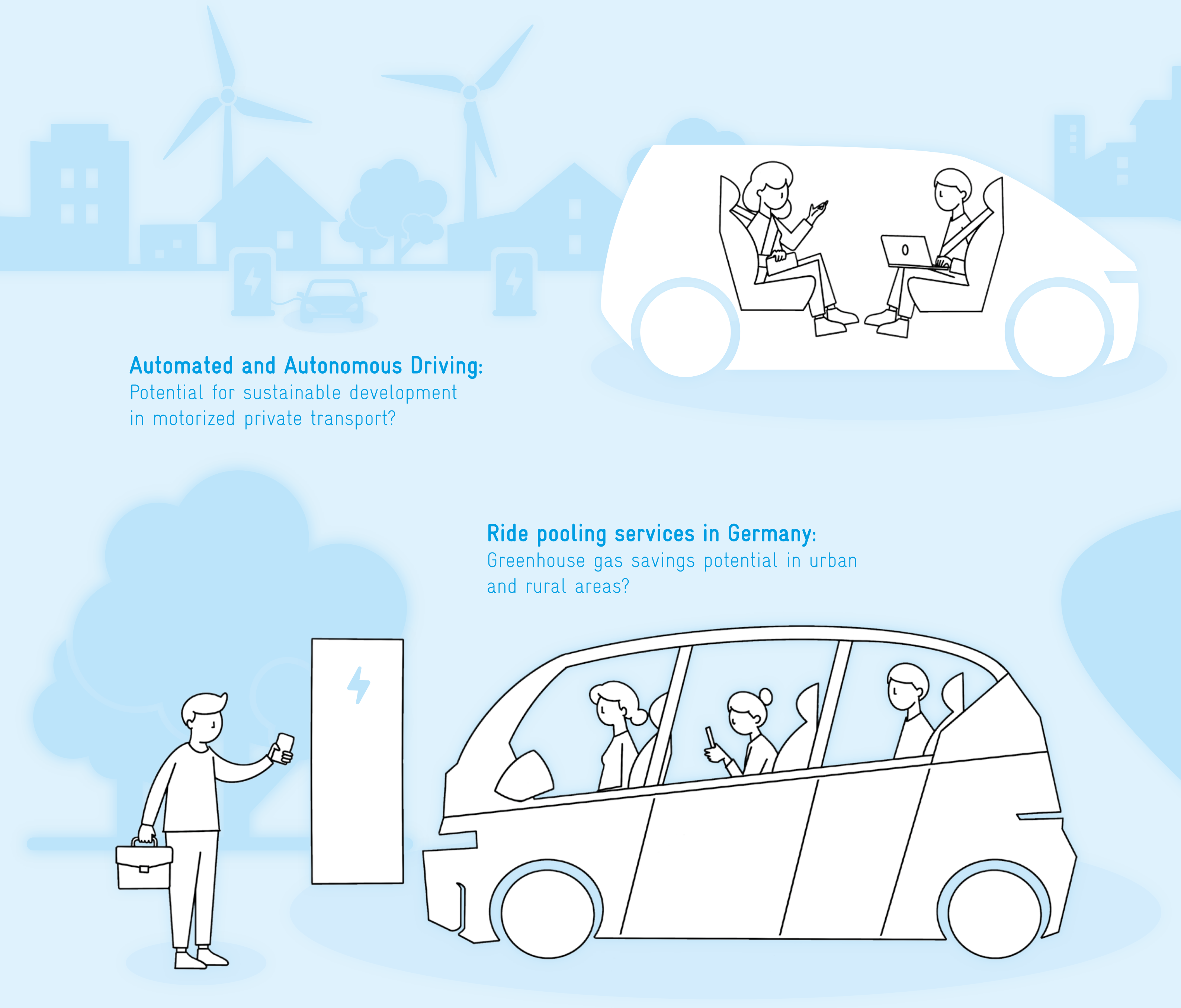
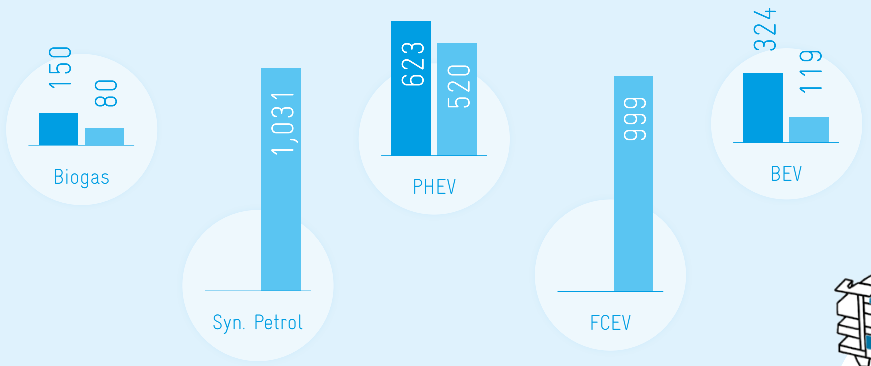
B 2 Motorized Private Transport on the Road to Sustainability

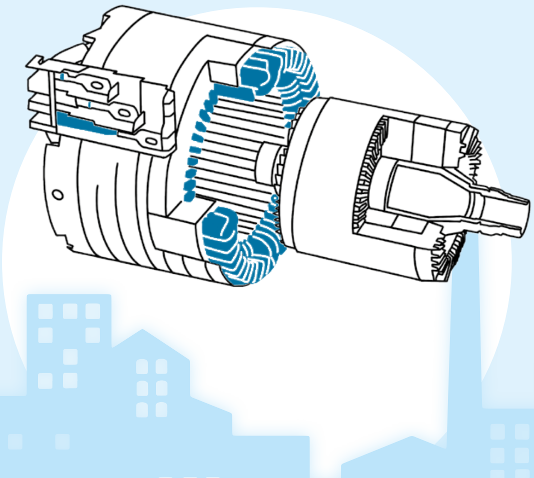
German policy is faced with the major challenge of having to bring emissions from the transport sector to zero as early as 2045. Private motorized transport is a major source of greenhouse gas emissions. A reduction in these emissions can be achieved at vehicle level through the use of new drive systems and alternative fuels. The battery-powered passenger car is proving to be the most ecologically and economically advantageous alternative. In addition, developments in digitalization and autonomous driving open up opportunities for innovative mobility services in order to contribute to the reduction of emissions by bundling transport, especially in the form of car sharing and on-demand transport.





GHG reduction costs of alternative drive systems and fuels compared to a conventional petrol engine in euros per tonne of CO_2 equivalent

2020 2030



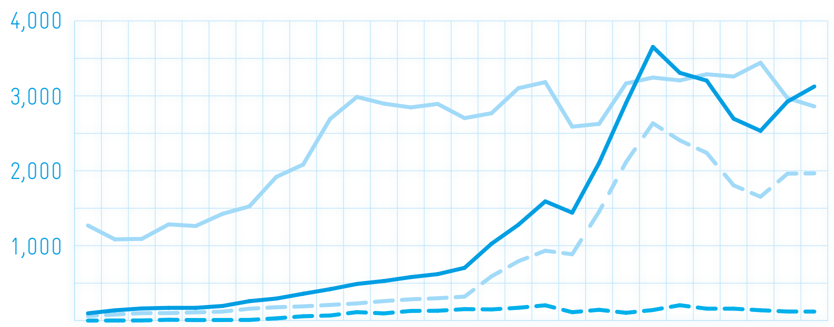
Life cycle assessment and economic analysis of conventional and alternative drive systems:

Are alternative drive systems the right way to go?

Innovation activity in the area of drive systems and automated driving: Where does Germany stand in international comparison?

Number of patent applications (1990-2017)

Alternative drive technologies
Fuel cell technologies
Battery electric drive technologies
Conventional drive technologies



B 2 Motorized Private Transport on the Road to Sustainability

German policy is faced with the major challenge of having to bring emissions from the transport sector to zero as early as 2045. Motorized private transport (MPT) is a major source of greenhouse gas emissions.[198] A reduction in emissions from MPT can be achieved in various ways: by reducing the total distance travelled, by using lower-emission vehicles and by changing the choice of transport modes. On the one hand, this chapter focuses on emission reductions at the vehicle level through use of new drive systems and alternative fuels. On the other hand, it examines the extent to which innovations through digitalization and automated driving can contribute to the bundling of transport, especially in the form of car sharing and on-demand transport.

Purely battery-powered electric cars are proving to be the most economically advantageous option for reducing emissions at the vehicle level. However, their purchase and operation are currently not sufficiently attractive without accompanying policy measures. To accelerate the spread of purely battery-powered electric cars, a higher CO_2 price and a well-developed charging infrastructure with competitive and transparent prices are needed.

With regard to new drive technologies, the German automotive industry is well positioned in international comparison. Together with Japan, it leads the world in terms of both patent applications and sales figures. In the area of automated driving, the USA, Germany and Japan are ahead, with the USA leading by far in the sub-area of autonomous driving.

Legal adjustments are still needed for the widespread use of autonomous vehicles to bundle transport. In this way, better offers and innovative business models can develop that make the switch from private transport to bundled forms of transport more attractive.

B 2-1 Life Cycle Assessments of Alternative Drives

The discussion about low-emission drive systems has triggered various technological developments. For a meaningful assessment of the ecological reduction potentials, especially of greenhouse gases (GHG), of these new drive systems, the Commission of Experts commissioned a study. In this study, the total GHG emissions, the emissions of other air pollutants and the use of critical raw materials during the production, use and disposal phases are balanced for vehicles in the compact class.[199] The key assumptions of this balance are shown in box B 2-2. The following drive systems are compared: conventional internal combustion engine vehicles (ICEV), powered by petrol, diesel, biogas or synthetic fuels,[200] battery electric vehicles (BEV), plug-in hybrid vehicles (PHEV) and fuel cell electric vehicles (FCEV) (see box B 2-1).

Key determinants of emissions and the relative advantage of alternative drive systems are the battery technology used, the size of the batteries installed, the option of replacement batteries, the total mileage and the electricity mix used in power generation.

Comparing state-of-the-art vehicles purchased in 2020, BEVs, FCEVs and PHEVs generate significantly more GHG emissions during vehicle production and disposal than conventional petrol and diesel vehicles (see figure B 2-3). GHG emissions in

Box B 2-1 Conventional and Alternative Drives

ICEV Petrol/Diesel: Vehicles with a conventional internal combustion engine drive develop kinetic energy from the combustion of conventional fuels such as petrol or diesel. Biofuels or synthetic fuels such as methanol or biodiesel can be added to these fuels.[201]

ICEV Gas: In gas drives, natural gas or biogas is compressed and carried in a special tank in the vehicle. There are vehicles with a pure gas drive as well as vehicles that can use both petrol and natural gas.

BEV: Battery electric vehicles convert electrical energy into kinetic energy in an electric motor. The motor is supplied with energy from a battery that is charged from the power grid and from recirculated braking energy.

HEV: In hybrid electric vehicles, an electric drive supports the combustion engine to save fuel. In the so-called full hybrid,[202] purely electric driving is possible at low speeds. The battery is charged exclusively by the engine and the recovery of braking energy.[203]

PHEV: Unlike a full hybrid electric vehicle, a plug-in hybrid electric vehicle has a charging device to charge the battery directly from the power grid.[204]

FCEV: In fuel cell electric vehicles, the energy to operate an electric motor is generated from the reaction of hydrogen and oxygen in a fuel cell. A battery, which is small compared to BEVs, is used to balance and temporarily store the energy produced by the fuel cell as well as recovered braking energy.[205]

manufacturing are only slightly lower in 2030 than in 2020 across all drive systems.[206] For petrol- and diesel-powered vehicles, emissions in vehicle manufacturing are higher in 2030 than in 2020 due to the assumed switch to hybrid drives. For BEVs, emissions decrease by 2030 due to improved manufacturing processes. However, this reduction is largely offset by increasing battery capacities. FCEVs have the highest emissions in manufacturing in 2020, but also in 2030 despite considerable technological progress.

Over the entire lifetime, vehicles powered by biogas cause the lowest GHG emissions (see figure B 2-4).[208] However, biogas is not a sufficiently scalable option.[209] Among the new technologies, BEVs already have the lowest GHG emissions in 2020. They are only about half as high as with a conventional petrol engine.[210] FCEVs do not yet have any advantages over conventional drives in 2020. This changes in 2030, however, because the high energy demand for producing the hydrogen required in use will then be covered by a lower-emission electricity mix. In comparison, however, FCEVs still perform worse than BEVs. A similar picture emerges for ICEVs powered by synthetic fuels. For PHEVs, GHG emissions depend crucially on driving and charging behaviour. If these vehicles are driven like petrol vehicles, emissions actually increase compared to petrol vehicles due to the higher weight and more complex technology.[211, 212]

In addition to greenhouse gases, transport also emits other pollutants that have a significant impact on the environment, primarily nitrogen oxides (NO_X)[213] and particulate matter.[214] These are now dominated by emissions from electricity and vehicle production, due to the constant tightening of exhaust gas limits. Conventional vehicles have the lowest NO_X and particulate matter emissions over their entire service life. While NO_X emissions from BEVs are slightly higher and particulate matter emissions are significantly higher than those from conventional vehicles, FCEVs and synthetic fuel vehicles perform worst for both pollutants.[215]

Despite the increased NO_X emissions from BEVs, the shift of these emissions from the exhaust pipe to the stacks of power plants and manufacturing facilities improves air quality in urban areas close to traffic. This is an aspect that has a positive impact on the evaluation of electrically powered vehicles.[216]

An assessment of the sustainability of alternative drive systems must also take into account the use of critical raw materials, the extraction of which

Box B 2-2 Assumptions on Vehicles, Batteries and Electricity Mix

The study looks at the environmental balance and the economic efficiency of a compact class vehicle (e.g. Ford Focus, VW Golf, Toyota Corolla) purchased in 2020 or 2030 and driven for 15 years. Realistic driving behaviour is assumed as far as possible. For PHEVs, a charging behaviour is assumed that enables the use of the electric drive component. In contrast, empirical results from Plötz et al. (2020) show a significantly lower use of the electric drive in PHEVs. In 2020, the vehicle batteries will still be produced overseas (China, South Korea, Japan, USA). For 2030, the study assumes cell production in Europe and thus a European electricity mix in battery production. The modelled vehicle uses nickel-manganese-cobalt batteries, in which technological progress will reduce the proportion of cobalt by 2030 and at the same time achieve a higher energy density.

Assumptions on Vehicle and Battery	2020	2030
Mileage over vehicle lifetime	187,500 km	187,500 km
Vehicle lifetime	15 years	15 years
Real fuel/energy consumption per 100 kilometres		
— ICEV Petrol	7.1 l	5.6 l
— ICEV Diesel	5.9 l	5.5 l
— ICEV Gas	4.7 kg	3.8 kg
— BEV	18.8 kWh	16.9 kWh
— PHEV	3.4 l + 11 kWh	1.8 l + 13.2 kWh
— FCEV	1 kg	0.8 kg
Average capacity of the vehicle battery for BEV (vehicle range)	55 kWh (ca. 290 km)	69 kWh (ca. 410 km)
One battery per vehicle life is assumed.		
Energy density per kilogram	150 Wh	200 Wh

Assumptions on Energy Mix	2020	2030
GHG emissions from electricity generation per kWh	470 g	146 g

The assumed development of the electricity mix follows the Greenhouse Gas Neutral Scenario of the former Federal Ministry for Economic Affairs and Energy (BMWi),[207] which assumes that GHG emissions in Germany will decrease by 65 percent from 1990 to 2030 and by 88 percent to 2040 by increasing the share of renewable energies.
For ICEV petrol and ICEV diesel, a switch to hybrid drives is assumed in 2030. HEVs are not considered separately in the study.

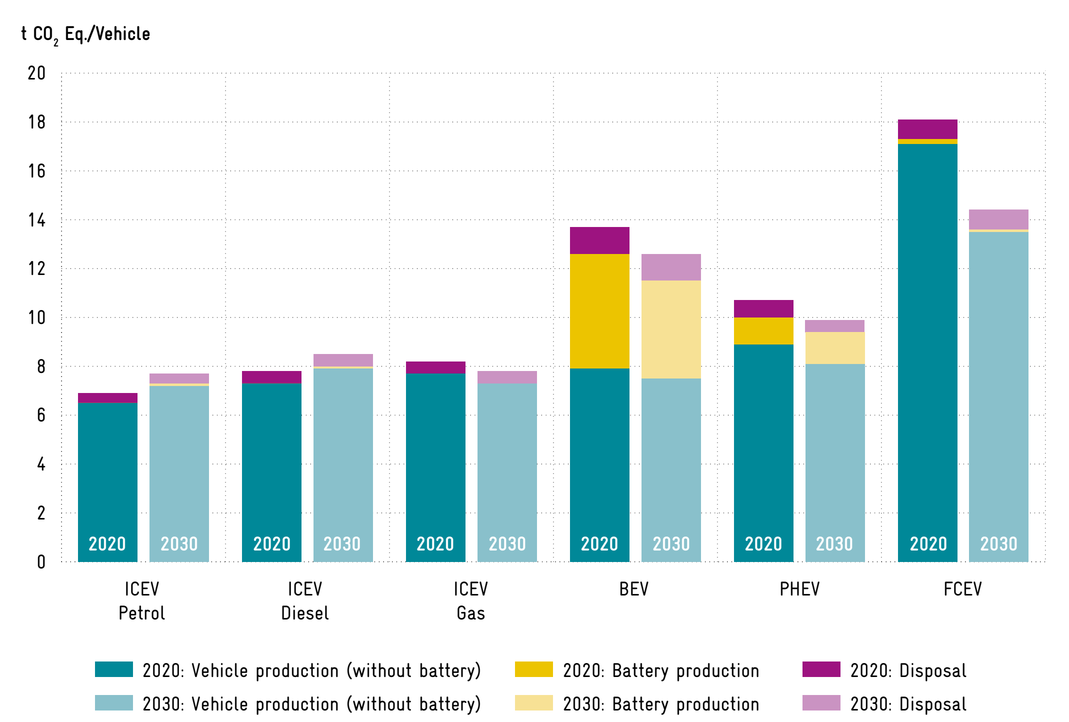
causes considerable external environmental costs in the producing countries. In battery production, cobalt and lithium are among the most important critical raw materials,[217] in fuel cells it is mainly elements of the platinum group, of which large quantities would be needed at the current state of the art.[218] Since the demand for critical raw materials will increase with rising demand for vehicles with alternative drives, despite expected technological progress and recycling, it is advisable to push ahead with the development of batteries that largely dispense with such raw materials, e.g. sodium-ion batteries.[219, 220, 221]

Resource Consumption of Different Drive Systems in Comparison

Vehicles with alternative drives are currently still significantly more expensive to purchase than conventional vehicles. From an economic perspective, the different drive systems can be compared with each other based on the so-called Total Cost of Ownership (TCO). The TCO evaluates the direct resource consumption in the production, use and disposal of a vehicle over its entire service life at market prices.[222]

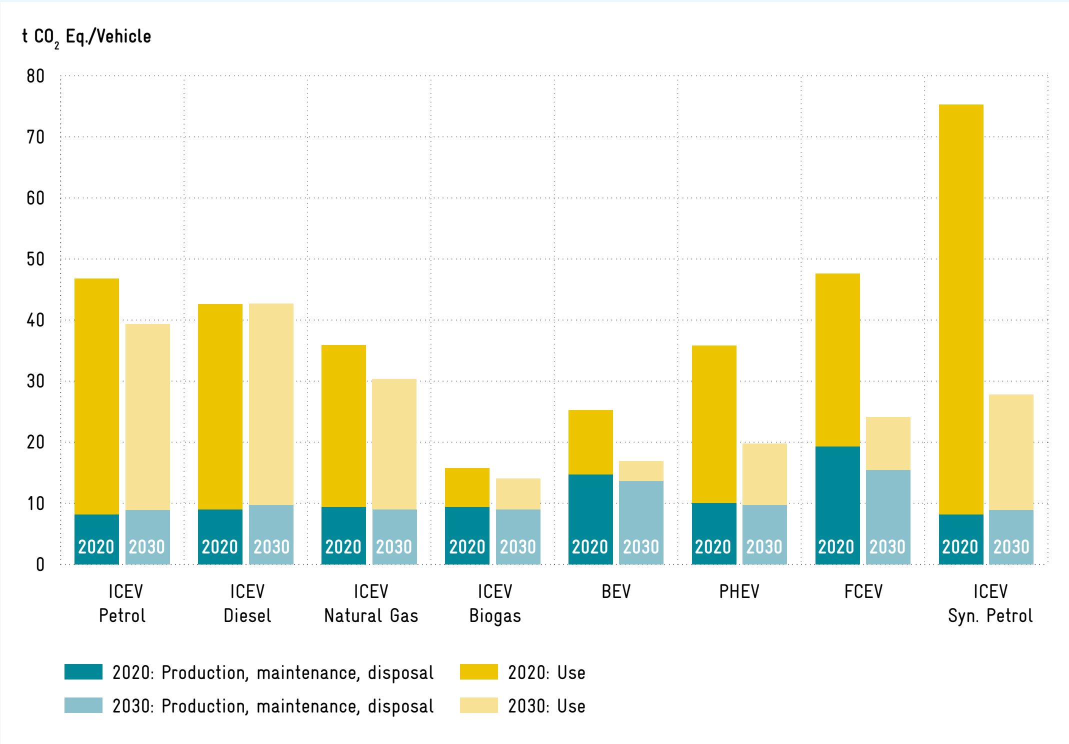
Figure B 2-5 shows the results of TCO calculations carried out by Fraunhofer ISI on behalf of the Commission of Experts. According to these, the costs of

Fig. B 2-3 GHG emissions from vehicle production and disposal for a compact vehicle purchased in 2020/2030 in tonnes of CO_2 equivalent



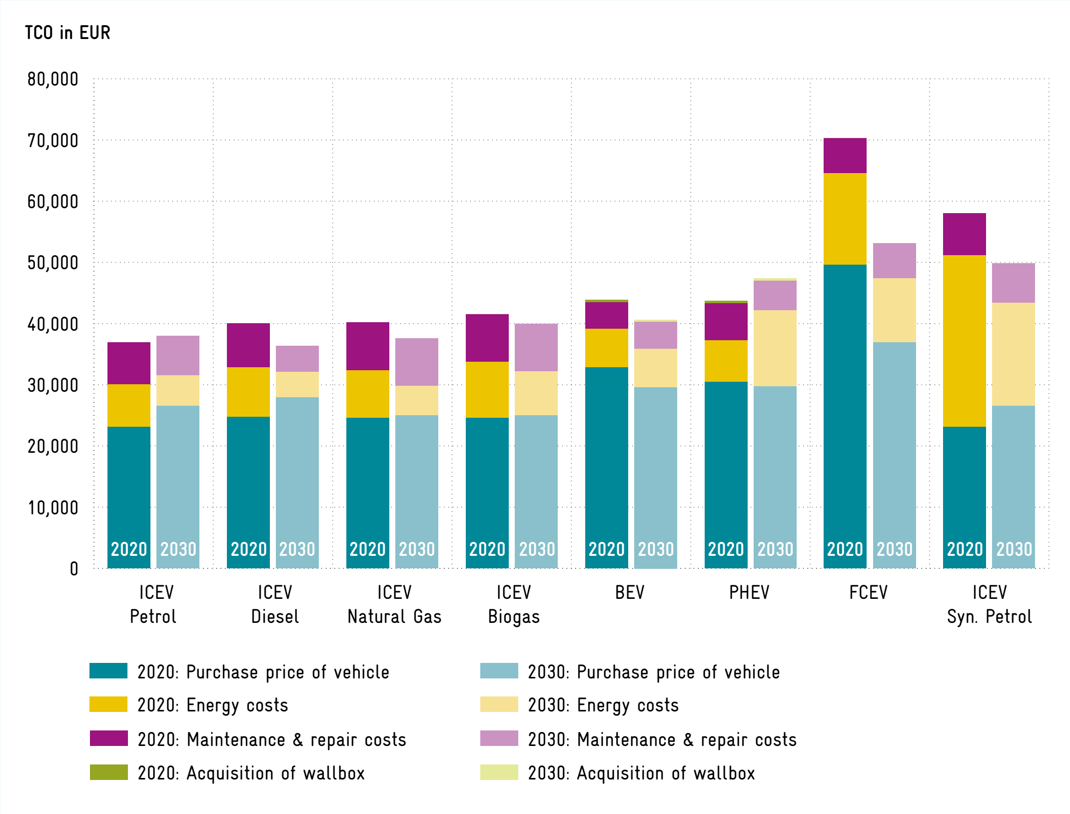
Source: Own representation based on Wietschel et al. (2022).

Fig. B 2-4 GHG emissions over the vehicle lifetime for a compact vehicle purchased in 2020/2030 in tonnes of CO_2 equivalent



Source: Own representation based on Wietschel et al. (2022).

Fig. B 2-5 TCO results for a compact vehicle purchased in 2020/2030 in euros



Purchase price of the vehicle including battery, if applicable.
Energy costs: Depending on the drive type, these include expenditure on petrol, diesel, gas, electricity and synthetic fuels consumed during vehicle use.
Maintenance and repair costs: During the use phase, costs are incurred for maintenance and repairs. These include all expenses for maintaining the vehicle in running condition that are not included in energy costs.
Acquisition of wallbox: This includes the cost of purchasing a charging station that allows PHEVs and BEVs to be charged via the in-house power connection.
All prices are to be understood as net prices.
Source: Own representation based on Wietschel et al. (2022).

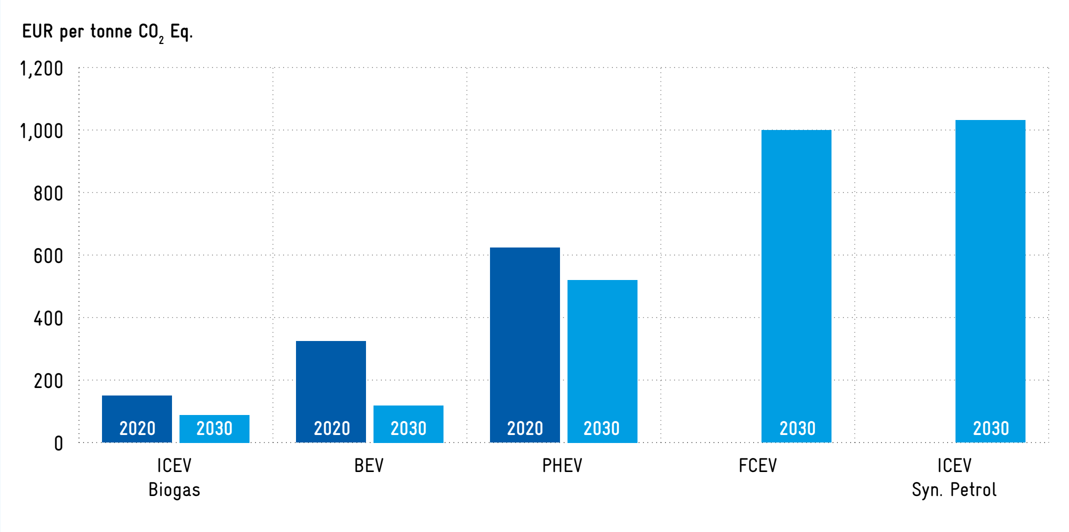
direct resource consumption are lowest for conventional ICEVs in 2020 and 2030. The TCO of biogas are also relatively low. For BEVs, the TCO in 2020 is €7,000 higher than for conventional petrol vehicles. For FCEVs and ICEVs powered by synthetic fuels, the difference is €33,500 and €21,000, respectively. In 2030, the TCO for alternative drive vehicles, except for PHEVs, are a good deal lower than in 2020, but the resource consumption costs compared to conventional ICEVs are still higher.

The higher costs of BEVs are mainly due to the manufacturing costs of the batteries, while those for FCEVs and ICEVs powered by synthetic fuels are due to the high energy consumption for the production of hydrogen and synthetic fuels, respectively.[223]

Costs of Greenhouse Gas Reduction for BEVs Relatively Low

Using the differences in TCO and emissions per vehicle lifetime between a vehicle with an alternative drive system and a vehicle with a conventional drive system, it is possible to determine what it costs to save one tonne of CO_2 by changing drive systems. Figure B 2-6 shows these GHG reduction costs for 2020 and 2030. Here, a conventional petrol engine serves as a reference. The ICEV biogas drive, although difficult to scale, has the lowest GHG reduction costs in both years. For BEVs, the GHG abatement costs are slightly higher, for PHEVs significantly higher.[224] FCEVs and vehicles fuelled with synthetic fuels produce even higher GHG emis-

Fig. B 2-6 GHG reduction costs of alternative drive types and fuels compared to a conventional petrol engine 2020/2030 in euros per tonne of CO_2 equivalent



GHG reduction costs for FCEV and ICEV Syn. Petrol cannot be meaningfully stated in 2020 because these have even higher GHG emissions than a conventional petrol vehicle in 2020.
Source: Own representation based on Wietschel et al. (2022).

sions in 2020 than a conventional petrol engine, so that GHG abatement costs cannot be meaningfully stated. In 2030, they produce less GHG emissions than the reference drive, but their GHG reduction costs are by far the highest due to the high electricity demand.

The TCO does not take into account the external effects caused by the emission of GHG during the production and use of the various drive type vehicles. From an economic point of view, a change to an alternative drive system is advantageous if the external costs of the conventional drive per tonne of CO_2 are higher than the additional costs of the TCO determined above (see figure B 2-5) due to the change of drive. If the estimated value of the external CO_2 costs of €215 per tonne of CO2 equivalent calculated by the Federal Environment Agency (Umweltbundesamt, UBA) is taken as a basis, it becomes apparent that the additional costs of BEVs will exceed the external costs in 2020. In 2030, however, they are lower, so a switch from conventional petrol to BEVs will then be economically advantageous. In contrast, the other alternative drive systems, apart from the option of biogas, which cannot be scaled up, have a negative economic benefit-cost balance even in 2030.

Purchase Premiums Only Partially Effective

Currently, the Federal Government subsidizes the purchase of a BEV with up to €9,000 as well as a waiver of the vehicle tax over ten years with a total value of €2,000 to €3,000. With a saving of around 20 tonnes of CO_2 over the life cycle of a compact-class vehicle (see figure B 2-4), the reduction of one tonne thus costs the state between €550 and €600 per tonne of CO_2 equivalent, which clearly exceeds the actual abatement costs.

Nevertheless, there may be reasons to justify start-up funding. Vehicles with alternative drives are new products that can still expect cost degressions through learning and economies of scale, which the market only incompletely rewards.[225] In addition, promoting the purchase of vehicles with new drives can trigger direct and indirect network effects. Vehicles with new drives become more attractive for users the denser the charging infrastructure becomes. Conversely, the more vehicles with alternative drives are on the road, the more worthwhile it is to expand the network for private providers of charging stations. A purchase premium can trigger the resolution of this chicken-and-egg problem.

However, in contrast to a CO_2 price, the purchase premium does not have a steering effect with regard to emission-intensive driving modes. Furthermore, deadweight losses cannot be ruled out in some cases. For example, it can be observed that the existing purchase premium is disproportionately used for PHEVs and relatively heavy, fuel-intensive and thus emission-intensive vehicles.[226] Finally, flat-rate incentives such as the purchase premium typically generate rebound effects.[227]

Need for Change in Purchase Incentives

The question arises as to how the state can provide sufficient incentives for switching to an alternative drive system when buying a car. In addition to the TCO and the CO_2 price, the taxes on petrol and diesel as well as the vehicle tax are key factors in the decision to switch.[228] Because fuel consumption is associated with higher GHG emissions, the taxes on fuel for ICEVs ultimately have the same effect as a CO_2 price. For example, the current petrol tax corresponds to a price of about €220 per tonne of CO_2, i. e. it is approximately at the level of the environmental costs of GHG emissions of €215 per tonne determined by the UBA.[229] Such a price will only be a sufficiently high incentive from 2030 onwards. As shown above, the cost disadvantages per tonne of CO_2 saved when purchasing a passenger car with an alternative drive instead of a conventional petrol car are currently still consistently greater. This is why additional incentives, such as a purchase premium, are needed to steer the purchase decision in the direction of more sustainable drive systems.

Besides a purchase premium, there are other options to achieve this goal. One alternative, envisaged in the coalition agreement, is to differentiate the vehicle tax according to the drive system so that it also takes into account the emission of CO_2 and other pollutants. The difference between the vehicle tax rates for ICEVs and those for alternative drive systems would then have to be sufficiently large to make a switch worthwhile. Such an instrument would then have a similar effect to a purchase premium.

Another alternative is to directly price the external effects associated with use and the kilometres travelled instead of a flat-rate tax on vehicle ownership, as is the case with vehicle tax. In particular, an increase in fuel taxes[230] and a comprehensive road toll system could have corresponding steering effects on vehicle use. Vehicle taxes would be eliminated altogether.

Price Transparency and Expansion of Charging Infrastructure Necessary

To promote indirect network effects, the improvement of the charging infrastructure would be the more effective lever, since on the one hand, unlike the purchase premium, it directly benefits many users[231] and, on the other hand, the purchase premium, which is very expensive for the state, can be better replaced by purchase incentives via CO_2 pricing. In addition to an expansion of the stock of fast charging stations, for which around €2 billion have already been made available on the basis of the Fast Charging Act (Schnellladegesetz),[232] rules for transparent pricing at charging stations as well as technological compatibility are necessary in order to generate low prices for charging electric cars and other alternative drive systems through competition. Currently, however, the market for charging electric cars is characterized by fragmentation with confusing technological interfaces and different payment systems, which makes it difficult to compare prices and find cheap charging stations.[233]

Since FCEVs are neither ecologically efficient nor economical in the foreseeable future, there is no need to further expand the still thin hydrogen filling station network[234] for MPT at present. In addition, research is working on the development of a new generation of hydrogen storage systems, the so-called liquid organic hydrogen carrier technology,[235] which allow hydrogen to be stored and transported with the help of liquid carrier media. This would allow the existing logistics of the mineral oil industry to be converted with relatively little effort for continued use.

B 2-2 Patent Activities and Sales in the Field of Alternative Drives

In the following, patent activities and market shares in the field of alternative drive technologies are examined globally and in comparison with other countries in order to describe Germany's respective position in international competition. The basis for this is a study commissioned by the Commission of Experts on relevant transnational patent applications in the period from 1990 to 2017[236] and on passenger car sales figures by drive system in the period from 2010 to 2020.[237]

Patent Activities in the Field of Alternative Drives Growing Sharply Worldwide

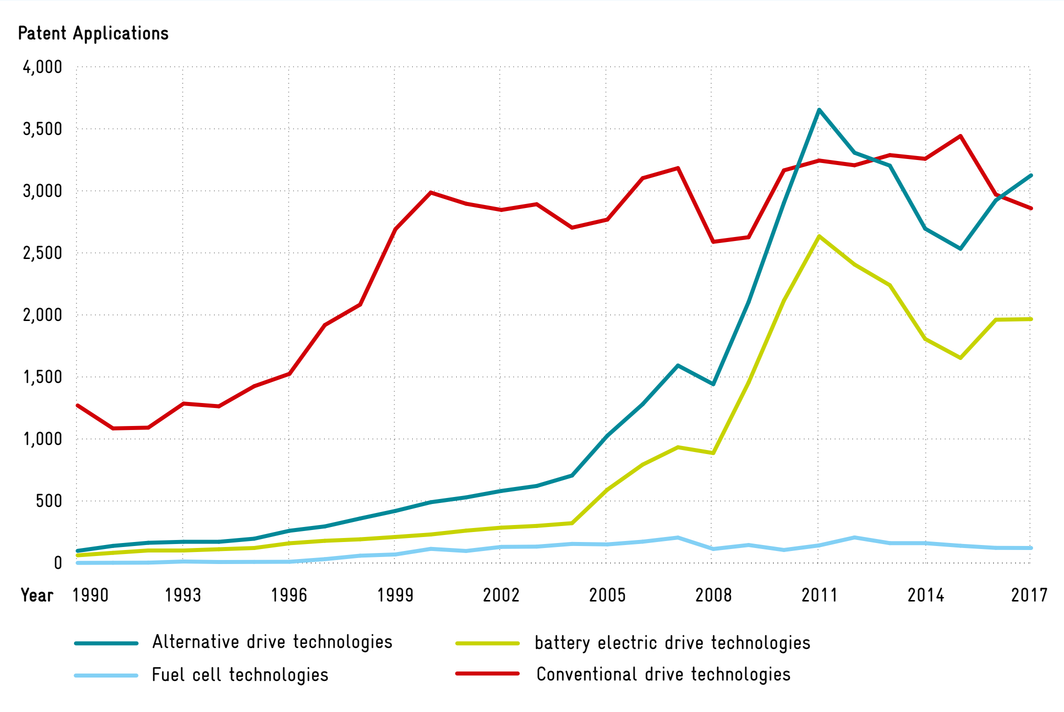
Worldwide, the number of transnational patent applications in the field of alternative drives has risen sharply since 2004. Since 2011, it has been at a similar level to the number of patent applications in the field of conventional drives (see figure B 2-7).[238] The increase was mainly driven by patent applications in the field of battery electric drives.

Germany Catches Up in Patents on Alternative Drives

An international comparison of transnational patent applications in the field of alternative drives shows that the strong increase in the years 2004 to 2010 can be traced back primarily to Japan. Since then, however, the transnational patent applications coming from there have been in sharp decline.[239] In contrast, positive momentum has been recorded for Germany and, at a lower level, also for China[240] and the USA, especially since 2014 (see figure B 2-8). In 2017, Germany was almost on a par with Japan with 758 transnational patent applications in the field of alternative drive systems – ahead of the USA and China with close to 400 patent applications each.

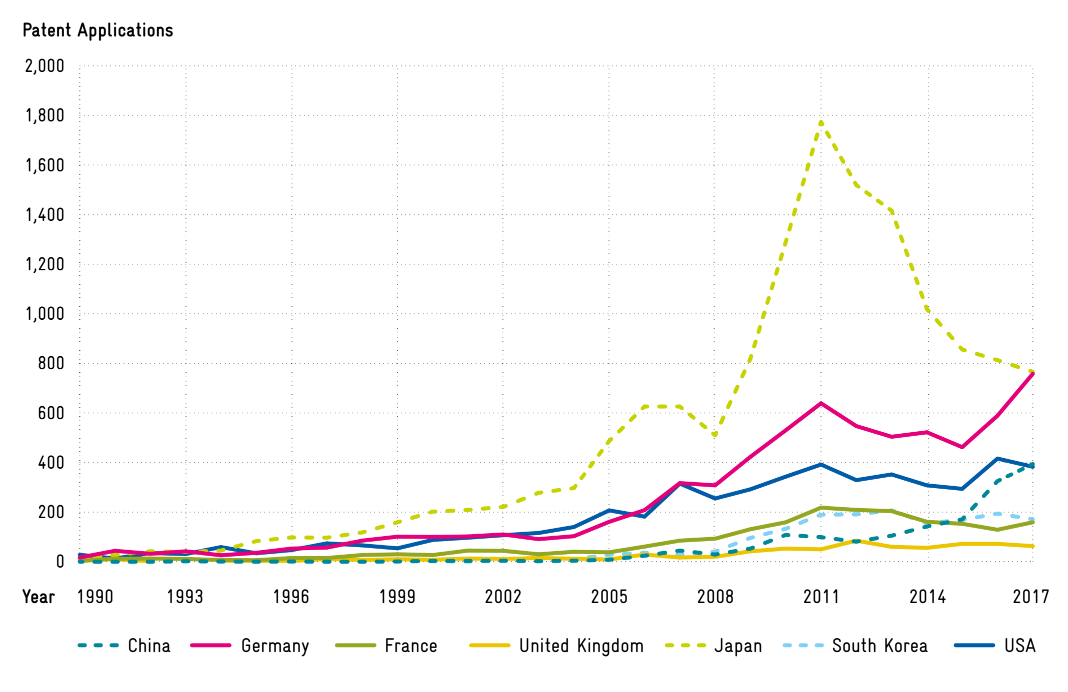
Normalized relative patent shares (RPS) are a measure of the specialization of countries in a certain patent area.[241] Figure B 2-9 shows the normalized RPS of alternative drive technologies. A positive value indicates specialization in this area. The development of the RPS from 2005 to 2017 shows increasing specialization in these technologies for Germany and especially China. For the USA and Japan, the development is in the opposite direction.

Fig. B 2-7 Number of transnational patent applications in the fields of conventional and alternative drive technologies 1990–2017



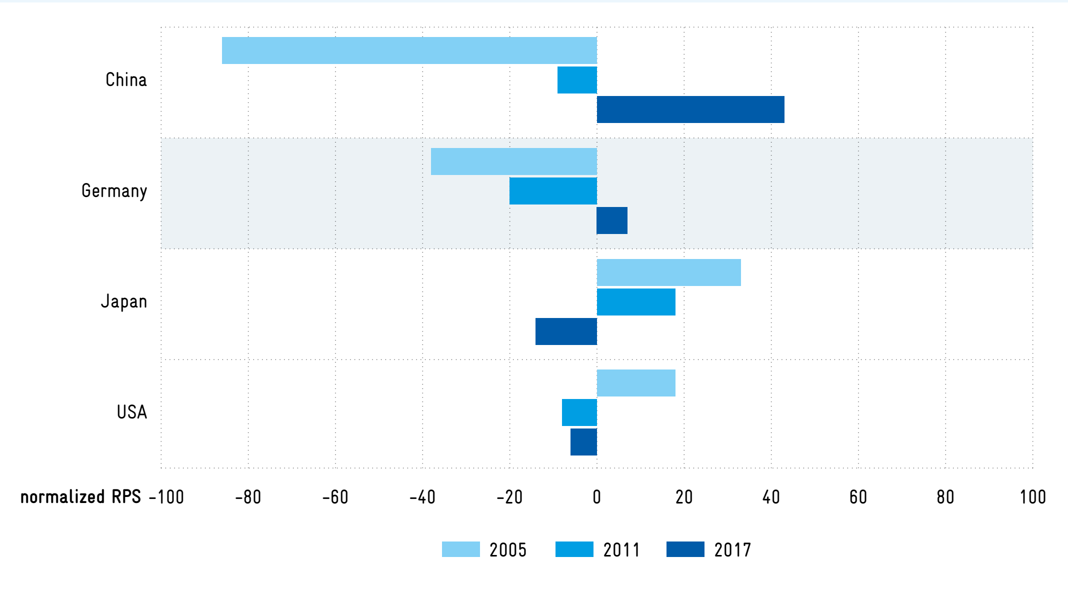
In addition to patent applications for battery electric drives and fuel cells, alternative drive technologies also include applications in the areas of power electronics and charging systems, which are not shown individually here.
Source: PATSTAT. Own representation based on Sievers and Grimm (2022).

Fig. B 2-8 Number of transnational patent applications in the field of alternative drive technologies in selected countries 1990–2017



Source: PATSTAT. Own representation based on Sievers and Grimm (2022).

Fig. B 2-9 Normalized RPS of alternative drive technologies in all drive system technologies of selected countries 2005, 2011, 2017



Normalized RPS of alternative drive technologies measured against all drive system technologies.
Legend: Japan has a normalized RPS of –14 in 2017. This value indicates that Japan's share of global patent applications in the field of alternative drive technologies this year is 86 percent of Japan's share of global patent applications in the field of all drive system technologies.
Source: PATSTAT. Own representation based on Sievers and Grimm (2022).

Rising Sales Figures for Alternative Drives

In addition to the innovation activity reflected in the patent applications, the market penetration of alternative drive technologies within individual countries is of great importance for a sustainability-oriented mobility transition. The development of the proportion of new registrations for the various drive systems in the period from 2010 to 2020 is examined below for Germany and selected comparative countries.

In 2020, there was a significant increase in the share of newly registered BEVs in Germany, starting from a low level, with an associated decline in new registrations of ICEVs (see figure B 2-10 a). As a result, in 2020 the share of BEVs sold in Germany was just under 6 percent, more than three times higher than in the previous year (see figure B 2-10 b). Germany was thus in the top group internationally in terms of the share of newly registered BEVs. This change is most likely also driven by the purchase premiums.[242] The share of ICEVs in vehicle sales was nevertheless still high at 85 percent.

However, by far the highest share of new BEV registrations in 2020 was registered in Norway with 42 percent. This high share of BEVs is due to various highly effective support measures. In Norway, the share of PHEVs in passenger car sales was also the highest in a global comparison at 16 percent. Here, Germany ranked second among the countries considered with a share of 7 percent (see figure B 2-10 c). In the case of pure hybrid vehicles (HEV), Japan recently recorded the highest share of new registrations with 20 percent, while this type of drive system hardly plays a role in Germany with a share of new registrations of less than 2 percent (see figure B 2-10 d).

Broad-based Promotion of Alternative Drives

The support measures in Germany regarding alternative drive systems focus primarily on battery electric drives. As the technology is well developed and ready for the market, current support focuses on greater market penetration. Important elements in the Government Programme on Electromobility (Regierungsprogramm Elektromobilität), which are promoted by the Länder and the Federal Government, but also by the EU, are purchase premiums, the expansion of the public and private charging infrastructure and the public procurement of electric vehicles, which are to make up at least 20 percent of the Federal Government's vehicle fleet.

In addition, in the area of alternative drive systems, the Federal Government and the Länder are supporting, to a considerably lesser extent, both research into vehicles powered by natural gas, hydrogen or fuel cells and their market launch.[243] In this context, the National Hydrogen Strategy (Nationale Wasserstoffstrategie) with the aim of accelerating the market ramp-up of new hydrogen technologies is of particular importance. In combination with alternative drive technologies, the use of new materials and processes in vehicle construction, for example by reducing the weight of the body and drive train, can also contribute to emission savings.[244] As part of the Technology Transfer Programme for Lightweight Construction (Technologietransfer-Programm Leichtbau), the Federal Ministry of Economics and Climate Protection (BMWK) supports cross-sector, cross-technology and cross-material research in the field of lightweight construction.

B 2-3 Automated and Autonomous Driving

Automated driving is an overarching term that encompasses both assisted and (partially) automated driving as well as completely driverless driving and the associated communication technologies that enable the networking of vehicles. Autonomous driving, as a sub-area of automated driving, describes the highest levels of automation, which include fully driverless driving and the associated communication technologies.

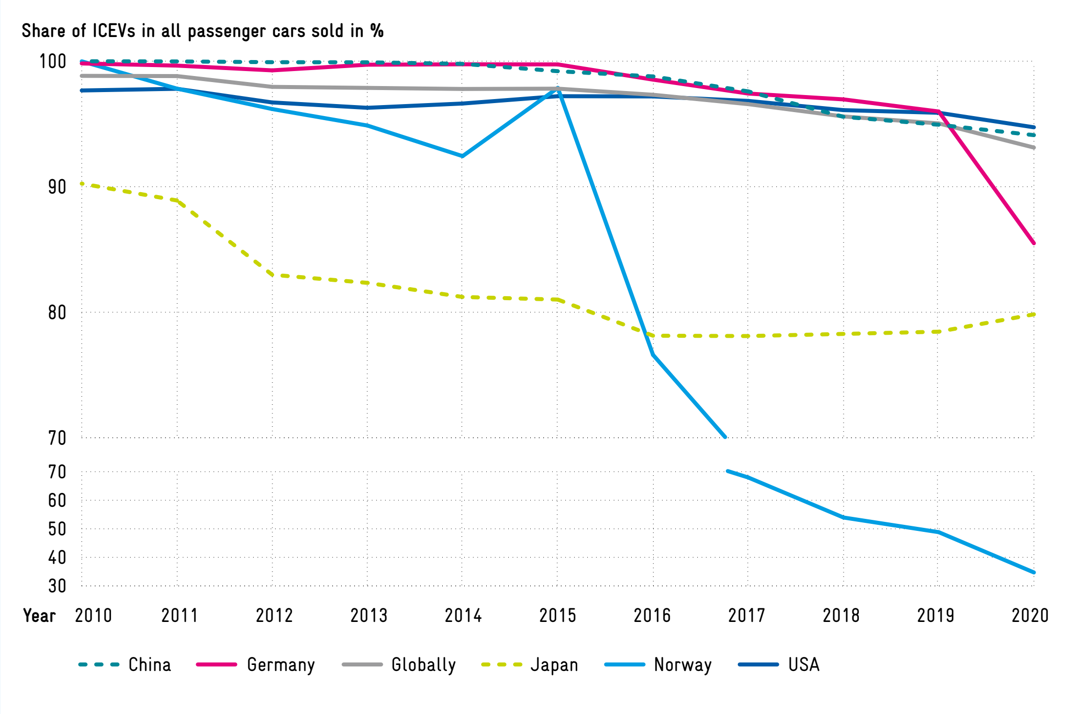
Change in Transport-related Emissions Due to Automated Driving

Advances in automated driving can contribute to a change in transport-related GHG emissions on two levels: gains in efficiency at the vehicle level (primary effects) and induced changes in mobility behaviour at the level of road users (secondary effects).

The main drivers of the primary effects, which increase with increasing degrees of vehicle automation, are harmonized driving characteristics, optimized engine control and the consideration of topography and traffic flow.[245] However, the efficiency gains through optimized driving behaviour are

Fig. B 2-10 Share of conventional and alternative drive systems in passenger car sales in selected countries and worldwide 2010–2020 in percent

a) ICEV



b) BEV

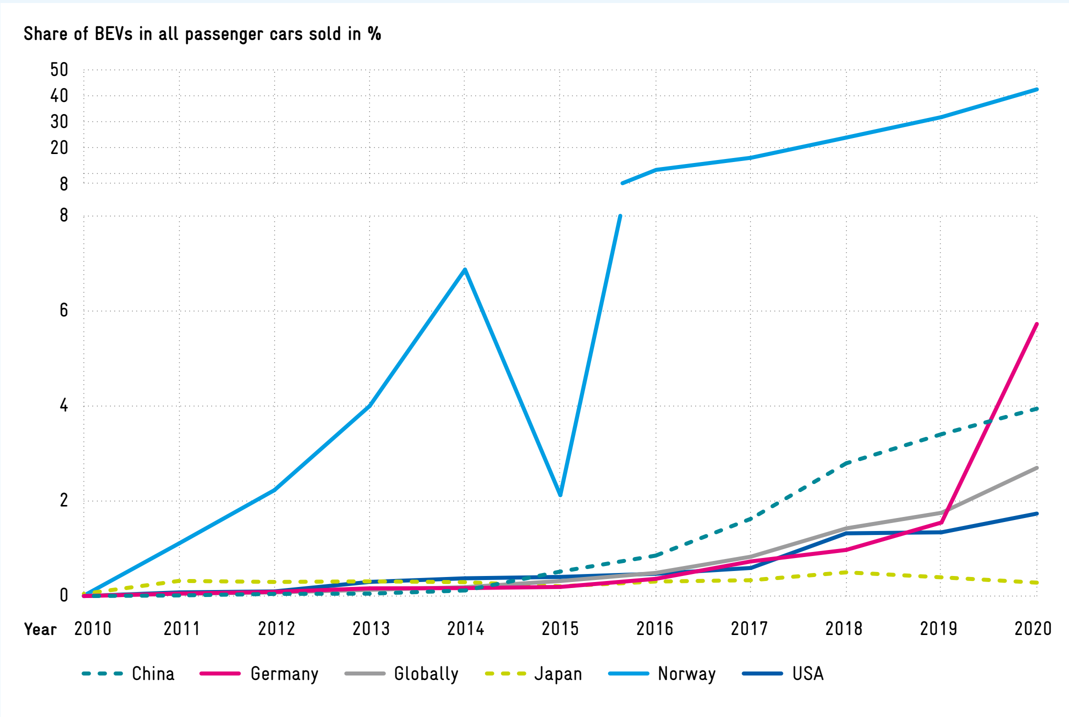
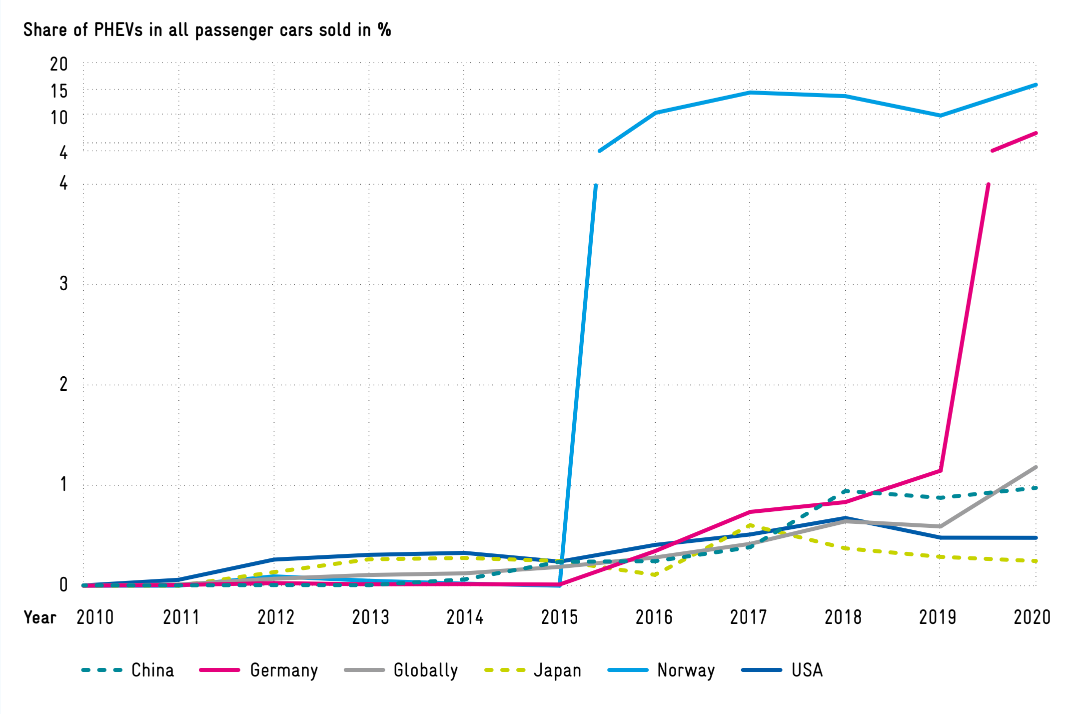


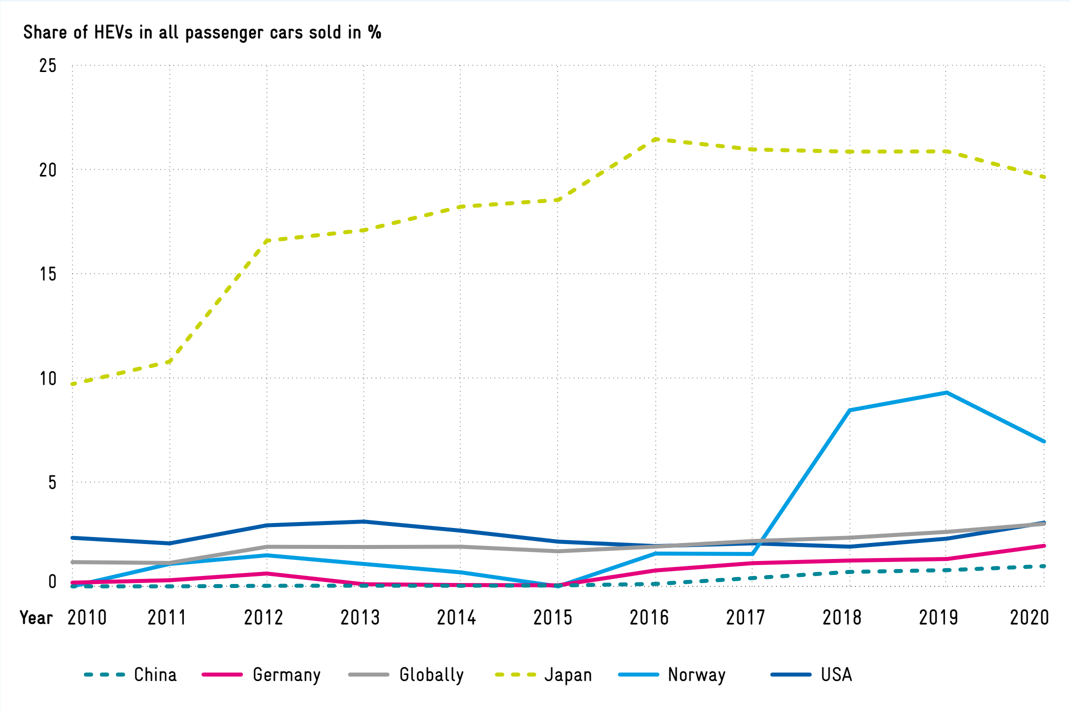
Fig. B 2-10 is continued on the following page.

Fig. B 2-10 Share of conventional and alternative drive systems in passenger car sales in selected countries and worldwide 2010–2020 in percent

c) PHEV



d) HEV



Source: Own representation based on Sievers and Grimm (2022).

partly offset by additional final energy consumption through networked automation systems, in the vehicles themselves as well as in mobile communications and in the digital infrastructure.[246]

Secondary effects arise because the efficiency and comfort benefits of automated vehicles change the relative attractiveness of transport modes. On the one hand, increased automation can lead to increased bundling of on-demand transport and thus lower mileage and GHG emissions. On the other hand, a growing share of private transport and the development of new user groups can lead to increased mileage of automated vehicles and thus increase emissions again, a so-called rebound effect.[247]

Traditional Automotive Nations Lead the Way in Automated Driving

In the period from 2005 to 2018[248] there was a significant increase in transnational patent applications in the field of automated driving (see figure B 2-11).[249] Initially, the development was driven primarily by patent applications in the field of assistance technologies, while in the further course patents on autonomous driving have become more important (see figure B 2-12). The increase in patent applications in the field of automated driving has been noticeable in Germany and Japan since 2008. In the USA, the development has only gained strong momentum since 2013. The USA and Germany have recently overtaken the previous leader Japan, with Germany only just behind the USA. China and South Korea follow at an already marked distance. However, five years earlier, both countries hardly played a role internationally in transnational patent applications in the field of automated driving and have quickly left France and the UK behind.

Development of Autonomous Driving in the USA Highly Dynamic

Germany was the international leader in transnational patent applications in the subfield of autonomous driving until around 2010 (see figure B 2-12). After that, however, the leading position was lost to the USA, which, after a highly dynamic development, recently filed the most patents in this field by a wide margin. It is true that the number of transnational patent applications from Germany in the field of autonomous driving more than trebled between 2014 and 2018, meaning that Germany has pulled clear of Japan and South Korea. However, in 2018, Germany filed less than half as many patent applications as the USA.

Automated and Autonomous Driving Supported

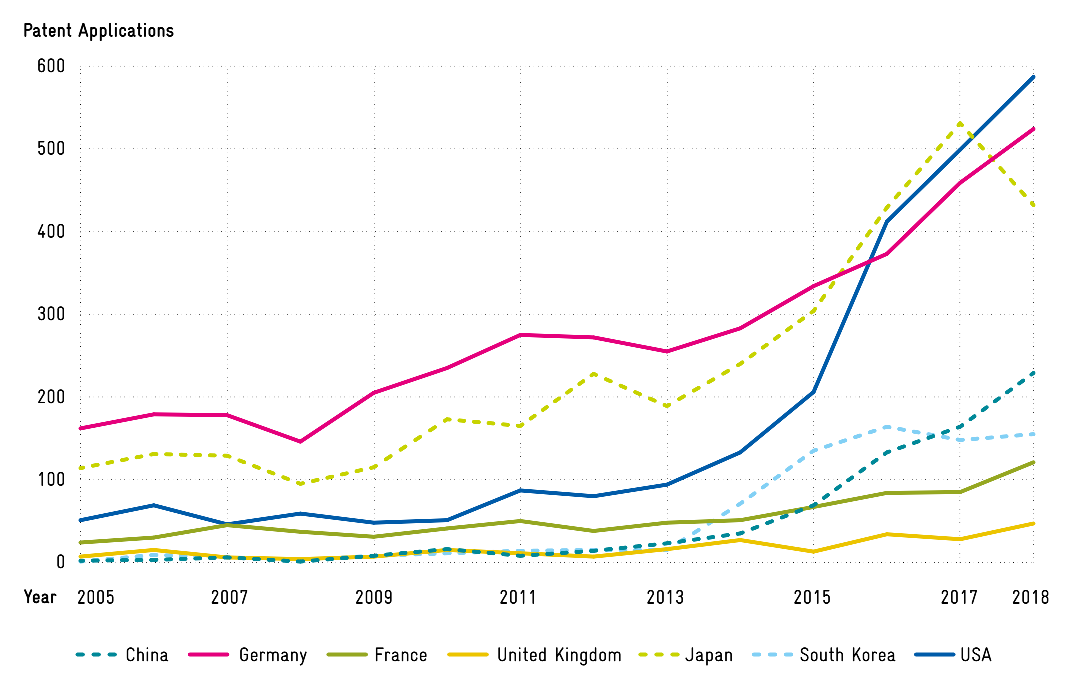
Innovations in the field of automated and autonomous driving are supported by a large number of support programmes, particularly at the federal level. The funding is concerted under the Federal Government's Strategy for Autonomous and Connected Driving (Strategie autonomes und vernetztes Fahren) implemented by the Federal Ministry of Transport and Digital Infrastructure (BMVI), which was launched back in 2015. The aim of the strategy is to make Germany the lead market and lead provider in automated and interconnected driving. To this end, among other things, the legal framework has been expanded, test fields for automated vehicles funded by the Federal Government and the Länder have been established[250] and R&D projects on both technical and social aspects of automated driving have been supported.[251]

To promote innovations in the field of autonomous driving, the BMVI has set up a funding guideline with a volume of €122 million in 2019 with the aim of further developing higher levels of automation up to autonomous driving and artificial intelligence in automobility. Since November 2021, the Federal Ministry of Education and Research (BMBF) has been funding software development for the digitalization of automobility with a total of €135 million, which also enables the further development of automated vehicles.[252]

German Legal Framework for Autonomous Driving Leads the Way

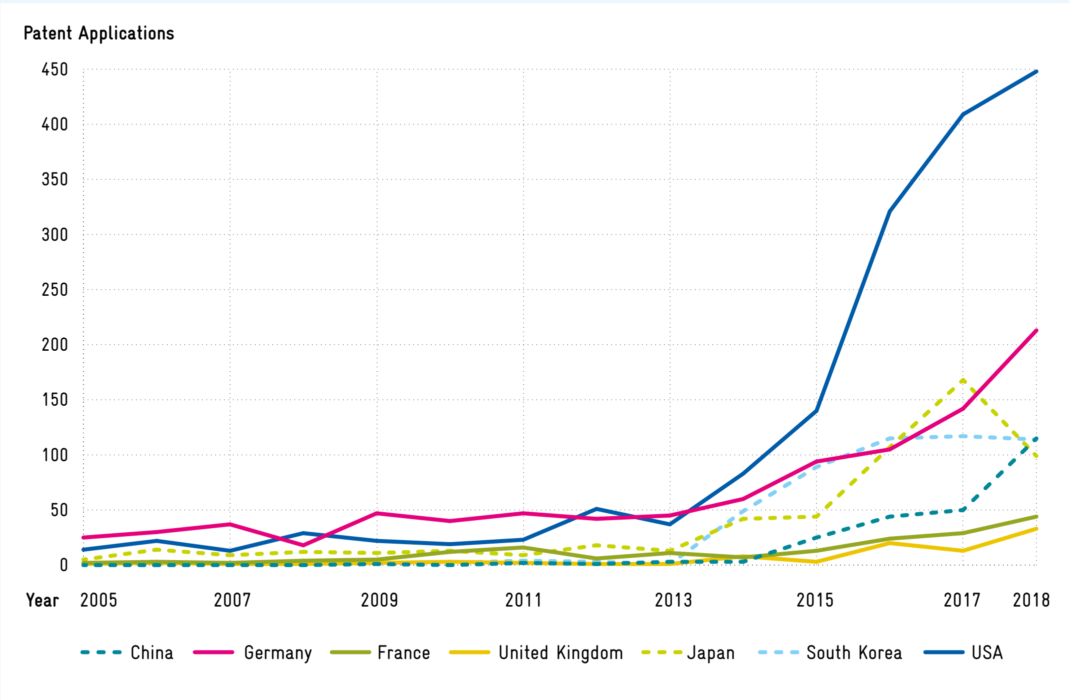
With the Act on Autonomous Driving (Gesetz zum autonomen Fahren), which came into force in July 2021, Germany is the first country in the world to have a legal basis for the regular operation of highly automated vehicles without a driver in specified operating areas.[253] This legal framework improves the conditions for the market launch of highly automated vehicles.[254] This puts Germany in a position to help shape the development of autonomous vehicle systems as a technology driver and to provide incentives for car manufacturers to develop such systems.[255]

Fig. B 2-11 Number of transnational patent applications in the field of automated driving in selected countries 2005–2018



Source: PATSTAT. Own representation based on Sievers and Grimm (2022).

Fig. B 2-12 Number of transnational patent applications in the field of autonomous driving in selected countries 2005–2018



Source: PATSTAT. Own representation based on Sievers and Grimm (2022).

B 2-4 Sharing Services in the German Mobility Landscape

GHG emission reductions can be achieved not only through new lower-emission vehicle technologies, but also through behavioural changes in the choice of transport modes. Although currently a good three quarters of all German households own their own car,[256] calls for a rethink towards sharing instead of owning, that is, the sharing of means of transport, are growing louder.[257] These demands are based on two facts: Private cars remain unused for most of the day, and the majority of car journeys involve the transport of only one person. At the same time, many people travel identical routes or sections of routes during peak traffic times, so it is obvious to share means of transport in order to conserve resources.

There are numerous business models that aim to improve the utilization of private cars. These include platform models that offer the coordination of shared journeys and carpooling.[258] In addition, sharing models have emerged in recent years that challenge the character of the car as a primarily individually used means of transport in private ownership. These include, above all, car sharing and ride pooling. Car sharing is the organized collective use of vehicles held by a provider who usually does not use them themselves and who has sole responsibility for the functioning of the vehicles.[259] Thus, car sharing is usually not the sharing of a commonly owned resource, but a commercial service offering in which the vehicles are available for sequential use by different people. Car sharing is now also offered by the major car rental companies and sometimes even by car manufacturers.[260] In addition, there is a range of usage subscriptions with terms ranging from a few hours to several months, creating a smooth transition from individual to shared use.

Ride pooling is a form of bundled transport, usually to transport several passengers flexibly between stops in an area as needed.[261, 262] Ride pooling is subject to the Passenger Transport Act (Personenbeförderungsgesetz, PBefG) and includes both bundled on-demand transport that is not part of local public transport and scheduled on-demand transport as part of local public transport.[263]

Density of Supply and Use of Sharing Services Still Low

In the case of car sharing, the supply in Germany currently reaches an average density of 33 vehicles per 100,000 inhabitants.[264] In the case of ride pooling, the average value is approximately one vehicle per 100,000 inhabitants. However, individual municipalities have much higher densities.[265] According to a representative survey in major German cities, car sharing was regularly used by 4 percent, but ride pooling by only 2 percent.[266]

Framework Conditions for Greater Use of Sharing Services

To clarify the extent to which politically adjustable factors can increase the use rates of car sharing and ride pooling and how a change in the use of these offers affects the structure of transport use, the Commission of Experts commissioned a simulation study.[267] Starting from the status quo, the effects of a combined change in the CO_2 price with an increase in fuel tax and subsidies for emission-free passenger cars were examined. In another scenario, the effects of an increase in parking fees and the parallel levying of tolls in the city area were analyzed. In addition, increased promotion of local public transport through the combination of higher frequency, a halving of transport fares and a reduction of waiting times was simulated.

Comparing these combined measures, raising the CO_2 price, fuel tax and subsidies for zero-emission cars causes the strongest increase in the usage shares of car sharing and ride pooling. A combination of these measures with higher parking and toll charges proves to be particularly effective. However, the effects of the examined instruments[268] remain very restrained overall. By 2030, usage shares of a maximum of 1.8 percent are expected for car sharing. For ride pooling, the usage shares are even lower, with a maximum of 0.3 percent. Both types of sharing services do not cover their costs, so they remain uneconomical without subsidies. All in all, car sharing and ride pooling do not appear to be in a position to establish themselves as alternatives to the use of one's own car in the foreseeable future. However, the expected growth in the use of car sharing and ride pooling is significantly higher in urban areas than in rural areas.

Ride pooling could be a cheaper alternative to existing local public transport services, especially in rural areas. The increased use of smaller, more flexible and better utilized vehicles could have positive environmental effects. Currently, a broader offer of ride pooling services still fails due to the high capital and personnel costs for additional vehicles.[269] However, personnel costs in particular could decrease significantly in the future due to new technologies such as autonomous driving, so that the profitability of the services would increase.

However, possible rebound effects must be taken into account.[270] It is to be expected that people who currently do not drive themselves at all or only rarely will make more frequent use of driving services by driverless vehicles if costs fall. Even though there are no studies on this yet due to a lack of data, it is known from other contexts that such rebound effects can be counteracted with suitable pricing, in this case a combination of CO_2 price and a road toll system.[271]

Unlike scheduled on-demand transport and taxi transport, bundled on-demand transport does not fall under local public transport according to the Passenger Transport Act (PBefG). It is therefore at a disadvantage compared to these. Journeys in bundled on-demand transport are subject to a VAT rate of 19 percent, while journeys in local public transport are only subject to 7 percent VAT. In addition, bundled on-demand transport can be partially restricted in operation by municipal control mechanisms.[272] This creates uncertainties for mobility service providers and inhibits the expansion of innovative ride pooling services.[273]

On a positive note, the new Passenger Transport Act (PBefG) regulates the collection of mobility data, which is to be available to both authorities and mobility service providers within the framework of the ‘Mobilithek’.[274, 275] This will enable the development of mobility concepts based on the networking of mobility data, such as intermodal route planning. However, a data interface with GAIA-X is not yet planned.

B 2-5 Recommendations for Action

The development towards sustainable motorized private transport is reliant on progress in lower-emission drive systems. The battery-powered car is proving to be the most ecologically and economically advantageous alternative. Accordingly, it is important to increase the use of this drive system in order to increase its attractiveness and acceptance as a result of network effects. In addition, developments in digitalization and autonomous driving open up opportunities for innovative mobility services in order to contribute to the reduction of emissions by bundling transport. The Commission of Experts therefore recommends the following measures to promote sustainable individual transport:

Setting Adequate Transport and Climate Policy Incentives and Increasing the Supply of CO_2-neutral Electricity

Since battery-powered electromobility for motorized private transport is currently emerging as both the most ecologically effective and the most economical of the lower-emission drive systems, its appeal should be increased compared to conventional internal combustion engines.

— To reduce the desirability of conventional internal combustion engines and at the same time give companies planning security with regard to the marketability of e-mobility and future developments of alternative drive systems, a sufficiently high CO_2 price should be implemented as quickly as possible by means of suitable measures (cf. chapter A 1).

— The Commission of Experts encourages the Federal Government to increase the supply of CO_2-neutral electricity, as intended in the coalition agreement, by expanding renewable electricity sources, among other things.

— To keep electricity prices low, electricity should be exempted from additional burdens without a steering effect, such as the EEG levy and the electricity tax.

Increasing Support for R&D on Sustainable Battery Technology and New Materials

— The current generation of batteries still entails considerable negative ecological effects in producing countries. The development of new types of batteries with a lower ecological footprint should be vigorously promoted.

- The new Federal Government should push for the establishment of corresponding environmental standards for imported batteries at the European level.

- Innovations and technological developments should continue to be promoted with regard to new materials, especially for weight reduction and resource-saving vehicle designs, in order to contribute to increasing battery ranges.

Expanding Public Charging Infrastructure and Establishing Transparency of Payment Systems

- In addition to the publicly funded expansion of the charging infrastructure, the Commission of Experts recommends that the Federal Government advocate transparent pricing structures at charging stations to promote the acceptance and market penetration of battery electric vehicles.

- Due to the high resource requirements of fuel cell passenger cars and due to expected technological innovations in the transport and storage of hydrogen, which may enable the use of existing infrastructure, there is currently no urgent need for action to expand the hydrogen filling station network for passenger cars with public funds.

Reforming the System of Purchase Premiums and Vehicle Taxation

In principle, purchase premiums are suitable for increasing the share of newly registered vehicles with alternative drive systems. However, stronger purchase incentives can be created through direct pricing of externalities and road use charges.

- The current purchase premium system should be phased out by 2025 as planned.

- Plug-in hybrids should be immediately excluded from purchase premiums, as they perform significantly worse in the life cycle assessments than battery electric vehicles.

- Pricing of CO_2 and other externalities should be achieved through a combination of a CO_2 price and a correspondingly adjusted petrol/diesel tax.

- The system of taxes and charges for road transport should be fundamentally reformed by replacing flat-rate vehicle taxes in the medium term with direct use charges, i. e. a comprehensive road toll system.

Improving Competitive Conditions for Bundled On-demand Transport

Various statutory regulations and ordinances have so far hampered the economic operation and development of innovative business models for bundled on-demand transport.

- Section 50 of the Passenger Transport Act (PBefG) should be reformed so that municipalities can exert less influence on bundled on-demand transport.

- Bundled on-demand transport and taxi services should be treated equally for tax purposes.