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Energiewende Outlook: Transportation sector

Analysis of various strategies to ensure a successful energy transition.

Executive summary

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Executive Summary

In the first part of this study we describe the current state of transport sector developments in the course of Germany's Energiewende, the transition towards a sustainable energy system (the so-called "energy transition") before then analysing the future challenges the transport sector faces in implementing this process.

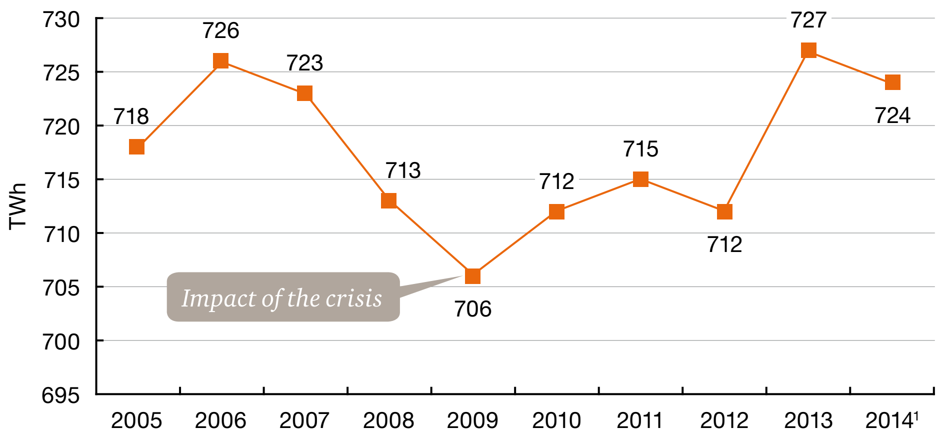
German government has set itself ambitious targets.

The stated aim of the German government is to reduce carbon emissions by between 80% and 95% below 1990 levels by 2050, with contributions to come from transport as well as from the electricity and heating sectors. In the field of transport Germany has set itself the additional goal of cutting final energy consumption by 10% by 2020 and 40% by 2050, with reductions to be achieved relative to 2005 levels (2005: 2,586 PJ)[1].

Transport currently accounts for around 28% of total final energy consumption.

Transport currently accounts for around 28% of total final energy consumption in Germany.[2] The chart below provides an overview of the evolution in the period 2005–2014.

Evolution of final energy consumption in the transport sector



[1] PwC Research: projection based on own transport model.

There is a distinct possibility that the transport sector will fail to meet its final energy savings targets.

Final energy consumption dropped to its lowest level in 2009 following the impact of the economic crisis, only to rise again up to 727 TWh in 2013. It was not before 2014 that we experienced a small reduction in consumption levels. As a result, final energy consumption in the transport sector was higher in 2014 than in 2005, the relevant base year. In view of this development there is a distinct possibility that the transport sector will not only fail to meet the medium-term energy savings targets established by the German government but also fall short of the long-term aims.

[1] See the Energy Concept adopted by the German government in 2010.
[2] See Working Group on Energy Balances (AGEB, 09/2014), "Evaluation Tables of the Energy Balance for Germany – 1990 to 2013", page 26, and the baseline scenario of our fundamental model. Please note that the final energy consumption figures given for the transport sector also include traction electricity used by rail companies and aviation fuel used in international aviation.

Target of the German government is a reduction by

80–95%

of the CO_2 emissions below 1990 levels by 2050.

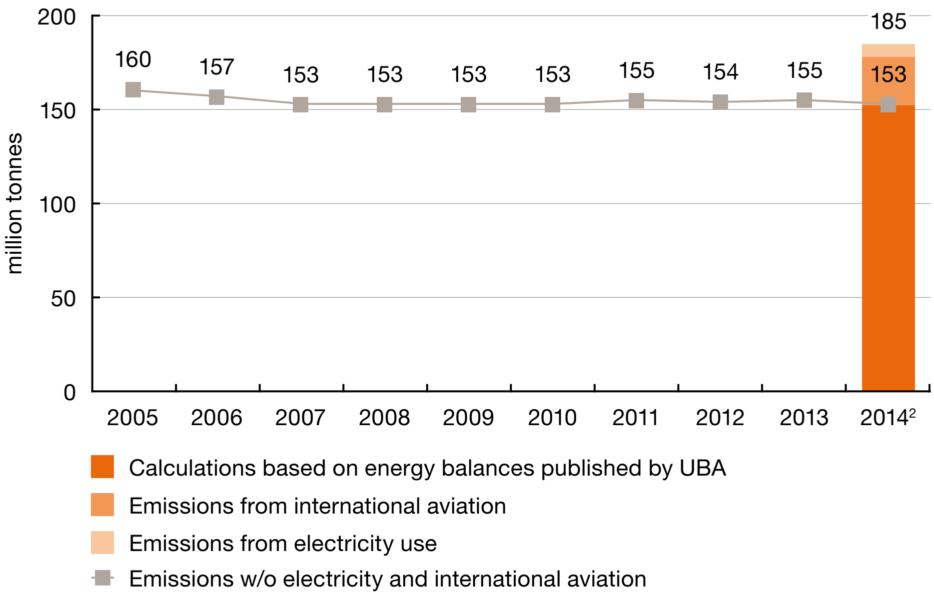
With a share of 94% fossil energy sources are still at the top of fuel supply and continue to play a dominant role in transport.

Carbon emissions declined by 5.5% in the period 1990–2014 (according to figures published by the German Federal Environment Agency).

According to the energy balances published by the German Federal Environment Agency (*Umweltbundesamt*, in the further course of this study referred to as "UBA"), transport-related carbon emissions declined by 3.2% between 2005 and 2013. By 2014 carbon emissions decreased by 5.5% compared to the 162 million tonnes emitted in 1990 (the base year set by the German government to measure achievement of its decarbonisation targets). It must be noted, however, that since 2007 carbon emissions have been stagnating at a level of approximately 153 million tonnes.

The UBA figures do not account for the amount of carbon emissions caused by transport-related electricity consumption (especially rail transport) and international aviation. As both parameters are taken into account in our scenario analysis for the years from 2014 onwards (see chapter E), the chart above shows the amount of carbon emissions from this sector as calculated based on the PwC transport model (around 185 million tonnes) in addition to the UBA figure of 153 million tonnes. According to the PwC model, carbon emissions by mode of transport are as follows:

Evolution of carbon emissions from the transport sector[1]

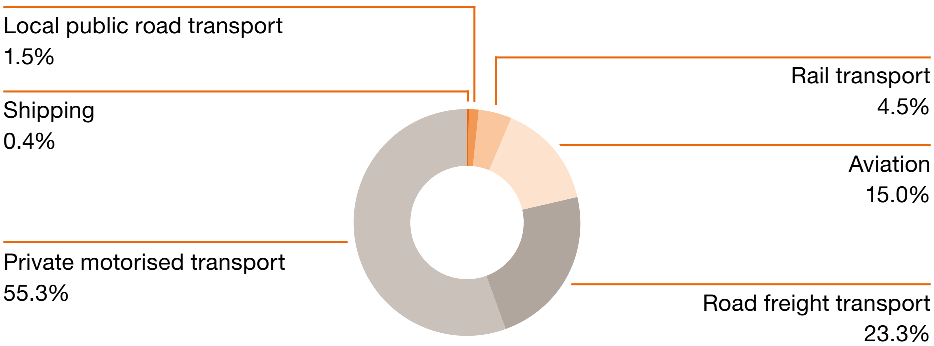


[1] See Federal Ministry for Economic Affairs and Energy (BMWi, 2014), "The Energy of the Future – First "Energy Transition" Progress Report".

[2] PwC Research: projection based on own transport model.

The largest amount of carbon emissions is caused by private motorised transport, which produces 102 million tonnes of carbon dioxide and represents 55% of transport-related carbon emissions. With a share of 23% road freight operations cause a significantly higher proportion of emissions than aviation, which emitted 15% of transport-related greenhouse gases in 2014.

Breakdown of carbon emissions by mode of transport



So far, the energy transition appears to have had little effect on the transport sector.

In summary it can be stated that thus far the energy transition appears to have had little effect on the environmental impact caused by the transport sector. The only observable development is that the energy efficiency of currently used motor vehicle technologies has been improving steadily. New technologies, however, have not been able to penetrate the market on a significant scale.

In view of the developments seen to date it can be concluded that the transport-related climate targets cannot be met unless the transport sector is transformed radically.

In this study we therefore base our analysis on the current state of energy transition developments in the transport sector and describe a range of currently discussed strategies aimed at meeting the future challenges. In doing so we do not only consider trends in the demand for mobility and in the delivery of transport services but also future developments relating to energy sources and in the field of propulsion technology in road motor vehicles as well as in rail, water and air transport.

55%

of transport-related CO_2 emissions are caused by private motorised transport.

The above analysis is further complemented by scenario calculations exploring various strategies aimed at delivering the energy transition in transport. To provide these we have defined a baseline scenario which we consider "likely"[3] to become a reality and developed six alternative scenarios on that basis. The first five alternative scenarios describe different trends in private motorised transport given that this mode plays a dominant role in transport, as has been described above. In the sixth scenario we analyse the effect of additional efficiency improvements in heavy goods vehicles (HGVs) relative to the baseline scenario. The individual alternative scenarios considered in this study are as follows:

Analysis is complemented by scenario calculations.

1. ***Deployment of 1 million electric vehicles by 2020, and 6 million by 2030, in line with current targets ("electric mobility scenario")***
2. ***High market penetration of hybrid vehicles and alternative fuels ("hybrid scenario")***
3. ***Slow market penetration of hybrid vehicles and alternative fuels ("slow scenario")***
4. ***Deployment of around 1.1 million CNG-powered passenger cars by 2020, and 8.1 million by 2050, in line with current targets ("natural gas scenario")***
5. ***Pessimistic market outlook for alternative propulsion systems ("status quo scenario")***
6. ***Alternative scenario: increasing the efficiency of heavy goods vehicles used in freight operations***

We have determined final energy consumption and carbon emissions for each of the scenarios and have also calculated the differences in costs between them to facilitate cost/benefit considerations in the adoption of future strategies for the delivery of energy transition targets in the transport sector. In carrying out our calculations we have focused on the varying effects different technologies and energy sources have on road transport. To analyse this we have made basic assumptions about the composition of the motor vehicle fleet and its evolution as well as about the required transport services, which are identical in all scenarios so as to ensure comparability. Based on these definitions and the specific energy use characteristics of the vehicle types passenger cars and heavy goods vehicles (MJ/pkm and MJ/tkm, respectively) we have calculated energy demand. Our assumptions about final energy consumption for the remaining modes of transport – rail, air and water –, in contrast, have not been derived from model calculations but have been based on the data available from PwC's study database.

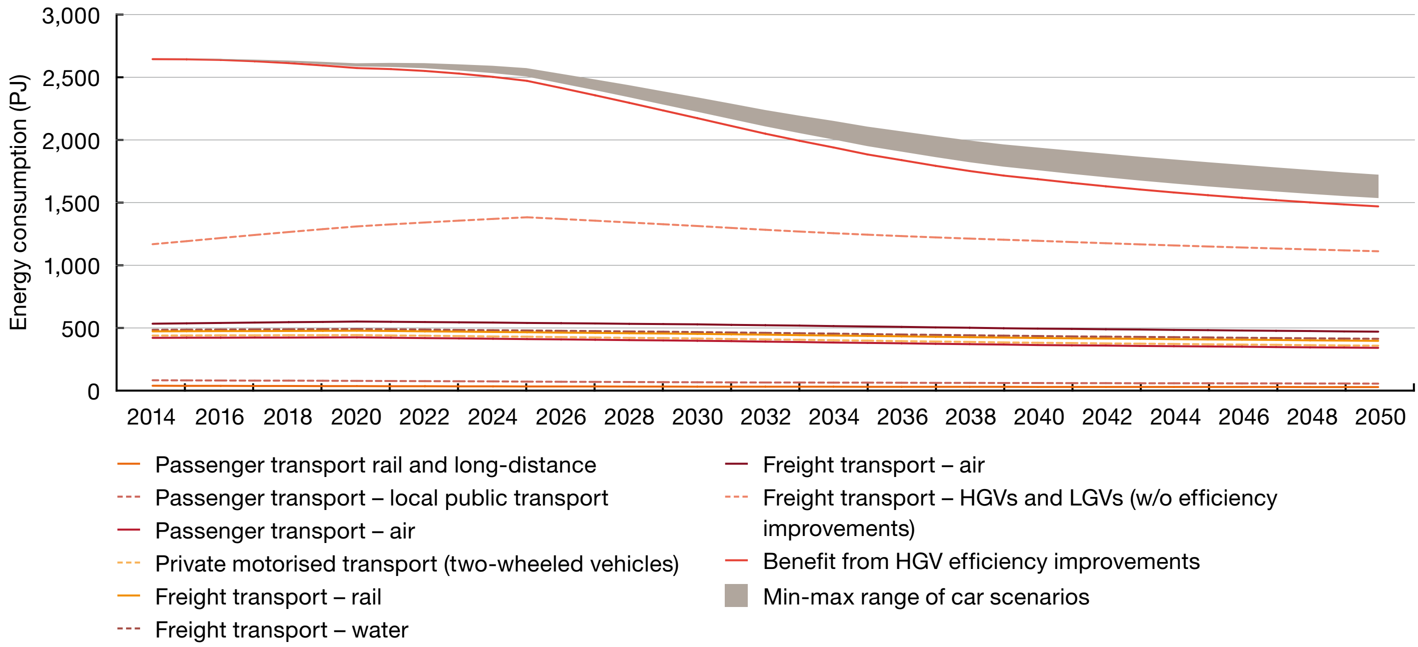
Scenarios focus on road transport.

If carbon dioxide emission factors are taken into account, the above approach allows us to calculate the carbon impact each scenario will cause between 2014 and 2050.

[3] The baseline scenario assumes that the share of passenger cars powered by petrol or diesel combustion engines will fall below 50% from 2048 onwards. In 2050 40% and 6% of the car fleet will be hybrids and electric vehicles, respectively.

Our calculations have provided the following range of projections for transport-related final energy consumption:

Final energy consumption for all transport scenarios



From among the car scenarios shown in the chart the electric mobility scenario delivers the best results, with 1,544 PJ of final energy consumption in 2050 (458 PJ of this accounted for by passenger car transport). With a final energy consumption of 1,723 PJ in 2050 the worst scenario is the status quo scenario (640 PJ of this accounted for by passenger car transport). The projections for the individual scenarios provide a range of 179 PJ. If related to passenger car transport only (see the area between the min-max range of the car scenarios and the curve representing HGV freight transport [without efficiency improvements]), the difference between the scenarios is no less than 39%.[4]

With one exception the differences between the individual scenarios represent the variations in final energy consumption in the segment of passenger car transport. Only one scenario also considers to what extent an HGV efficiency scenario could deliver an additional positive effect. Other than in this context final energy consumption levels for all other modes of passenger or freight transport are not varied but remain unchanged in all scenarios.

An additional benefit of 94 PJ in 2050 can be delivered by combining the electric mobility scenario and the HGV efficiency scenario (represented by the curve "benefit from HGV efficiency improvements") to take advantage of the lower final energy use of HGVs in the latter scenario.

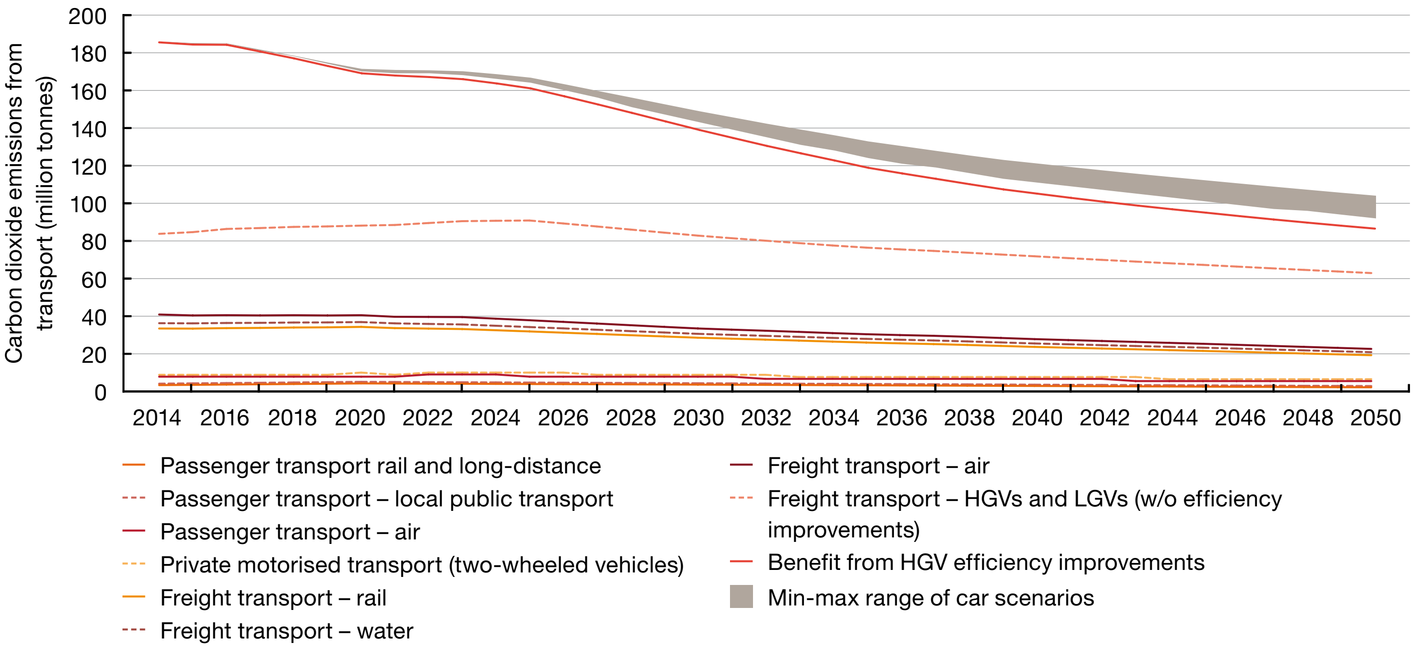
[4] The difference of 179 PJ related to the lower final energy consumption of 458 PJ.

The German government's goal of reducing final energy consumption for transport by at least 40% below 2005 levels (2,586 PJ)[5] by 2050 can only be achieved under the electric mobility and HGV efficiency scenarios, with the combined scenario even outperforming the targets. The results for the hybrid scenario come close to the target (39%). All other scenarios fail to deliver the planned reductions.

Under the electric mobility scenario and the HGV efficiency scenario the 2050 savings targets are achieved.

Based on the final energy consumption levels calculated for each scenario, and considering the composition and carbon emission factors of the energy sources used, our calculations provide the following range of projections for the carbon impact of the individual scenarios:

Carbon emissions from transport for all scenarios



While under the electric mobility scenario 92 million tonnes of carbon dioxide will be emitted in 2050 (with passenger car transport accounting for 28 million tonnes), the status quo scenario will result in carbon emissions of 104 million tonnes (with passenger car transport accounting for 40 million tonnes). If related to passenger car transport only, the difference between the scenarios is no less than 43%.[6]

As was the case in our analysis of final energy consumption, the differences in carbon emissions between the individual scenarios again represent the variations attributable to passenger car transport except where the HGV efficiency scenario is concerned.

Again, an additional benefit of 6 million tonnes in 2050 can be delivered in this case by combining the electric mobility scenario and the HGV efficiency scenario. This would result in 18 million tonnes less carbon emissions than under the scenario with the worst results.

[5] Federal Ministry of Transport and Digital Infrastructure (2014), statistical publication "Verkehr in Zahlen", page 298.
[6] The difference of 12 million tonnes related to the lower carbon emissions level of 28 million tonnes.

Electric mobility and hybrid scenarios compare favourably with other scenarios.

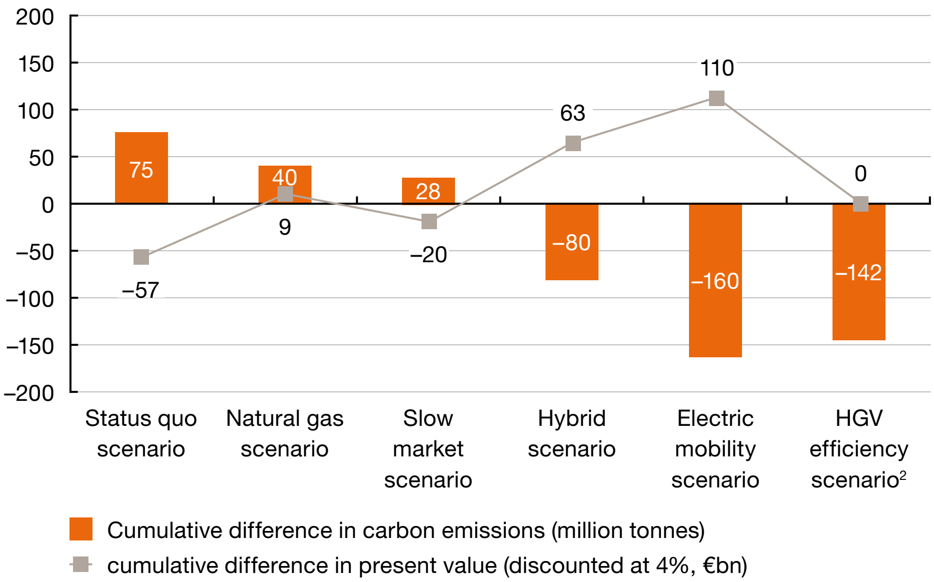
The results of our calculation method show that the best scenario, i.e. the electric mobility scenario (including electricity use and aviation), would deliver carbon emissions reductions of around 50% below 2014 levels, and 54% if combined with the HGV efficiency scenario. With reductions of 49% below 2014 levels the results obtained for the hybrid scenario are similar to those for the electric mobility scenario.

But transport sector will probably fall short of the German government's decarbonisation targets.

If it is further taken into account that according to UBA calculations carbon emissions reduced by "only" 5.5% in the previous period 1990–2014, then these figures show clearly that the transport sector is likely to fail in delivering its contribution to meeting the target established by the German government for the energy sector, which as a whole is to contribute overall reductions in carbon emissions by between 80% and 95% by 2050, and will probably fall short by a considerable margin even in the least carbon intensive of scenarios (as regards the developments in electricity and heating in this context please see the respective studies recently published by PwC).

To facilitate a comparison between the various scenarios, the differences in cumulative carbon emissions and total costs (new car capital expenditure and fuel costs over the period 2014–2050)[7] relative to the baseline scenario are presented for each scenario in the chart below:

Cumulative total costs and carbon emissions for all transport scenarios compared to baseline scenario[1]



[1] The costs shown in this chart only include the costs resulting from the evolution of the passenger car fleet.

[2] Assumptions with regard to total costs under the HGV efficiency scenario are identical to the baseline scenario.

[7] The present value of the total costs incurred under the baseline scenario was €1,815 billion (discounted at 4%).

Under the electric mobility scenario a reduction of

c. **50%**

of CO_2 emissions can be achieved by 2050 (compared to 2014).

Carbon emissions and total costs are negatively correlated.

As can be seen in the chart, there is a negative correlation between carbon emissions and total costs in all scenarios other than the natural gas scenario, i.e. scenarios producing lower carbon emissions generate higher costs, and vice versa.

Scenarios build on realistic assumptions

When analysing the scale of the quantitative differences between the scenarios it should be noted that the trends we have defined for all alternative scenarios have been based on our assumptions for the baseline scenario, which we believe to reflect the most likely future development, and that accordingly the alternative scenarios also develop in a way we would consider to be realisable in practice (the only exception here being the goal to deploy 1 million all-electric vehicles by 2020, which appears very ambitious from today's perspective). Furthermore, we have assumed that alternative propulsion systems will be introduced gradually. The differences between the individual scenarios are therefore gradual rather than extreme, but we believe they reflect the trends likely to result from the various paths of development analysed.

In our analysis of the individual scenarios' results we refer to the energy efficiency characteristics assumed for the individual propulsion technologies considered in the different scenarios and the carbon emissions caused by the energy sources used:

Specific carbon dioxide emissions for different fuels

Energy source	Specific consumption (2050) MJ/pkm	Emission factor (before biofuel addition) g/MJ	Biofuel addition (2050)	Specific CO_2 emissions (after biofuel addition) g/pkm
Petrol	0.88	73.4	12%	56.84
Diesel	0.76	73.2	12%	48.96
Natural gas	0.88	56.2		49.46
Hybrid (plug-in)	0.45	63.33		28.5
Electricity	**0.18**	**62.00**		**11.16**
Petrol	**0.27**	**73.4**	**12%**	**17.44**
Hydrogen	0.97	62.00		60.09
Hydrogen	0.97	0		0
Electric vehicles (BEV)	0.31	62.00		19.22

1 Passenger kilometres (pkm) are a measure of passenger transport output. In freight transport, output is measured in tonne kilometres (tkm).

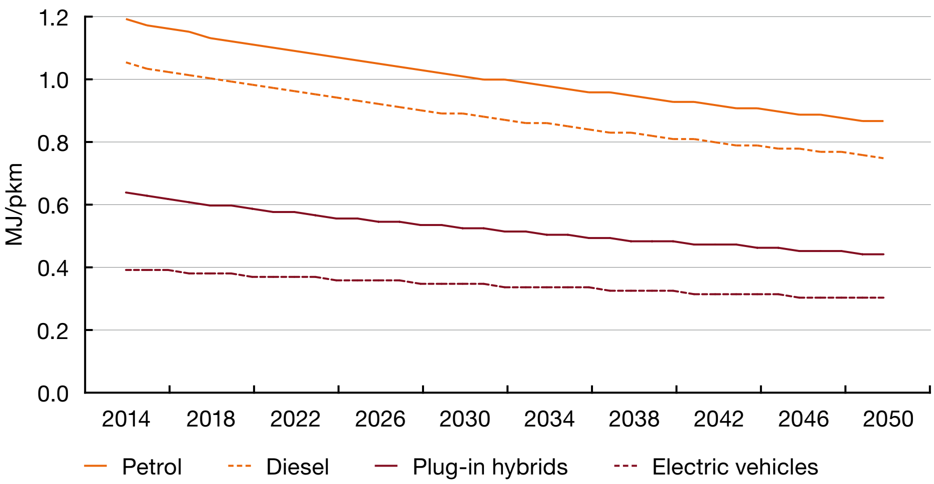
2 Weighted average based on specific consumption.

3 Specific electricity consumption assuming an electrolytic efficiency of 65%. Transport model calculations have been based on average emission factors of electricity in 2050.

4 Based on the assumption that electrolysis uses only excess power generated from renewable energy sources, which is an assumption we did not base our calculations on.

The table shows specific consumption values for the year 2050, which assume significant improvements over time for all propulsion systems as illustrated in the chart below:[8]

Evolution of specific energy consumption of new vehicles for different propulsion technologies



According to our model calculations average consumption for the existing car fleet as a whole will be significantly higher than that for new registrations in the first few years from 2014 onwards. This means that increasing the use of more energy efficient propulsion systems will be slow in delivering a notable effect. In the period to 2050, however, the currently observable potential for savings across the entire existing fleet will largely be delivered.

Carbon intensity of electrically powered technologies will decline notably.

The specific CO_2 emission factors of primary energy sources do not change over time given that they are physical quantities. Our calculations, however, have been based on the assumption that the share of biofuel additions to petrol and diesel will increase to 12% by 2020 before stagnating at that level – and the carbon emission factor for this energy source is assumed to be zero. The carbon intensity of electricity will also improve significantly, not least due to the planned increase in the share of renewable power generation envisioned by the German government. In line with the assumptions defined for the baseline scenario analysed in the PwC short study on electricity we have assumed that the carbon emission factors for electrically powered technologies will go down by more than 50%.

Based on what we know today this means that the carbon impact of electric vehicles will decline steadily over time and that by 2050 they will be the least carbon intensive alternative by far. Hybrid vehicles may deliver benefits, depending on the ratio between petrol or diesel and electricity use, respectively. The carbon intensity of cars powered by natural gas would be lower than for petrol and diesel fuel.

[8] The consumption curves for natural gas and petrol (after addition of biofuel) can hardly be distinguished, as they are very similar.

But if calculations are based on a relatively high, 12% share of biofuel, which is the assumption in our model from 2020 onwards, then the savings delivered by natural gas cars are more or less equal to those achieved by new diesel engines with added biofuel. It is a possibility, however, that a biomethane quota will be introduced in the future, in which case natural gas cars would have a considerable advantage over vehicles running on petrol or diesel.

Electric mobility scenario entails high costs of market entry, which decrease over time.

The differences in costs are primarily due to the significantly higher capital expenditure for electric vehicles and – though to a lesser extent – hybrid vehicles than for conventional propulsion systems, especially in the initial stages of their development. Maintenance costs are also significantly higher for these vehicle types at first. The benefit of lower fuel costs, in contrast, has a relatively small impact in the first years of our period of analysis. In our calculation model, however, we have assumed that over time the costs of electric vehicles will experience a notable decline compared to other energy sources as they increasingly penetrate the market, which means that these costs can in part be considered costs of market entry. Yet in relative terms these positive effects in later periods are not sufficient to cause a big impact given that we have analysed costs based on their present values, i.e. by discounting the cashflows of all periods to their value today.

High market penetration needed to achieve the required economies of scale.

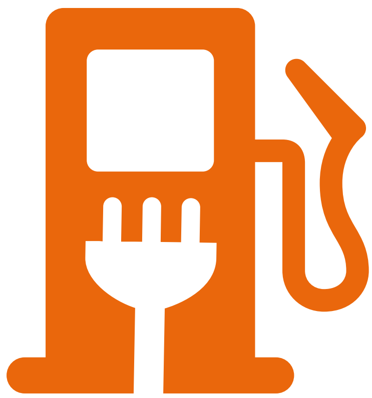
In view of this background it is understandable that the technology is picking up rather slowly. It is essential, however, that a critical mass is reached in the coming years to ensure that higher market penetration and greater product maturity can lead to economies of scale and that the technology is further developed. Following a positive phase of development the technology might increasingly deliver economic benefits, too.

In light of the German government's target to deploy 1 million electric vehicles by 2020 the 18,948 all-electric vehicles that were registered at the beginning of 2015 are a sobering figure. We therefore believe that the electric mobility scenario considered in this study is unlikely to become a reality, not least as this would also require more infrastructure investment and government funding for electric vehicles.

A more realistic prospect is that a hybrid solution combining electric vehicle and combustion engine technology will be able to gain traction more rapidly. This assumption is supported by, among others, the number of hybrid car registrations, which had at least climbed to 85,575 by the beginning of 2015. Using this technology also mitigates the issue of insufficient battery driving ranges. The extent of the benefits that could be delivered by a hybrid solution, however, is primarily driven by the mix of energy sources used, i.e. the ratio between electricity and petrol or diesel.

2015

85.575 registered hybrid cars.



Summarising theses

1 As things stand, there is a distinct possibility that the transport sector will not only fail to meet the medium-term energy savings targets but also fall short of long-term goals. The German government has set itself the aim of cutting final energy consumption in the transport sector by 10% by 2020, and 40% by 2050, compared to 2005 levels. In reality, however, both in 2013 (727 TWh) and in 2014 (724 TWh according to currently available data) final energy consumption was slightly higher than in 2005 (718 TWh).

2 With regard to decarbonisation the German government plans to reduce carbon emissions by between 80% and 95% below 1990 levels by 2050, with contributions to come from transport as well as from the electricity and heating sectors. It is not clear at present how this is to be achieved, either. According to figures published by the German Federal Environment Agency carbon emissions declined by no more than 5.5% in the period between 1990 and 2014.

3 In summary it can be stated that thus far the energy transition appears to have had little effect on the environmental impact caused by the transport sector. The only observable development is that the energy efficiency of currently used motor vehicle technologies has been improving steadily. New technologies, however, have not been able to penetrate the market on a significant scale.

4 In view of the developments seen to date it can be concluded that the transport-related climate targets cannot be met unless the transport sector is transformed radically.

5 Given that road transport by passenger car or HGV is responsible for a very large share of the carbon impact caused by the transport sector, these are also the segments that could deliver the largest reductions in future carbon dioxide emissions. In 2014 private motorised transport produced 55% of carbon dioxide emissions, 23% were caused by road freight operations. Transport by air and rail accounted for only 15% and 5% of transport-related greenhouse gas emissions, respectively.

6 Rail transport has a relatively good carbon balance, which is likely to further improve over time given the rising share of renewable power generation planned to be deployed in the future. Partially shifting freight operations from road to rail could deliver a significant contribution in meeting the decarbonisation targets.

7 Looking at the results obtained for each of the five passenger car scenarios, where in view of their key importance we focused on the impacts of different propulsion technologies, it can be stated that the evolution of carbon emissions and total costs in the various scenarios tend to be negatively correlated, i.e. scenarios producing lower carbon emissions tend to generate higher costs, and vice versa.

8 The only single scenario fully delivering on the German government's target of reducing final energy consumption in the transport sector by at least 40% below 2005 levels by 2050 is the electric mobility scenario, with the hybrid scenario at least coming close. All other scenarios fail to achieve this aim. Despite the fact that we have not modelled extreme scenarios and that all scenarios rely on different propulsion technologies, the results we obtained for passenger car final energy consumption varied by 39% between the best scenario (electric mobility scenario) and the worst (status quo scenario), with the baseline scenario, which we assumed to reflect the most likely development, delivering consumption levels that are rather at the top of the range.

9 If the slow decline in carbon emissions in the period 1990–2014 is taken into consideration, our calculations show that the transport sector will clearly fail to meet the German government's decarbonisation targets for 2050. Under the baseline scenario carbon emissions will fall by no more than 46% between 2014 and 2050 across the entire transport sector. And this despite the fact that even the baseline scenario assumes that the share of hybrid vehicles will increase to 40% by 2050, with traditional combustion engines falling below 50%.

10 The carbon impact caused by passenger car transport varies by 43% between the best scenario (electric mobility scenario) and the worst scenario (status quo scenario). In this context it should be taken into account that combustion engines have been assumed to also deliver increasing savings and that from 2050 onwards 12% biofuel with an emission factor of zero will be added to the fuel. Without biofuel addition the differences between the results obtained for the individual scenarios would be even larger. It should further be noted that the biomass used in this context is a scarce resource which could instead also be used in heating or to provide secured available generation capacity in the electricity sector and thus carries a high opportunity cost.

11 The gas scenario delivers slightly worse results than the baseline scenario – this is due to the fact that both electric and hybrid scenarios have an advantage over gas, on the one hand, and second, that biomethane additions have not been considered in our calculations.

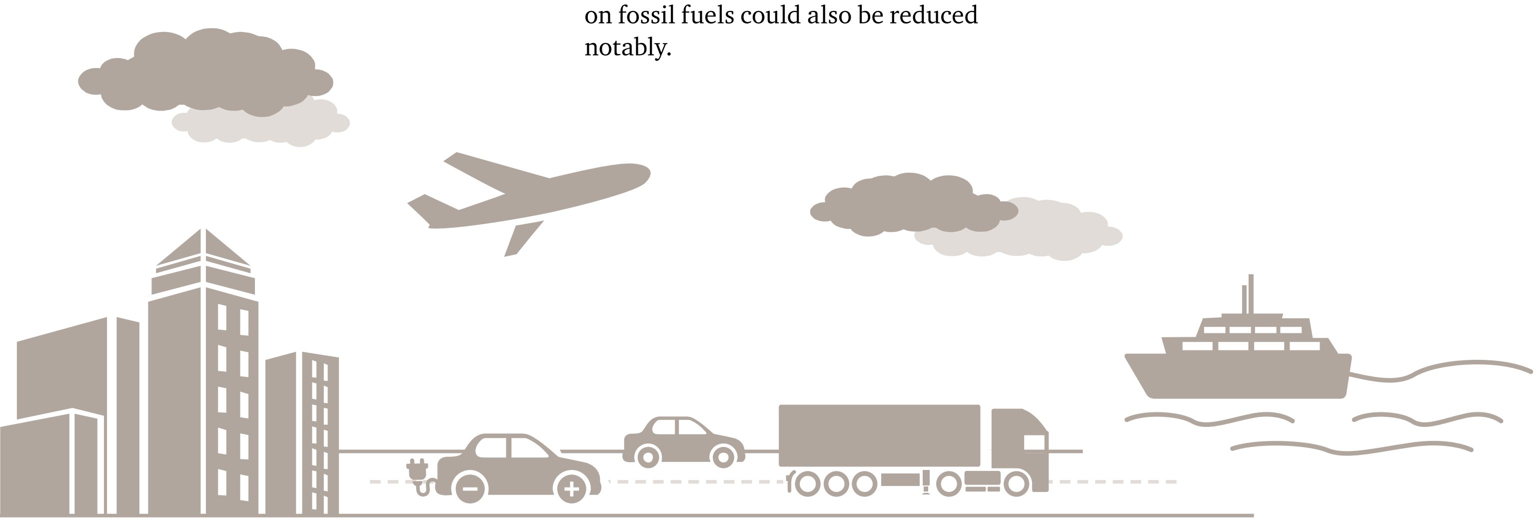
12 Under the electric mobility scenario carbon emissions will decline by 50% between 2014 and 2050. If this scenario is combined with the so-called HGV efficiency scenario, under which carbon emissions are also reduced significantly in freight operations, then emissions could fall by up to 54% according to our calculations. The reduction in carbon emissions from HGV transportation could be delivered by increasing HGV fuel efficiency or by using less carbon intensive fuels, such as liquefied natural gas (LNG).

13 The benefits delivered by the electric mobility scenario will increase as the share of renewable power generation rises. Increasing the share of all-electric vehicles to 40% of the entire car fleet would result in an electricity consumption of around 85 PJ (approximately 24 TWh), which would be equivalent to less than 5% of the 600 TWh of total power consumption assumed by us in 2050.

14 We further assume that the high initial costs these alternative propulsion technologies incur will decrease considerably as market penetration increases, and that cost disadvantages will become less important over time. Our reliance on fossil fuels could also be reduced notably.

15 However, in view of the current registration numbers, with only 18,948 all-electric vehicles being registered at the beginning of 2015, it is to be expected that we will not meet the German government's goal of deploying 1 million electric vehicles by 2020, and that the electric mobility scenario analysed in this study will not become a reality, either, not least as this would require more infrastructure investment and government funding for electric vehicles.

16 We would consider it a more realistic prospect that a hybrid scenario combining electric vehicle and combustion engine technology will slowly gain traction. This assumption is supported by, among others, the number of hybrid car registrations, which had at least climbed to 85,575 by the beginning of 2015. Using this technology also mitigates the issue of insufficient battery driving ranges. The extent of the benefits that could be delivered by a hybrid solution, however, is primarily driven by the mix of energy sources used, i.e. the ratio between electricity and petrol or diesel.



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