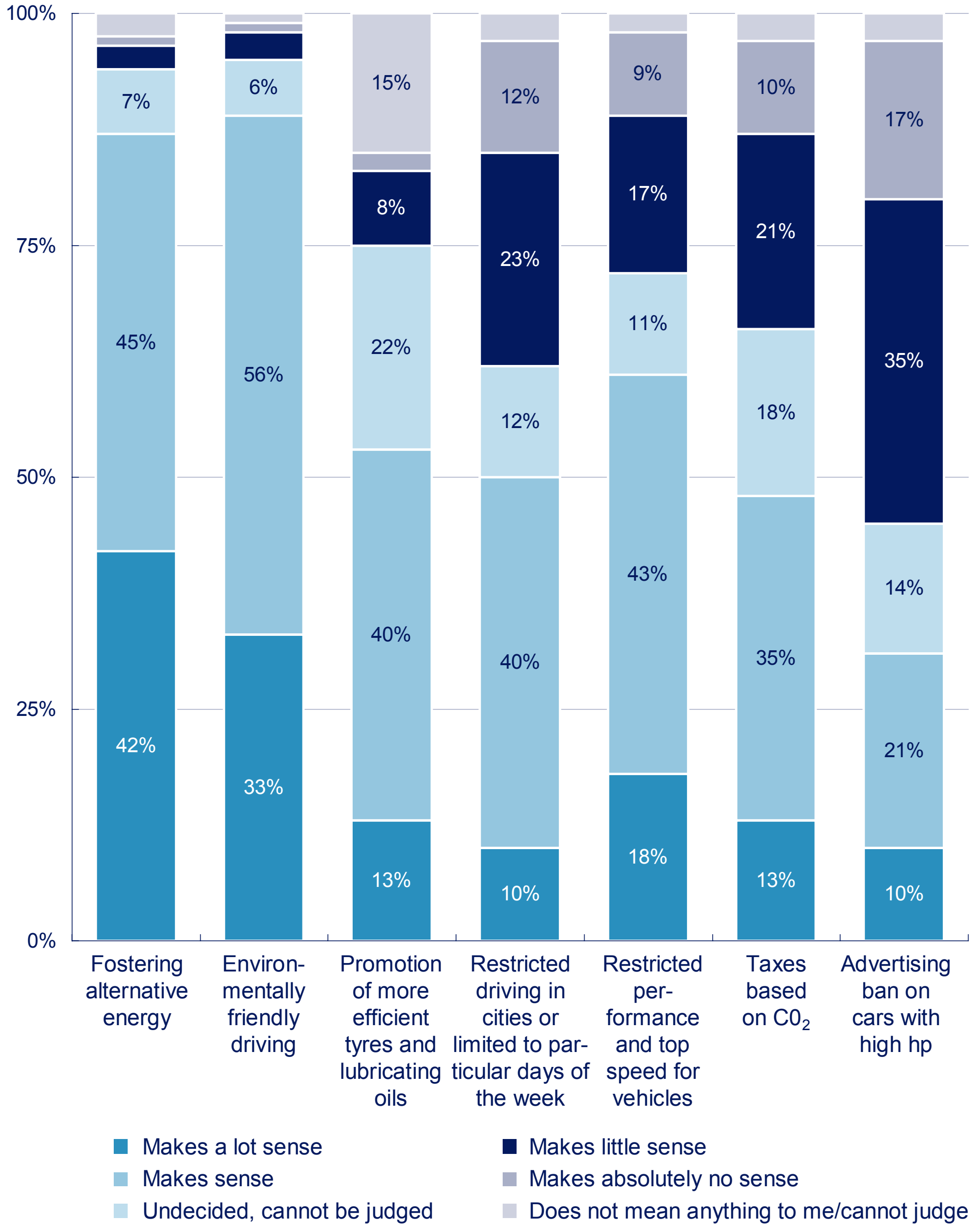
The next question, on which measures to reduce carbon dioxide emissions did motorists believe made sense, resulted in the following ranking:

- Environmentally friendly driving: 89%
- Promotion of alternative energy: 87%
- Restricted performance and top speeds for all vehicles: 61%
- Advancement of efficient tyres and oil: 53%
- Restricted driving in cities or on particular days of the week: 50%

- CO_2-based taxes: 48%
- Advertising ban for vehicles with high hp: 31%

More environmentally friendly driving and fostering alternative energy sources were judged to be the most sensible of the given measures. The least sensible was considered to be the advertising ban on cars with strong hp, with 52% declaring it to be (somewhat or completely) meaningless. In general, answers to this question tended to be hesitant and most opted for the more moderately formulated middle categories than for either extreme.

Question 6: What do you think of the following measures to reduce CO_2 emissions?

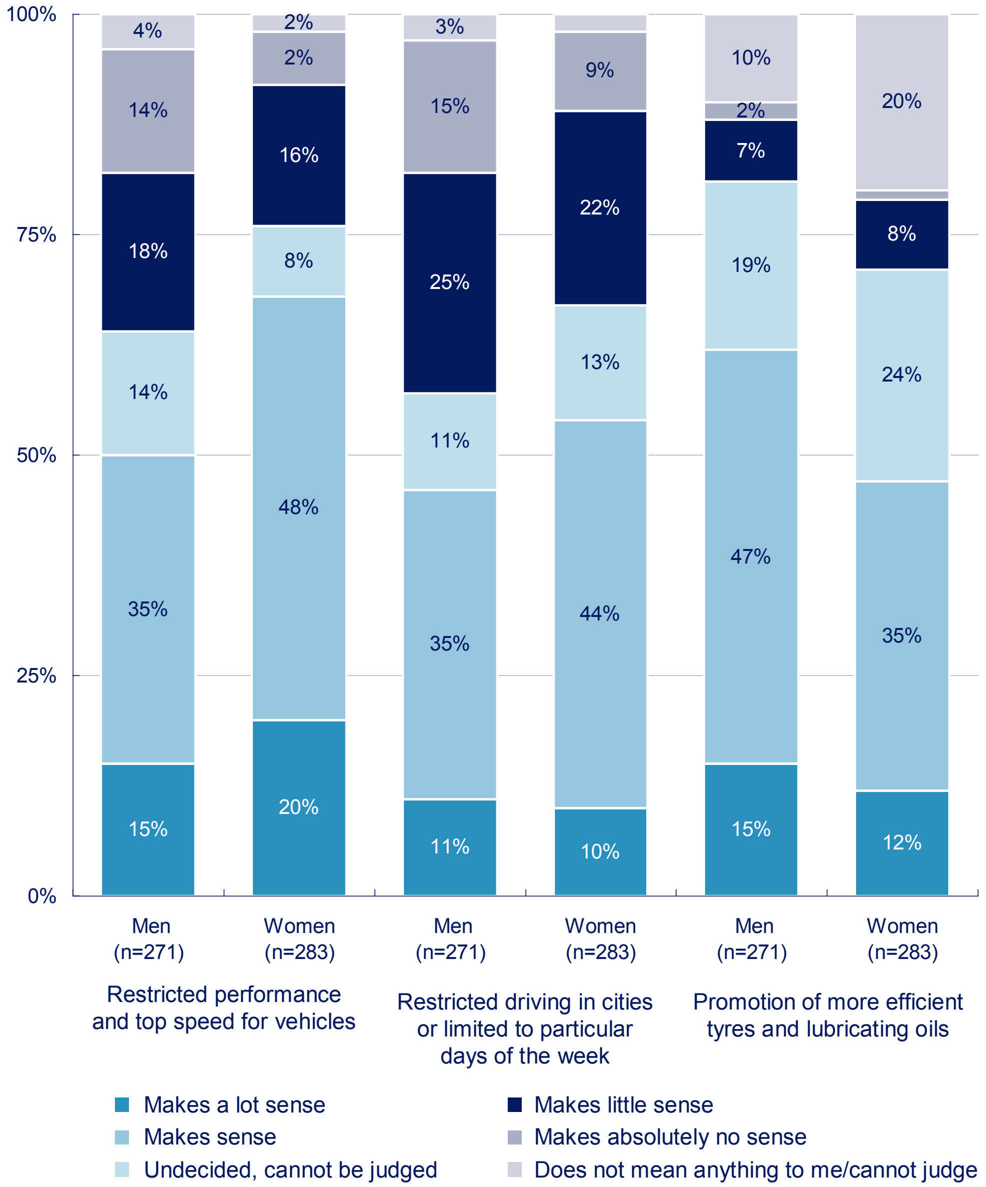


Source: PwC survey

Fig. 81 Customers' judgement on possible actions – overview

The comparison of men and women confirmed the presumption that women, with 68%, were more likely to support the restriction of performance and speed as (very) sensible than men, only 50% of whom agreed with the statement. A similar trend can be identified in relation to restricted mobility in cities or on particular days of the week: 54% of women and only 46% of men believe this strategy makes sense. The promotion of more efficient tyres and lubricating oils is, on the contrary, valued by 62% of men as (very) sensible, but only by 47% of women. The latter may be explained by the fact that every fifth woman driver said that the suggestion meant nothing to her and she could, therefore, not rate it.

Question 6: What do you think of the following measures to reduce CO_2 emissions?



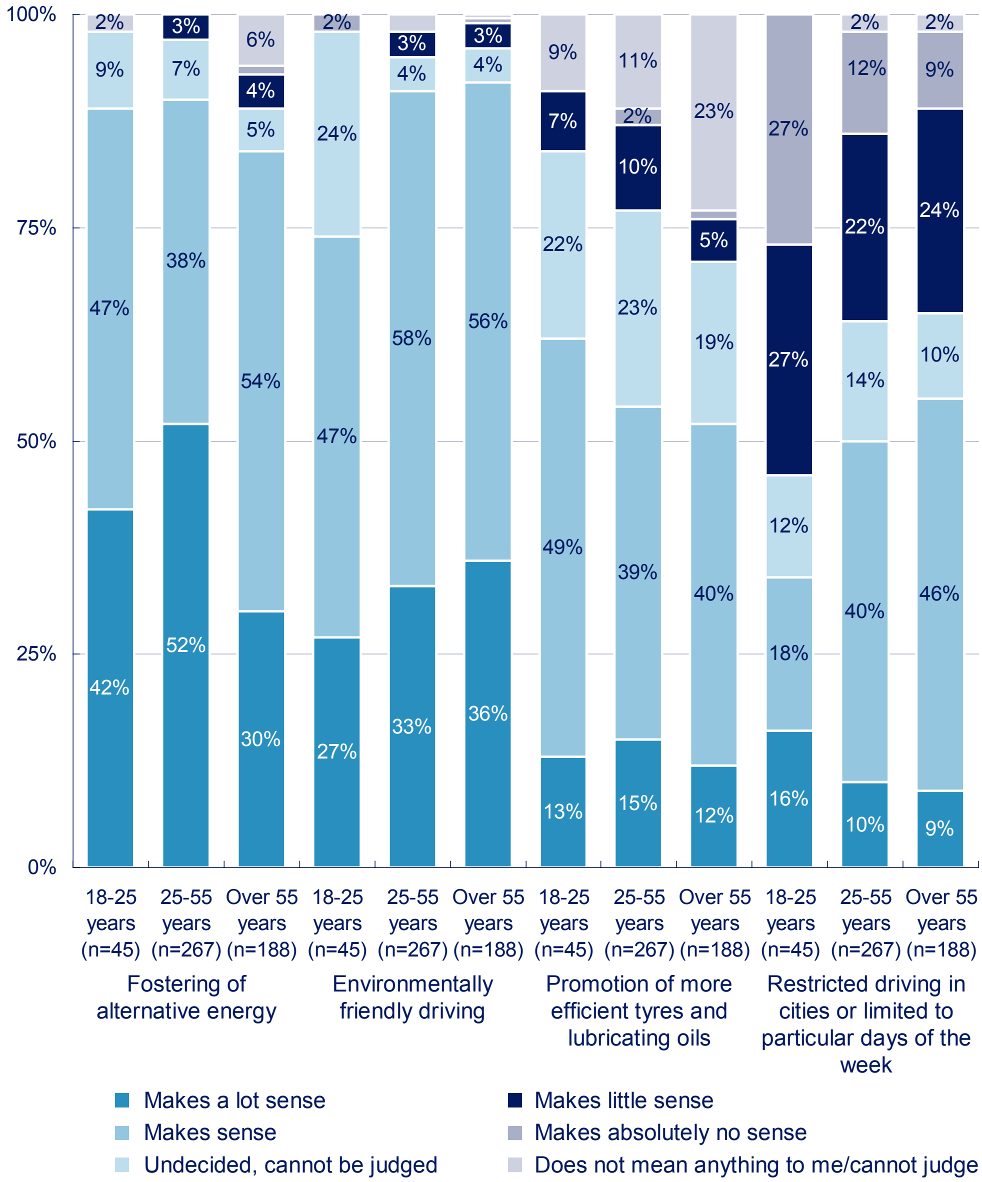
Source: PwC survey

Fig. 82 Customers' judgement on possible actions – by gender

Comparing how each age group rated these measures reveals that younger drivers between the ages of 18 and 25 are less likely to support restrictions to their mobility.

Environmentally friendly driving and the fostering of alternative energy sources are met with the most accord across all age groups. While young drivers rate alternative energy very highly (89% believe it to be [very] sensible), just 74% of respondents under 25 supported environmentally friendly driving techniques. In contrast, 92% of older drivers supported this measure. Restricted performance and top speeds also met with little approval from younger motorists. Only 44% of the under 25s welcomed this measure as (very) sensible compared with two out of three drivers over 55. Similar trends appeared in relation to restrictions on driving in cities or on particular weekdays, which were described as sensible by every third young respondent but by 55% of older drivers over the age of 55. Technical measures, such as, the promotion of more efficient tyres and lubricating oils were rated more positively by younger drivers with 62% in agreement. Only 9% said they this measure did not mean anything to them – the lowest proportion of all age groups. The percentage of drivers over the age of 55 who said they did not understand this measure was notably high at 29%.

Question 6: What do you think of the following measures to reduce CO_2 emissions?



Source: PwC survey

Fig. 83 Customers' judgement on possible actions – by age (1/2)

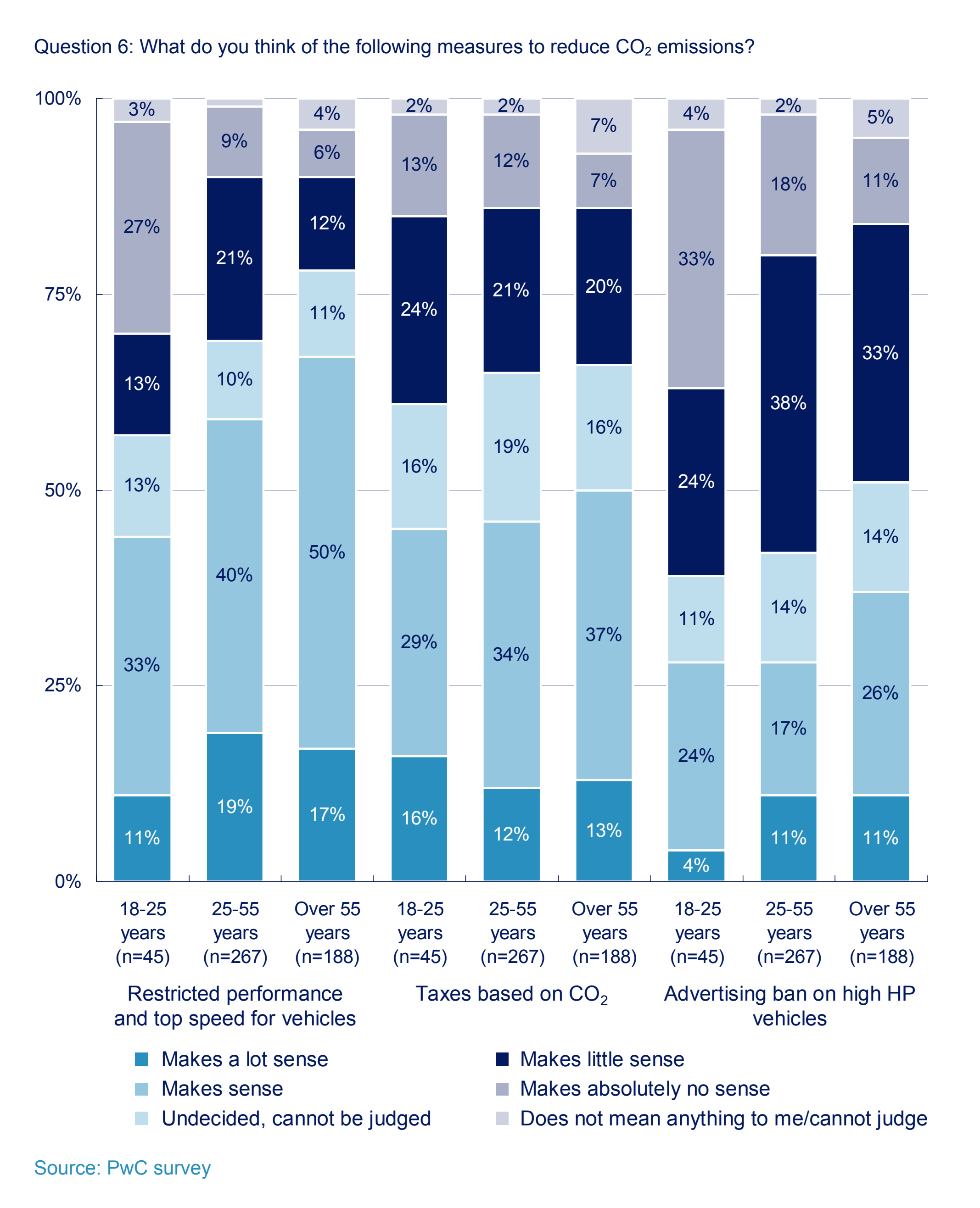
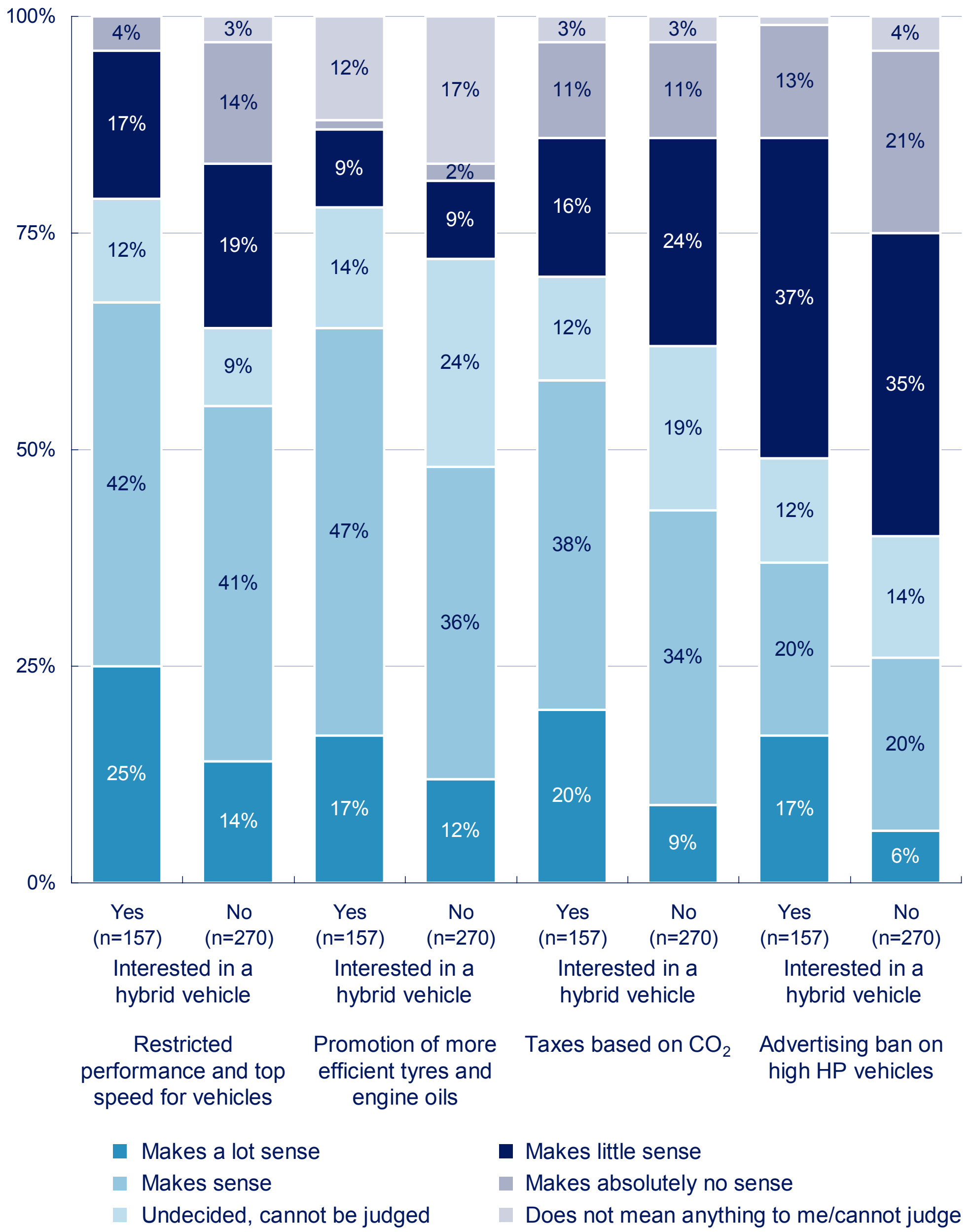


Fig. 84 Customers' judgement on possible actions – by age (2/2)

On average, 67% of those respondents interested in hybrid cars agreed with all seven measures and were generally more open to further initiatives and restrictions in traffic than the group that would not consider buying a hybrid, 56% of whom showed support for the given measures. Sixty-seven percent of hybrid car supporters agreed with limits on performance and top speeds of vehicles in comparison to just 55% of those not interested in hybrids. Efficient tyres and lubricating oils were considered to be sensible by 64% of hybrid supporters (but only 48% of those not interested). In the case of CO_2-based taxes, more hybrid supporters were in favour of the measure (58%) than those not interested in hybrids (43%). Even the advertisement ban on vehicles with high horsepower was approved by 37% by the hybrid group whereas only 26% of respondents not interested in hybrids supported this measure.

Question 6: What do you think of the following measures to reduce CO_2 emissions?



Source: PwC survey

Fig. 85 Customers' judgement on possible actions – by attitude

Technological innovations – insecurity and price sensitivity slow down the pace of change

Although 31% of respondents said they would possibly consider a hybrid when buying their next car, 15% do not even know what a hybrid is. Sixty-three percent of men said that they would definitely not purchase a hybrid. Woman motorists seem to be particularly uncertain about this issue and every fifth said she did not know this type of vehicle. In comparison, not even every tenth man was unaware of what the hybrid was.

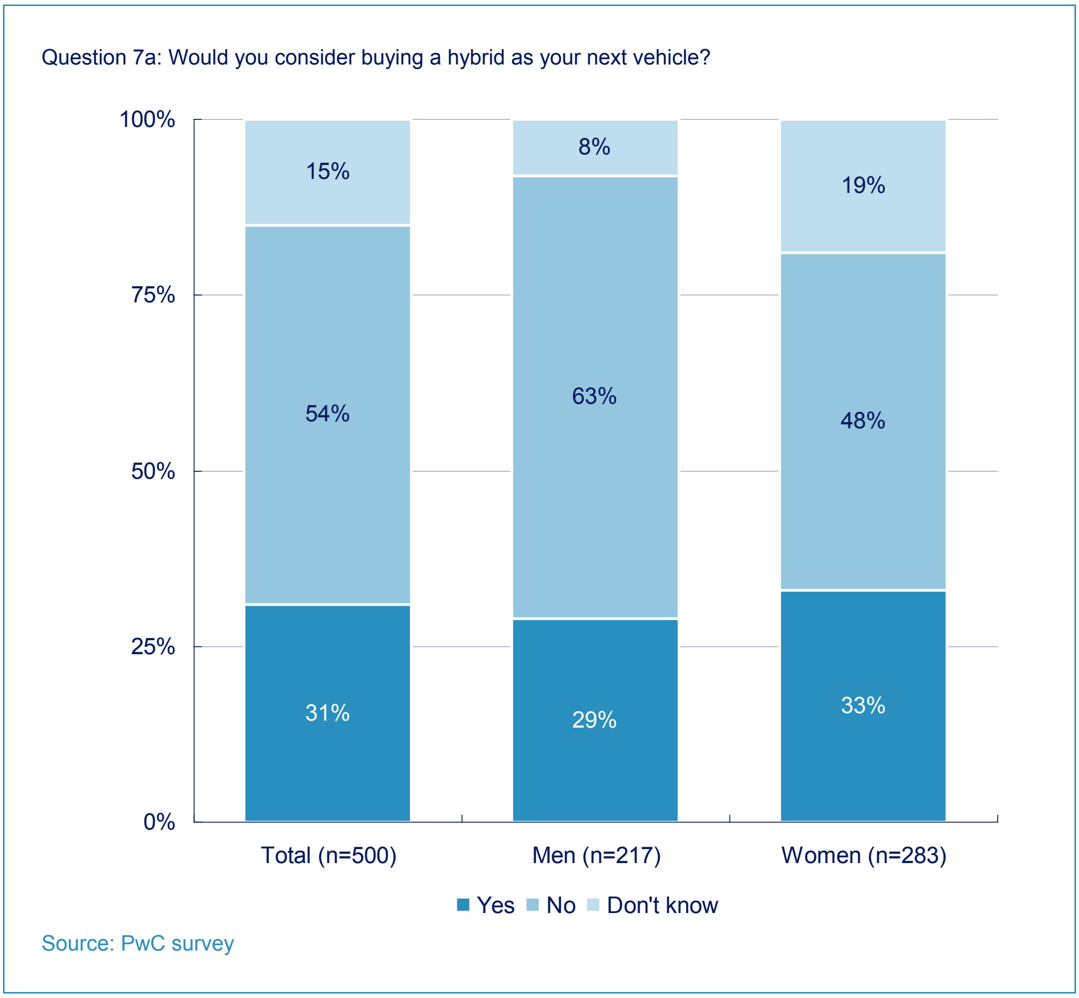


Fig. 86 Customers' judgement on hybrids

Younger respondents expressed greater interest in hybrid cars: 40% of those under 25 said they would consider buying a hybrid but only 35% of respondents between 25 and 55 and just 25% of those over 55 years. Eighteen percent of older respondents claimed not to know of hybrid vehicles whereas among younger drivers it was only 13%.

Taking the 72 percent of all respondents who previously claimed that CO_2 emissions from cars contributed considerably to global warming, only 35% were interested in a hybrid car. Of the smaller group of respondents that did not judge carbon dioxide emissions to be a significant factor of global warming, 22% still expressed interest in hybrids.

Whether respondents would contemplate buying a hybrid car or not turned out to be less dependent on their income than expected. Thirty-nine percent of respondents with a net income per household of at least 2,500 euros said that they were planning to purchase a hybrid. Respondents with lower incomes were not too far behind at 33%.

Sixty-eight percent of respondents who expressed interest in hybrids were also likely to buy one even if it was more expensive than a normal car.

Older respondents are generally less open to hybrids than younger drivers. Those that are interested in hybrids would generally not be deterred by higher prices: 85% of interested over-55s would also buy a hybrid car if it was more expensive but only 61% of 18–55 year olds.

Not surprisingly, low-income households demonstrated a greater sensitivity to prices than those in the higher income bracket. About eight out of ten respondents with a household income of more than 2,500 euros said they would pay more for a hybrid whereas only six out of ten respondents with lower incomes would be prepared to.

Just 10% of those interested in hybrid cars would consider buying one regardless of the difference in price. Three percent found that an additional 500 euros was too much to pay for a hybrid, 18% would not pay more than 1,000 euros extra. A further 10% said that had set their limit at about 1,500 euros and an extra charge of 2,000 euros would be too much for 23% of interested respondents. A further 29% ‘abandon ship’ when the price difference goes above 2,000 euros.

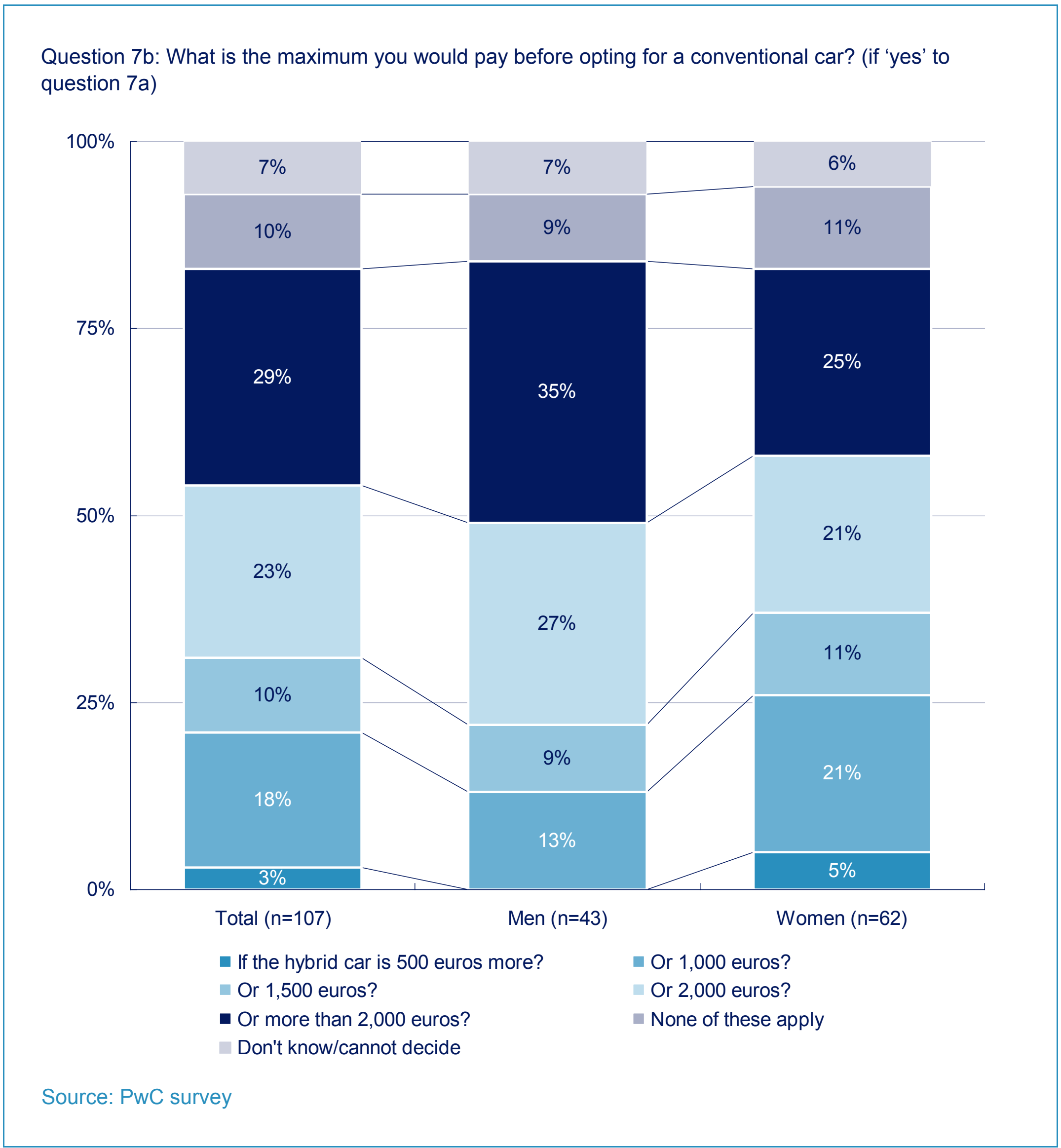


Fig. 87 Judgement of interested customers on price premiums for hybrids

Motorists who said that they had not changed their driving behaviour tended to be more sensitive to prices. Twenty-five percent of those interested in hybrids were not prepared to pay more than 1,000 euros. In comparison, 35% of respondents who had changed their driving behaviour said they would be first put off by additional costs of over 2,000 euros. This was also the limit for 36%. Women proved to be more sensitive to prices than men in this context. Overall, fewer men said that they would consider buying a hybrid car than women but, at the same, time they are not put off by price differences to the same extent as women.

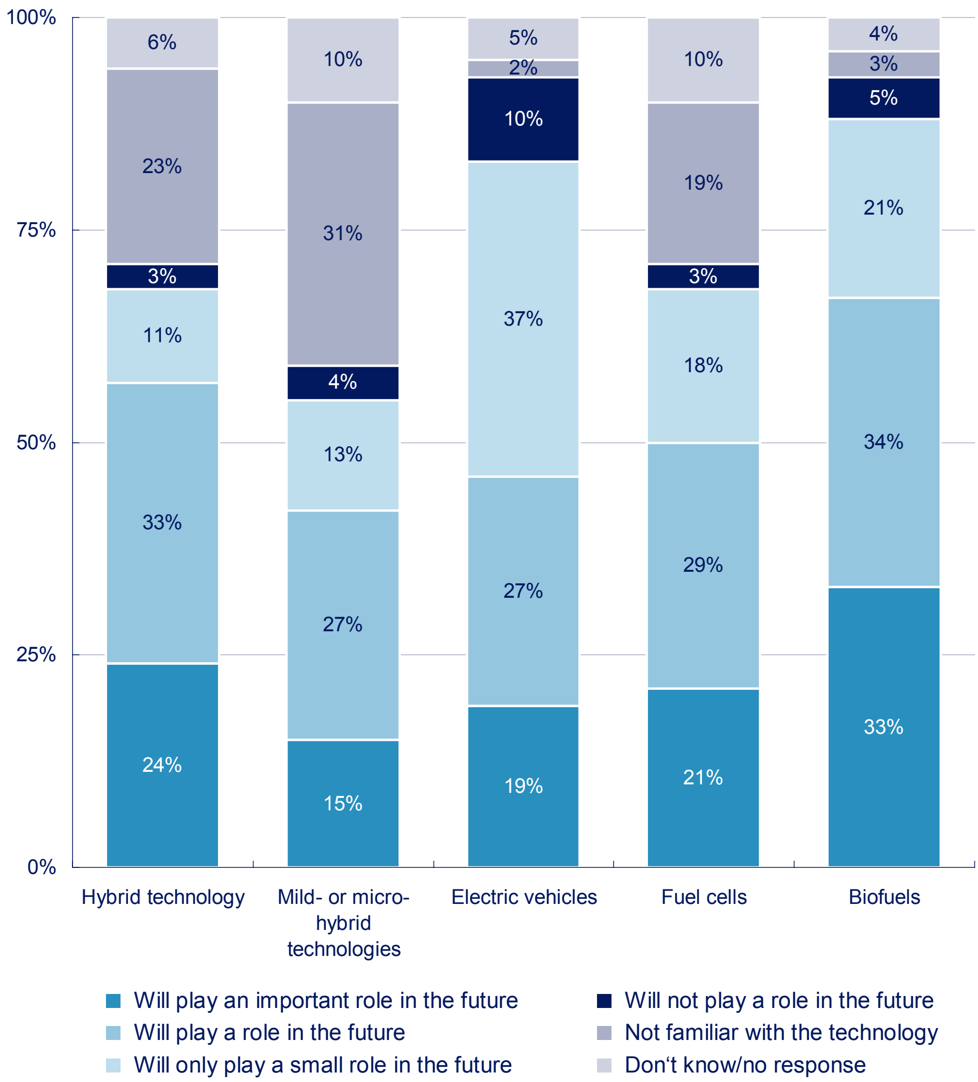
Conclusion: Of the 31% that would consider buying a hybrid when they next purchase a car, one-third is not prepared to pay more for a hybrid than for a conventional car, leaving 21% (= 107 persons) of the original sample size of 500 drivers. However, this group could not indicate any one limit that could be considered a price threshold; this is probably because their limits also depend on the size and cost of the available alternatives. More detailed analyses of car models and prices are not plausible at this stage on account of the sample size. What can be concluded, however, is that women, young drivers, and respondents with lower incomes tended to be more sensitive to prices than men, older respondents and households with higher incomes.

Attitudes towards technological innovations based on their significance for the future

Responses to the significance of each of the listed technologies in the future were varied When interpreting the answers to this question it is important to take into account that these technologies are, to some extent, not well known as well as the fact that a large proportion of respondents did not feel confident enough to rate the technologies.

Sixty-seven percent of all respondents were of the opinion that biofuels would play an important role in the future. In second place with 57% came the hybrid engine, although, at the same time, 23% of respondents did not know what a hybrid was. The fuel cell ranked third with 50% and was not known by 19% of respondents. The response to electric cars was ambivalent: 46% felt it had a future and 46% did not. Thirty-one percent of respondents had never heard of 'mild' or micro hybrid engines, for example, start-stop.

Question 8: How do you rate the following technologies?



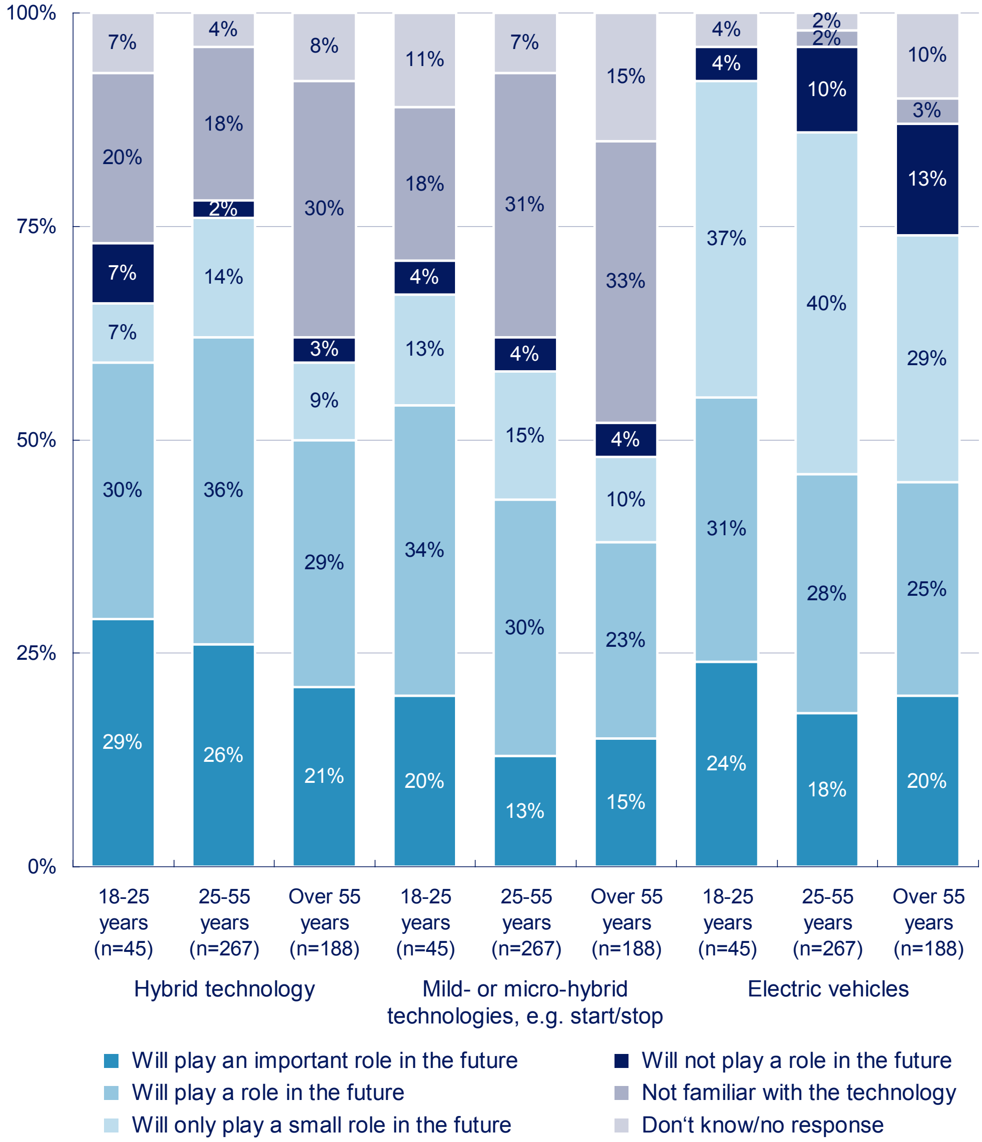
Source: PwC survey

Fig. 88 Customers' judgement on 'green' technologies – overview

With the exception of biofuels, more men than women considered the named technologies to be significant for the future. However, it cannot be inferred that women do not believe that such technology is important for the future; rather they often did not know much about this new technology. The terms 'mild' or 'micro hybrid engines' meant little to 37% of woman drivers, hybrid systems were unfamiliar to 32% of women and 27% could not rate fuel-cell cars.

Younger drivers in general rated the future role of the various technologies more positively than older drivers. The differences in ratings of hybrid systems were, however, less notable with 59% of motorists between the age of 18 and 25, and 50% of over-55s saying they were important for the future. Opinions on electric cars did not indicate any grave differences between age groups either: 55% of younger and 45% of older motorists believed that these cars were significant to the future. Mild hybrid drive or micro-hybrid systems were considered significant by 54% of younger drivers but only by 38% of older respondents, which may be explained by the fact that these technologies are not as well known in all age groups.

Question 8: How do you rate the following technologies?



Source: PwC survey

Fig. 89 Customers' judgement on 'green' technologies – by age (1/2)

Fuel-cell cars are valued as important by 62% of younger motorists and by just 46% of the older generation. Biofuels are described by both younger and older drivers as the most important technology of the future, however, the level of agreement varies considerably: whereas 87% of younger drivers judge this technology to be of significance, only 61% of over-55s agree with the statement that fuel cell technology is the way of the future. Once again it becomes apparent that the younger drivers are clearly ahead of the older generation when it comes to technological knowledge, which may partly explain the differences in the ratings.

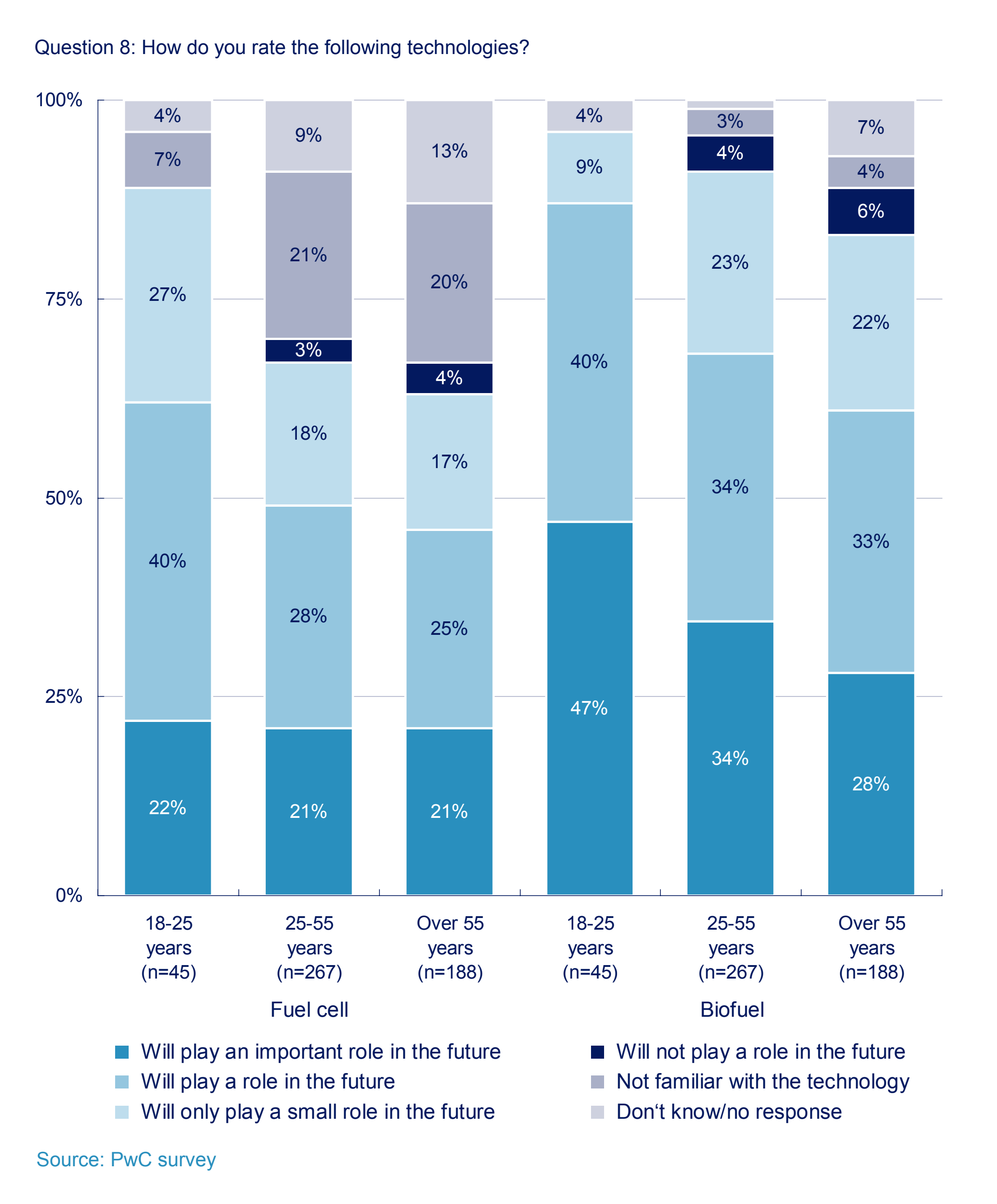


Fig. 90 Customers' judgement on 'green' technologies – by age (2/2)

On average, respondents who intend to purchase a hybrid car rated these technologies as more important than drivers with no interest in hybrids. Eighty-two percent of interested respondents said that the hybrid system was forward-looking in contrast with just 57% of those not interested. Biofuels were positively rated by 78% of potential hybrid car owners and by 63% of the remaining group. Mild and micro-hybrid systems were considered somewhat more important by hybrid supporters too with 53% in favour compared to 41% of respondents not interested in hybrids.

Drivers with higher annual mileages were most likely to claim that technologies linked with hybrid systems would play a significant role in the future. Sixty-three percent rated the hybrid system positively, whereas only every second driver with mileages of less than

10,000 kilometres per year felt the same. Forty-seven percent of frequent drivers believed that mild or micro-hybrid systems were the technologies of the future in comparison to 37% of less frequent drivers. It is, however, possible that these results are biased by a halo effect. The questions were all positioned at the end of a survey from which respondents could already discern that ‘hybrid systems’ seemed to imply something ‘good’. The considerable affirmative response to these technologies may well serve to ease the drivers’ own consciences, especially in the case of frequent drivers.

E Outlook – pathways and success strategies

"By 2020 we expect the combustion engine to still play the dominant role. The basic elements of hybrid vehicles such as start-stop will be implemented in almost all vehicles by 2020. We expect Mild-Hybrids to have a market share of about 10% in Europe in 2020. Full hybrids on the other hand will play a minor role (max. 5%) due to remaining problems with the battery. The battery restrictions also will not allow electric vehicle to play more than a niche role by 2020. Fuel cell vehicles, assuming that the technical hurdles such as storage and the fuel cell cost and packaging will be overcome, might gain a market share of 1 to 3% by 2020. In addition CNG and Flex Fuel vehicles with ethanol might play a role in 2020 with estimated market shares of 5 to 10% each." Professor Hans-Jörg Bullinger, Fraunhofer Gesellschaft

1 Potential pathways for the automotive future

Following up on the three categories engine concepts, alternative fuels and beyond engine technology as shown in Figure 91, we expect that all categories will play an important role in achieving limits for 2012 and beyond.

Strategies and pathways to reduce CO_2 emissions

Engine concepts

- ICE will remain the dominant engine concept in the fore-seeable future; key elements for emission reduction are: downsizing, turbocharging and direct injection
- Hybridisation will continue
  – micro and mild: will be integrated into ICEs
  – full: limited potential but a must for all manufacturers
- Fuel cell: no short term effect but should be part of each manufacturers' strategy

Beyond engine technology

- Weight reduction has potential but life cycle aspects to be taken into consideration
- Driving resistance and regenerative braking will receive some focus
- Energy storage commitment in R&D can imply a key competitive factor
- Eco-driving a responsibility for manufacturers and customers

Alternative fuels

- Natural gas represents a transitional solution, in comparison to crude oil longer available
- Biofuels have potentials but will not be able to replace fossil fuels completely
- Hydrogen will take some more years before developing its strength

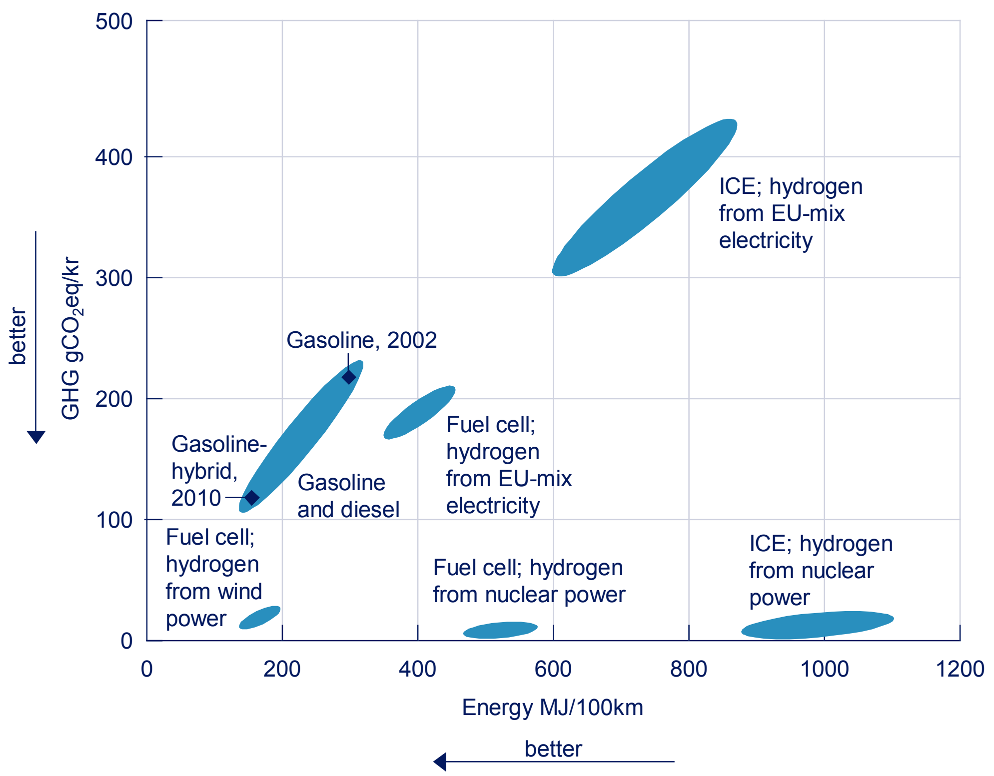
Source: PwC Automotive Institute

Fig. 91 Summary of expected developments

Achieving the 2012 limits will require the automotive manufacturers to come up with a holistic approach, using all potentials inherent in engines, transmissions, rolling resistance, weight reduction, eco-driving, etc. and alternative fuels. Looking at engines, ICEs will mostly contribute to emission reduction through downsizing, turbocharging and other technologies like direct injection. In addition the trend towards hybridisation will continue. In particular micro and mild hybrid technology will be integrated into the ICE technology; although full hybrids certainly represent a field no automotive manufacturer can afford to ignore, they will most likely not become a major player. The fuel cell is perceived as an important field of research and should be part of each manufacturer's strategy; however market introduction is quite a time away, and thus does not allow fuel cells to contribute to CO_2 emission reduction in the short term.

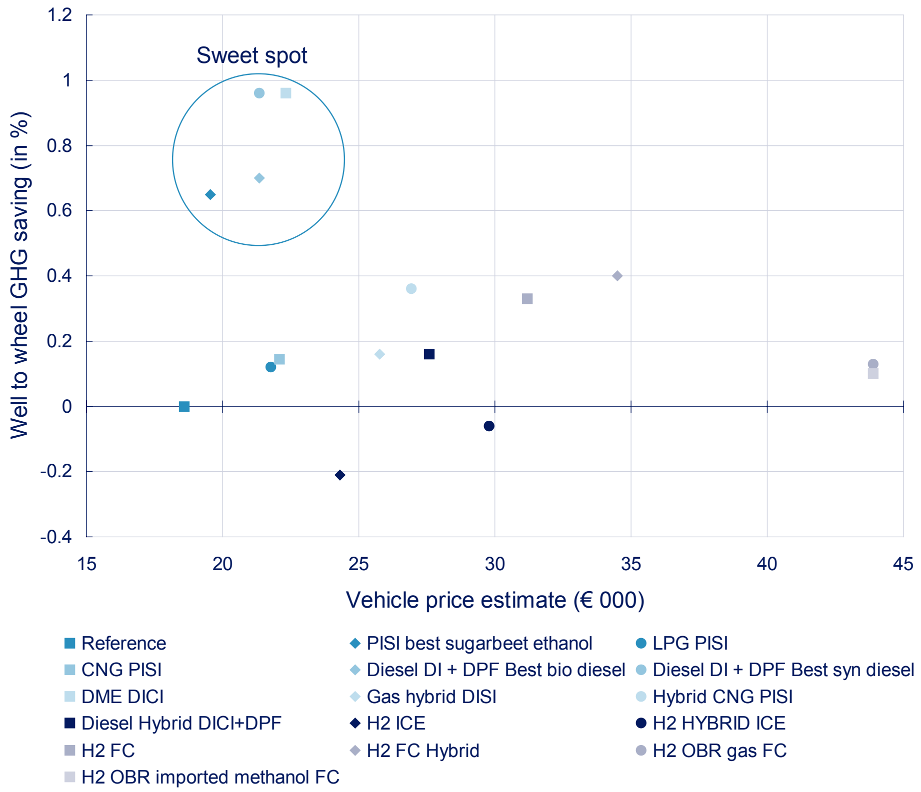
Alternative fuels, especially second-generation biofuels, have the ability to contribute to CO_2 reduction and to reduce dependency on oil. However, due to a linkage to the food industry and limited acreage, biofuels should not be pushed too intensively in order to avoid negative side effects. Overall, biofuels will develop further, however they do not have the potential to completely replace fossil fuels.

Looking more closely at the details, we see first that powertrain development splits off into many directions. The EC's 2007 update to its WtW analysis gives some clues as to where money will be best spent to reduce GHG emissions most effectively. The chart below examines the cost of various vehicle technologies for 2010+ vehicles and their potential for GHG reduction as compared to the control vehicle (a VW Golf-sized vehicle with a 1.6 l PISI engine).



Source: EC, WtW 2004

Fig. 92 Potential of new technologies

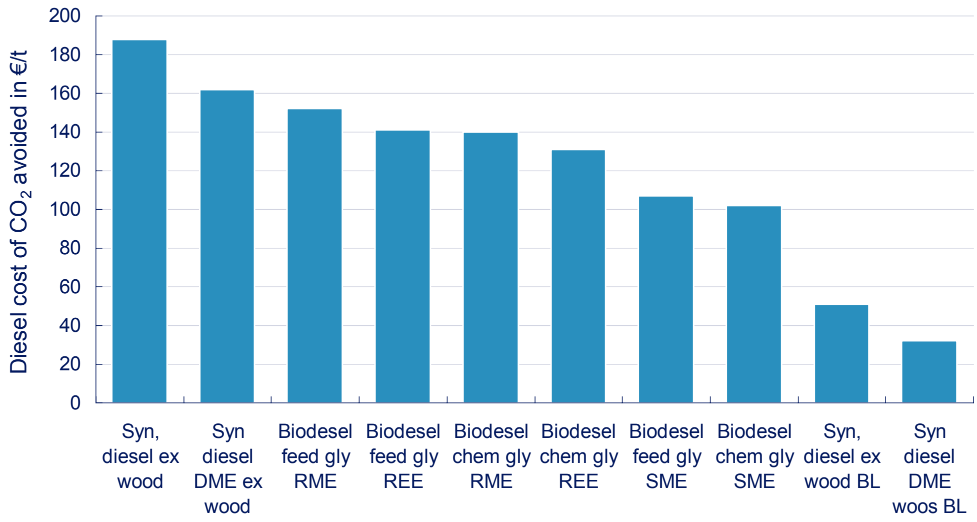


Source: EC, WtW

Fig. 93 Cost-benefit analysis – technology cost, fuel and GHG saving

The ‘sweet spot’ area clearly has the immediate potential – the incremental cost of vehicles will not be enough to reduce demand significantly, while GHG reduction will remain significant. What is shown is that development of conventional ICE engines can significantly contribute to CO_2 reduction if development is carried out in conjunction with development of alternative fuels. The importance of the fuel source in terms of the cost-benefit analysis cannot be disregarded.

Given the EC’s analysis, biodiesel seems to be the most cost-efficient means of reducing well-to-wheel GHG emissions. However, the study shows that the source of the biodiesel is also an important consideration as seen in the figure below.



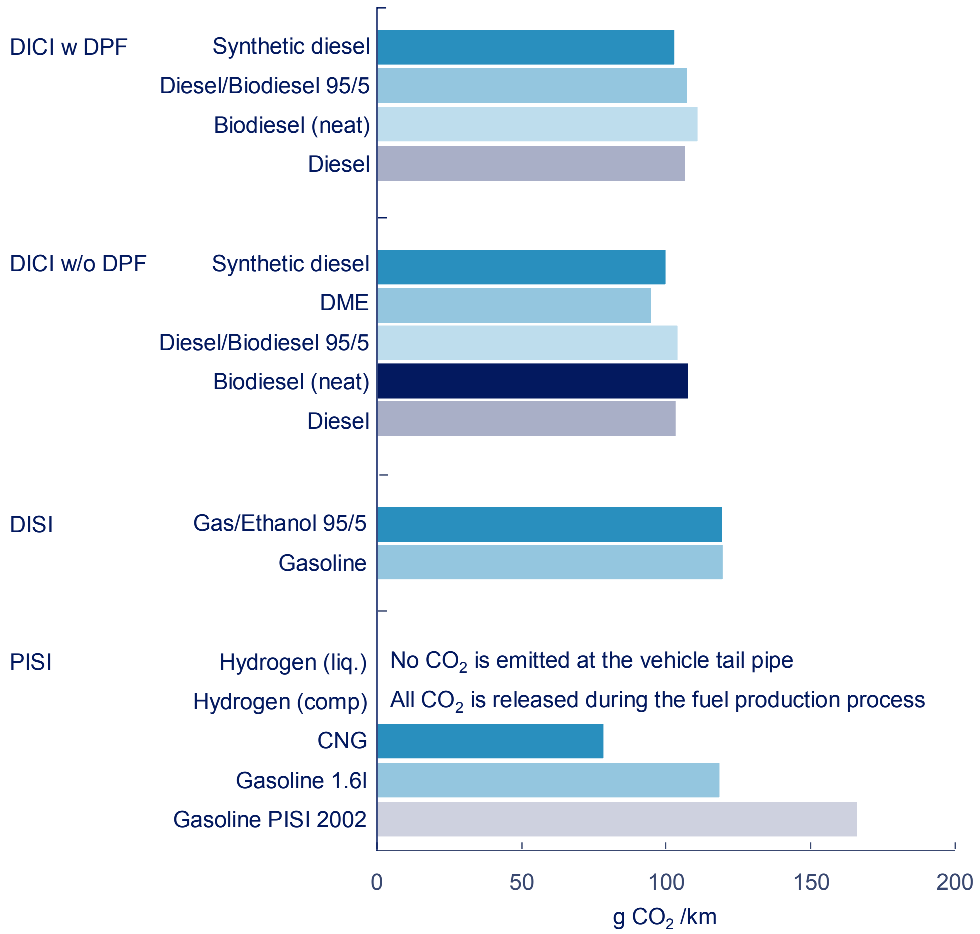
Source: EC, WtW

Fig. 94 Diesel cost of CO_2 avoided

However, biofuels do have their downsides, for example, land use sets natural limits. Furthermore, competition with food cultivation is risky. In the past, food prices and energy prices developed quite differently. If both sectors were competing for arable land, prices would definitely be linked to each other. With the growing demand for energy, food prices might skyrocket, which would hit the poor the hardest and have severe consequences for society in general. Furthermore, the risk that some countries might log rain forests in order to make a profit from biofuels would in fact harm the environment more than biofuels could help in the transport sector and thus be counterproductive. In conclusion, biofuels are a suitable way of reducing CO_2 as long as they are treated carefully and, due to their limitations, only used as complementary fuel in the transport sector. The way forward here is to extend the use of second-generation biofuels, which have a higher efficiency and extract the most energy out of a given acreage.

While there are still issues with biofuel viability, given the analysis it seems clear that the most efficient route for vehicle manufacturers and suppliers is extracting efficiency with improvements to existing ICE engines – be they diesel, gasoline or flex-fuel engines – while working together with the oil and chemical industries on cost-effective biofuels and synthetic diesels. Thus, on a WtW basis the promotion of biofuels in Europe, as well as in the US, seems to be a step in the right direction. Although strategies also have to be executed on a regional basis – due to regional engine type preferences – carmakers with a global presence will most certainly need a portfolio of suitable powertrains in order to continue competing on global level.

As the EC study is calculated on a WtW basis, full hybrids do not fare too well on a cost-benefit basis (micro hybrids or start-stop systems are factored in as a cost for all the 2010+ ICE vehicles considered). However, the proposed regulation for 2012 is a tank-to-Wheel (TtW) directive, and in this case hybrids do have a fuel economy benefit in a typical driving cycle analysis as shown in the chart below. The level of benefit depends on the fuel and type of engine the hybrid drive is applied to.



Source: EC, WtW

Fig. 95 Hybrid vehicles – CO_2 emissions by engine type and fuel

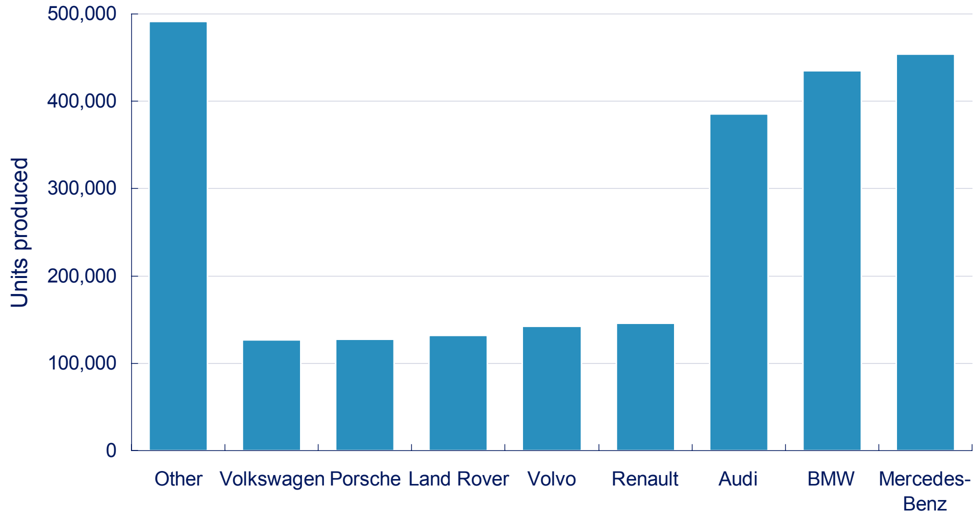
For these TtW reasons and the fact that biofuel and synthetic fuels can only be part of the solution (and cannot be measured directly in the EC's TtW directive) hybridisation still has a role to play in reducing CO_2 emissions from motor vehicles. Therefore we expect that the electrification and hybridisation of vehicles will continue. However, this is not necessarily true for the entire spectrum of hybrid technologies.

Micro hybrids will probably have full or close to full market penetration in Europe by 2012, since it is not too expensive[23] for manufacturers to add them to vehicles and they can save anywhere between 3–6% in terms of fuel economy. The level of further hybridisation will depend on the CO_2 'footprint' of individual automakers and how big a change will be required to meet the 130 g/km CO_2 target. It will also depend on the EC's final decision on how CO_2 across Europe will be accounted for – will it be on a total basis so fuel-efficient manufacturers subsidise the less efficient or will there be some element of differentiated parameter-based measurement such as a continuous function or segmentation? Also of interest is the level of sanctions that the EC will impose on automakers not making the limits – their extent will determine automaker behaviour and strategy too. If sanctions are not very high, automakers could choose to accept them year after year rather than alter their behaviour.[24]

Overall, we do not expect the EC to implement 'radical' legislation, which would lead to undesired behaviour and significantly harm at least the premium manufacturers. We rather expect the EC to forego an average 130 g/km CO_2 emission target per manufacturer and to implement some kind of vehicle differentiation into the regulation. Such legislation would

[23] estimated at 200 euros for a typical installation by the Well-to-Wheels study
[24] cf. Mercedes-Benz and BMW with CAFE in the US

require each manufacturer to contribute to the overall emission target while allowing premium manufacturers to focus on improving the ecology of their high-end products instead of removing such products from the market. Transferring that to full hybrids, and taking into account the high cost of full hybrids and the still imperfect ecological balance, we expect the market for full hybrids to further develop although on a low level only; this is partly due to not being pushed by manufacturers and partly because the average customer will not be willing to pay a substantial price premium for the technology.



Source PwC Automotive Institute

Fig. 96 Expected premium vehicles with >2.5 l engines in the EU in 2012

With respect to the long-term future we expect that the ICE will probably be knocked from its dominant position by a fuel cell that takes advantage of the existing electric components used in hybrids. This step will be much smaller from a hybrid than from a pure ICE engine and will reduce the cost for manufacturers from one concept to another. However, fuel cell dominance is still decades away. Even if it punctually introduced on the market in the middle of the next decade, it will still take some time for the fuel cell to be fully accepted by customers. Not only will the price and functionality need to be attractive, but the infrastructure will need to be fully established. The vehicles will also have to demonstrate durability, low error rates and finally their lifetime cost, which takes time. Normally it is not until the second generation that the majority is willing to buy such a new technology. Finally, even if the fuel cell clearly outperforms all rival technologies at that point, it will take another decade before the existing car inventory has been replaced.

Consequently, internal combustion engines will remain an important part of road transportation over the next decades. Even though this may come as a disappointment since zero-emission transport is still far away, it demonstrates that improvements to the current engines are crucial for the environment and are not just short-term solutions. The same is true for hybrids, which are often considered a ‘bridging’ technology that will be outdated as soon as the fuel cell is available.

2 Strategies for success – in search of sustainable answers

“The future development as well as the technical feasibility is uncertain to a large extent, thinking in options is therefore important for politics and industry.” Dr Uwe Lahl, Bundesumweltministerium (Federal Ministry for the Environment)

So far, many voices have emphasised the negative impact the new regulatory legislation might have on the automotive industry. As an example, DB Research sees the automotive industry as a losing party in the CO_2 debate, based on the expected regulatory and market impact. However, from our standpoint this is not necessarily the case. As we have seen in our study, the industry is undergoing major change amplified by regulatory actions and market development but this, by the way, is not the first time. Every change creates winners and losers – and the winners are characterised by the right strategy. *"Regulatory pressure may lead to innovations we otherwise would not see. In particular, the suppliers should benefit from this. The technological skills required to meet CO_2 targets could strengthen the position of domestic automotive manufacturers vis-à-vis their overseas competitors."* Jos Dings, T&E European Federation for Transport and Environment.

As a first basic principle, automotive companies need to accept and include in their response that the CO_2 challenge differs significantly from other (environmental) regulations like the EC Directive on mobile air-conditioning systems or particulate filters. It is simply far more complex.

The regulatory effort for CO_2 reduction will require automotive manufacturers to choose from a broad and complex set of reduction strategies that will affect almost all components of the vehicle, its design, manufacturing and distribution. At the same time, automotive manufacturers need to consider how their strategy will affect not just CO_2 emissions but the wallet of the consumer. Therefore, any response by a carmaker will in our view only be successful if the customer understands the impact on his personal wealth in comparison to other available solutions and products. In a nutshell, CO_2 is not just a regulatory burden, but need to be understood as an important characteristic of a car that hopefully will impact the consumer's purchasing decision. Soon we will be able to see the efforts of the automotive manufacturers and suppliers at the upcoming IAA in Frankfurt.

Taking the customer into consideration not only increases complexity, it also opens the door for strategic advantage. With the introduction of the Prius, Toyota set an example of improving its image by promoting the Prius as an environmentally friendly product with leading technology. Just recently, smart followed by promoting its fortwo as the lowest emission car in series production. Restrengthening its image as a market leader in innovation and quality as well as efficiency enables automotive companies to create a price premium and to achieve a competitive advantage, coming along with above average returns.

Given the global necessity to put tremendous efforts into CO_2 emission reduction to curb global warming, the demand for low emission vehicles will grow globally. Providing environmentally friendly technologies will therefore be a selling point in major markets globally. In conclusion, the obligation of the industry to develop more efficient vehicles is, in contrast to many statements, not necessarily a punishment for the German industry. CO_2 reduction needs to be regarded as an opportunity to develop vehicles and technologies that will dominate the global markets in the future. Innovation was always seen as critical success factor in the German automotive industry.

What strategies can manufacturers and suppliers pursue in order to succeed in the CO_2 (r)evolution?

There is no simple answer and still a variety of uncertainties. Today the expected European legislation is still not defined. We do not know what approach will be taken to reach the 2012 targets and what will come in the aftermath. Will there be more extraordinary weather phenomena – new, devastating natural catastrophes, like Hurricane Katrina in New Orleans, which will impact the environmental discussion? How will demand change, given new legislation and possible extreme weather conditions? At which point will oil become scarce and how will other sectors and regions that heavily impact the oil prices develop?

Overall the next years will pose substantial challenges for automotive companies and individual pathways will vary. But all of the information we have gathered and analysed has indicated key building blocks for success for automotive companies in their CO_2 reduction efforts:

1. Continue to improve your existing portfolio and focus on your core competencies

   The current combustion engine technologies will dominate for at least the next decades. Automotive companies have been working on improving the existing technologies, e.g. by developing new injections systems, using new materials and reducing the losses in transmissions and other components. As real alternatives without any major downsides are not yet available, the industry has to go on, intensifying their efforts to get the most out of the entire system.

   Downsizing and turbocharging will dominate the next generation of gasoline powered vehicles. Although diesel is already quite advanced, there is still further potential to be tapped in the different components. Finally, the convergence of both engines will provide saving potential for combustion engines.

2. Do not ignore any of the new technologies

   An increasing share of electric components is going to be part of future vehicles. Micro and mild hybrids will become more and more standard. Full hybrids will achieve a niche role, but based on cost-benefit calculations and energy storage issues they are only viable to a certain level. However, hybrid developments will be vital for future fuel cell development, which will come to the market in the next decade. In this regard expertise in the hybrid technology arena is pivotal in bridging the gap from the combustion engine to the development of the fuel cell. From our standpoint, ignoring this trend in technological development today will lead to significant costs in the future to catch up or buy in the competencies from competitors.

3. Develop a portfolio of technologies

   Gasoline and diesel engines will remain the dominant technology for the next decades. Full hybrids will fulfil a niche role and hydrogen, as soon as the remaining problems have been solved, will take an adequate share of the market. Customers will definitely require all major manufacturers to offer a broad range of technologies that satisfy their individual needs, making it important for manufacturers not to limit their strategy to just one technological direction.

4. Assess technology acquisition strategies

   Technology acquisition could be vital in achieving success in new technologies in an affordable way. Many companies are looking at focused acquisitions to increase their internal capabilities in key future technologies.

5. Evolve an effective innovation strategy

   Having a portfolio of technologies that are constantly undergoing improvement requires thorough innovation management. The number of technologies and teams increases the complexity of R&D. Facilitating communication and defining and improving the processes within and between the teams will make it possible to deliver new technologies within the required timeframe. Moreover, integrating suppliers early into the process and properly managing their collaboration will prevent unnecessary delays in the provision of components.

6. Develop innovation networks and collaborative communities

   Everyone going their own way, developing each technology in-house, requires tremendous resources. Taking a strategic approach and coordinating with partners can reduce the cost of development significantly. Partnering should therefore be seen as a viable option, especially in areas that require large investments. The hybrid partnership between DaimlerChrysler, BMW and GM can serve as an example for such a partnership.

7. Manage the risk of your networks

   Partners, especially suppliers, might run into financial difficulties. In particular, suppliers that are active in the development of future technologies face the risk that their resources are not sufficient to bridge the time-to-market introduction. Failing suppliers could severely delay the process and set back the entire development.

8. Cooperate not only within the automotive sector, but also with the fuel industry

   Oil firms, distributors and other fuel providers will play a major role in the future, as many of the new technologies and fuels need an adequate infrastructure. The existing gasoline and diesel infrastructure and the available stations will provide a basis for distributing other fuels, like gas, higher blended biofuels or hydrogen. A close collaboration with these firms to establish the distribution network is deemed necessary.

9. Pursue and agree on industry standards for new technologies

   Industry standards in new technologies could facilitate market entry. Current gas and hydrogen approaches, where different storage forms require different infrastructures, impede market acceptance and penetration. Besides significantly reducing development and distribution costs, suppliers and later on garages could use standardised parts and tools. Individual solutions would delay or even prevent the establishment of new technologies.

10. Communicate your success and achievements to the public

    Ultimately, consumers will be the key to success. From our standpoint, the German manufacturers have underestimated the upsides of presenting their achievements in fuel efficiency more proactively. The general consensus of the marketing departments appeared to be that the ecological and dynamic characteristics of vehicles do not fit together that well. Today, especially through the initiatives of the Japanese, this perception has changed. Environmentally friendly technologies are not only giving the brand a better image in terms of sustainability, but also in terms of technological leadership, traditionally the image inherent to the German manufacturers.

The upcoming IAA in Frankfurt will give the German industry a chance to showcase both its change in thinking and its competitive determination towards developing efficient vehicles.

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Expert interviews

Dr Henrik Adam & Oliver Hoffmann
Director Sales & Engineering
Thyssen Krupp Steel AG

Professor Hans-Jörg Bullinger
President
Fraunhofer Gesellschaft

Jos Dings
Director
T&E European Federation for Transport and Environment

Dr Klaus Draeger
Member of the Board of Management
BMW AG

Peter Fröschle
Senior Manager Strategic Energy Projects & Fuel Cell Market Development
DaimlerChrysler AG

Thomas Kamla
Head of CO_2 Team
Audi AG

Dr Uwe Lahl
Department Manager
Bundesumweltministerium

Dr Thomas Schlick
Executive Director
VDA – Verband der Automobilindustrie

Professor Ulrich Seiffert
Professor
Technical University of Braunschweig

Dr Joachim Wolf
Executive Director Hydrogen Solutions
Linde AG, Linde Gas Division

Methodology customer research

The representative customer research was performed by an independent market research institution (PhoneResearch Hamburg), guaranteeing the data security and anonymity of the people interviewed. Five hundred drivers were interviewed over the telephone between 23 and 27 July 2007.

Contacts

Felix Kuhnert
Leader Automotive Advisory
Friedrichstraße 14
70174 Stuttgart
Germany
Phone: +49 711 25034-3309
E-mail: felix.kuhnert@de.pwc.com

Andreas Bockwinkel
Manager Automotive Advisory
Friedrichstraße 14
70174 Stuttgart
Germany
Phone: +49 711 25034-3430
E-mail: andreas.bockwinkel@de.pwc.com

Calum J MacRae
European Lead, PwC Automotive Institute
The Atrium St George's Street
Norwich
United Kingdom
Phone: +44 160388-3240
E-mail: calum.j.macrae@uk.pwc.com

Christian Johansson
Senior Consultant Automotive Advisory
Friedrichstraße 14
70174 Stuttgart
Germany
Phone: +49 711 25034-3548
E-mail: c.johansson@de.pwc.com

PwC Automotive Institute and AUTOFACTS global light vehicle outlook

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