Electromobility – Fact check

Frequently asked questions

In view of global climate change and air pollution problems in cities, there is growing pressure for action to be taken to reduce transport emissions and end this sector's dependency on fossil fuels. Electric vehicles are a much-discussed option in this context.

But are electric vehicles the answer to transport-related environmental problems? Are they genuinely more climate-friendly than vehicles with an internal combustion engine? How much electricity will be needed for e-mobility in future? What are the alternatives? Are sufficient raw materials available for battery manufacture? Are e-vehicles popular with users? How does Germany compare with other countries, and what does this mean for the future of its car industry?

The Oeko-Institut's researchers have been addressing these and other e-mobility issues for many years within the framework of numerous national and international research and consultancy projects. On the following pages, the team of experts answers some of the important and frequently asked questions about e-mobility.

The questions – an overview

Why electromobility? An up-to-date assessment by the Oeko-Institut

Over the past 20 years, transport, in contrast to other sectors, has made no contribution to reducing greenhouse gas emissions in Germany. There is a risk that it will miss climate targets by a wide margin in the coming years as well. Against this backdrop – and with the added pressure of persistently high air pollutant emissions from conventional vehicles – electromobility is one of the most important options for reducing emissions and supporting the urgently needed switch to renewables in transport.

Electric vehicles are far more energy-efficient than vehicles powered by internal combustion engines. Even with the current energy mix in Germany, they already offer climate benefits, which will further increase as the energy transition (*Energiewende*) progresses. But this will not happen of its own accord: pro-active measures are still needed to expand the use of renewables. In order to meet the additional electricity demand from transport, further efforts must be made to increase energy efficiency outside the e-mobility sector as well. Alternative fuels in combination with internal combustion engines are only a long-term solution in sectors which offer no scope for vehicles to be powered directly by electricity, mainly aviation and shipping. It is not a sensible strategy to postpone the market launch of electric vehicles until they can run on 100% renewable energy. Bringing electric vehicles to market takes time, but electromobility can only make its much-needed contribution to climate change mitigation in the near future if the market scale-up happens soon.

The manufacture of e-vehicles is energy-intensive and absorbs additional resources. These resources will be available in sufficient quantities globally, so it will be possible to replace the conventional fleet with electric vehicles. Here too, the usual principle applies: compliance with environmental and social standards in the mining and processing of these resources is essential. Material efficiency and a comprehensive recycling system must be established at an early stage.

In Germany in particular, e-mobility is a key issue for car manufacturers and their suppliers. However, other markets and regions are currently in the driving seat. They see e-mobility as a major opportunity for their companies, actively aspire to technological leadership and are pressing ahead with transition. In view of the growing pressure in this highly dynamic world market, “business as usual” would be a high-risk strategy for stakeholders in Germany. They risk losing their scope to shape the transition and failing to forestall structural instability, i.e. uncontrolled systemic change on a wide scale. Against this background, it is important that policy-makers respond swiftly and put in place reliable long-term frameworks in order to facilitate an orderly exit from the old technology and a managed switch to the new, thus providing the stability that all stakeholders need for forward planning.

Nevertheless, simply switching to electric vehicles is not enough to ensure environmental sustainability in mobility. Although it will enable climate targets to be achieved, this technological change is not enough to cut air pollution or the consumption of land, energy and other resources. What is needed is comprehensive transport system transformation (*Verkehrswende*) which, in future, will enable people to travel shorter distances to their destinations, to benefit from safe and convenient bicycle, pedestrian or public transport, and to experience the public space not merely as a road or car park.

Electromobility is a key entry point into sustainable transport. However, it is important not to lose sight of other options for making mobility more attractive, green and sustainable.

1. Do electric vehicles, over their lifespan, have a smaller climate footprint than conventional cars?

E-vehicles already have a positive climate footprint, even when the manufacturing process and power generation are factored in. Technological advances and consistent progress on the energy transition will further amplify the benefits.

It is often suggested that energy-intensive manufacturing of e-vehicles produces higher emissions than the vehicles avoid when in use. It is true that the greenhouse gas emissions reductions achieved during their service life must be set against the additional emissions produced in manufacturing these vehicles, especially their batteries. Overall, however, the climate footprint of an electric vehicle is already much smaller than that of cars with internal combustion engines. This is shown by calculations produced using the "E-Mobility Calculator for commercial vehicle fleets" (available in English), created by the Oeko-Institut as part of the "ePowered Fleets Hamburg" (in German language) project. If a medium-sized diesel-powered vehicle with an expected service life of 180,000 km is replaced with a comparable electric vehicle, this cuts greenhouse gas emissions by around one third over its lifetime, amounting to 12 t CO_2eq.

The calculation was based on the German energy mix during the usage period, and the manufacture of the vehicle was factored in. The footprint takes into account the additional emissions from the manufacture of the e-vehicle, estimated at around five tonnes for a vehicle with battery capacity of roughly 35 kilowatt-hours (kWh), according to recent studies, although there are considerable uncertainties associated with this figure.

Pure electric vehicles, which are powered solely by batteries, perform better, in terms of their greenhouse gas emissions, than plug-in hybrids or e-vehicles with range extenders (small petrol-driven auxiliary power units). Even so, all these variants perform better than a diesel-powered vehicle. In order to protect the climate, these hybrids should achieve the highest possible share of electric driving. It is mainly the small and medium-sized e-vehicles which reduce the climate impact by around a third compared with their conventional counterparts. Bigger vehicles, which generally have very large battery capacities and a 300-400 km range, usually achieve around 10 per cent greenhouse gas reduction.

Over the coming years, the climate footprint of electric vehicles will continue to shrink. Firstly, the progress on the energy transition will lead to a higher renewables share in the energy mix, further reducing emissions during service life. And secondly, a reduction in CO_2 emissions can be expected in the manufacturing process as soon as a switch to mass production makes fabrication more efficient and if manufacturing countries make more intensive use of clean, green electricity by expanding their use of renewables.

Nevertheless, the right course should be set now in order to further increase the contribution to climate change mitigation. This can be achieved, for example, by aiming for and achieving the highest possible fleet share of highly efficient, appropriately sized battery electric vehicles (BEV). There also needs to be a reduction in the overall number of private cars, e.g. through car sharing schemes and a modal shift to public and non-motorised transport.

2. How does the energy transition in power generation affect the climate footprint of e-mobility, and how can users and manufacturers contribute?

As a result of Germany's Renewable Energy Sources Act (EEG), the share of the various renewables in power generation is increasing. The Act also safeguards the further expansion of renewable energies, which will boost the climate benefits associated with electric vehicles. Vehicle manufacturers, charging station operators and e-vehicle users can make their own individual contribution to the further expansion of renewables by investing in systems which are not currently supported under the Act – or by purchasing high-quality green electricity.

Electromobility is often understood as emissions-free driving. In reality, however, its climate footprint very much depends on the source of the electricity powering the vehicle; in other words, on the energy mix. In 2016, 32 per cent of Germany's electricity was generated from renewables. Under these conditions, e-vehicles already have a better climate footprint than cars with internal combustion engines, and a higher renewables share in power generation in future will improve it further. The Oeko-Institut's model analyses show that if conventional vehicles are replaced by e-vehicles, in 2030, each additional tonne of CO_2 produced in the electricity sector for the powering of e-mobility will be offset by two avoided tonnes of CO_2 in the transport sector, halving the CO_2 emissions produced during a vehicle's service life.

Policy frameworks play a key role in supporting the increase in the renewables share in power generation and boosting the climate benefits of electric vehicles. The German Renewable Energy Sources Act (EEG) has set a goal of generating 40-45 per cent of the electricity supply from solar, wind and hydro by 2025, with a target of 55-60 per cent by 2035. The Act is thus the key mechanism for increasing the climate benefit of electric vehicles. This is the conclusion drawn in the "Scientific Analysis and Dialogue Project: Guaranteeing the climate benefit of electromobility" (in German language).

If electricity demand increases – for example, due to rising demand from e-mobility – this will require more power to be generated from renewables in order to achieve the targets set. It does not matter, at first, who produces the power from renewable energy sources (RES). However, it is important, in terms of the credibility of electromobility as a climate change mitigation measure, that electric vehicle users, like all other electricity consumers, continue to contribute to the costs of the additional RE systems via the surcharge imposed in accordance with the Renewable Energy Sources Act (EEG surcharge).

Outside the EEG framework, vehicle manufacturers and charging station operators can also contribute to the expansion of renewables by investing in additional RE power generation facilities which do not receive financial support under the EEG. This increases RES power generation in Germany without recourse to funding under the Act. Furthermore, by purchasing green electricity, electric vehicle users can make their own contribution to the renewables expansion by initiating the installation of new systems, investing in roof-mounted solar, for example, or joining energy cooperatives. With green energy products, it is important to ensure that ambitious quality criteria provide a genuine impetus for the additional expansion of renewable energies. Many green power and electric traction products do not meet this criterion, merely causing renewable energies to be redistributed among electricity consumers.

Under present conditions in Germany, additional expansion of renewables outside the EEG framework means that less additional capacity will need to be installed with EEG funding to achieve policy goals. The relative target for renewables expansion will not increase. In this instance, the

EEG acts as a ceiling on the amount of electricity generated from renewables and on greenhouse gas emission reductions.

3. How much electricity will e-mobility need in future?

Today, e-mobility plays a relatively minor role in electricity demand. However, the intensive electrification of transport in future, which is the goal, will create substantial additional electricity demand, which must be met by increasing installed renewables capacity. A high proportion of battery electricity vehicles in the fleet would lead to annual demand of up to 100 terawatt-hours (TWh), equivalent to 20 per cent of Germany's current electricity consumption.

Electromobility is more energy-efficient than conventional vehicles powered by diesel or petrol engines, so switching to e-mobility would cut energy demand in the transport sector. This would substantially reduce fossil fuel use but drive up electricity demand.

In the short term, this is likely to have minimal impact on the electricity sector. Even if the German Government's goal of having six million electric vehicles in use by 2030 is achieved, the additional electricity demand will amount to less than 20 TWh per year– equivalent to roughly 4 per cent of Germany's total electricity consumption in 2014. This is shown in the Oeko-Institut's study "eMobil 2050 – Scenarios for possible contribution of electric mobility to long-term climate change mitigation" (in German language).

Ambitious long-term scenarios with electric vehicles accounting for more than 75 per cent of the total passenger car fleet show that passenger car e-mobility could increase electricity demand to 85-100 TWh per year – roughly equivalent to the amount of wind power generated in 2015 from 26,000 existing or approximately 10,000 new onshore wind turbines.

These figures show that over the long term, electromobility will have substantial impacts on power generation in Germany. It should therefore be factored into the costs of expanding power generation from renewables if it is to live up to its claim of providing emissions-free mobility. In addition to the projected 85-100 terawatt-hours per year, mentioned above, electricity demand of roughly 50 terawatt-hours per year will come from road haulage, based on an assumed substantial shift to the direct use of electricity for battery-powered and overhead cable trucks and delivery vehicles (see also Question 10).

The additional electricity demand from electromobility also has implications for the power distribution infrastructure. The project "Scientific Analysis and Dialogue Project: Guaranteeing the climate benefit of electromobility" (in German language) shows that the additional electricity demand resulting from an increase in the number of electric vehicles could potentially overload local distribution networks if e-vehicle charging takes place in an uncontrolled manner. Smart charging strategies, based on time-managed charging to match supply and demand, must be an integral part of e-mobility in future. New business models will also be developed to offer incentives to shift charging to certain times of day.

4. Which technical alternatives to e-mobility exist?

Sustainable synthetic fuels allow low-carbon operation of conventional vehicles; however, compared with e-mobility, they require a far greater expansion of renewables. In future, their use will only be viable from an energy economics perspective with a very high share of renewable energies, and only because there is currently no prospect of any alternatives for aviation and shipping in particular. The potential volume of sustainable synthetic fuels globally cannot be estimated at present.

In addition to electromobility, there are various other options for a low-emissions energy supply for transport, such as natural gas and biofuels. They produce lower greenhouse gas emissions than fossil fuels but reduce climate-damaging emissions by only a few per cent (natural gas) or – viewed globally – are only available in small and insufficient quantities and conflict with food security (biofuels).

Synthetic fuels based on RES electricity (power-to-X fuels) are another climate-friendly option being discussed. Here, RES electricity is converted into liquid or gaseous fuels. Examples are hydrogen from electrolysis, synthetic methane and synthetic liquid fuels, which are produced through a chemical reaction between hydrogen and carbon dioxide.

Battery-powered e-mobility has an advantage over synthetic fuels: there are minimal energy losses during charging and the utilisation of electricity in vehicles is highly efficient. The use of hydrogen in fuel cell vehicles requires at least double the amount of electricity. This is the conclusion drawn in the Oeko-Institut's working paper "Electricity-Based Fuels: A Comparison – Current Status and Long-Term Outlook" (in German language). Fuel cell vehicles are already associated with higher costs than battery electric vehicles and are only offered to a very limited extent by car manufacturers. A distribution and refuelling infrastructure for hydrogen vehicles would also have to be built from the ground up.

The advantage of synthetic methane and synthetic liquid fuels is that they can be used in conjunction with existing vehicle designs, and a well-established infrastructure is available. In terms of passenger kilometres travelled, however, their electricity consumption – based on currently available technologies – is at least five times higher than with battery electric vehicles. Powering road transport would thus require more electricity than is currently consumed by all of Germany's existing electricity customers combined, according to another project, "Renewbility III – Options for a Decarbonisation of the Transport Sector" (in German language). Direct use of electricity for these modes of transport is therefore the preferred option. The far higher electricity demand results, firstly, from losses in the chemical processes used to manufacture the fuels from electricity and carbon dioxide, and secondly, from the much lower efficiency of the internal combustion engine compared with electric vehicles.

Electricity-based synthetic fuels are often referred to as a climate-friendly option in connection with sector coupling of power and transport. Studies show, however, that the long-term storage of electricity in hydrogen is only viable from an energy economics perspective once high market shares are achieved for renewables. The energy needs of the transport sector also far exceed the amount of synthetic energy required for storage purposes. The use of sustainable synthetic fuels would thus require a major expansion of renewable electricity capacity.

Furthermore, production of these fuels is likely to take place at lower-cost locations outside Germany. Initial technical and economic analyses of the global potential of synthetic fuels exist, but as happened with the debate about biofuels some years ago, sustainability issues – such as the availability of land and water resources, social impacts and political stability at potential production sites – have rarely been considered. For that reason, it is not yet possible to assess the potential of sustainably produced synthetic fuels and their possible contribution to climate change mitigation on a global scale, as shown in the Oeko-Institut's presentation "Power-to-X – Electricity-Based Fuels as a Climate change mitigation Option in Road Haulage?" (in German language).

5. Is e-mobility enough to solve transport-related environmental problems?

Electromobility is a key measure for reducing transport-related greenhouse gas emissions. Other negative impacts of transport, such as non-energy resource consumption, noise pollution, land consumption and traffic-related deaths, require a more far-sighted rethink of the transport sector. In addition, even in the long term, electromobility is not a viable technical option in two significant transport segments: aviation and shipping.

According to recent analyses by Agora Energiewende, without additional policy measures, Germany will miss its climate target for 2020, with a projected 30-31 per cent reduction in greenhouse gas emissions compared with the 1990 baseline instead of the 40 per cent aimed for. Indeed, almost complete decarbonisation is required by 2050 in order to keep global warming below 2˚C or even 1.5˚C. The main area of concern is the transport sector, where greenhouse gas emissions have actually increased since 1990.

Electromobility is a key component of climate change mitigation in the transport sector and also provides a solution to inner-city air pollution. However, battery electric vehicles are not suitable for use everywhere, and although they are highly energy-efficient, they still consume renewable energies. What's more, different climate solutions are needed for international aviation and shipping, for example. Based on the current state of technological development, electromobility – based on direct inputs of electricity – is still a remote prospect for these segments.

So simply switching to more efficient electric vehicles will not ensure sustainability in the transport sector. Electromobility on its own will not reduce the increasing competition for urban land as parking space vs. public space. Noise pollution is decreased only in areas with speed restrictions, and the high demand for non-energy raw materials remains unchanged. Nor does electromobility bring the aim of the "Vision Zero" road safety strategy – to reduce traffic-related fatalities to zero – within closer reach.

In other words, besides progress on e-mobility, other approaches are needed, such as the compact city – or city of short distances – with improved shopping, infrastructure provision and leisure facilities, an attractive public transport system, a safe and extensive cycling and pedestrian network and good car sharing schemes. This would enable more people to manage without a car. Less parking would be required, freeing up land for cycle paths, green spaces and leisure amenities.

A shift towards better quality of life in inner cities may also have economic benefits, as the findings of the "Renewbility III – Options for a Decarbonisation of the Transport Sector" (in German language)project show. In the most ambitious scenario, passenger kilometres travelled by car decrease dramatically by 2050, with no need for radical restrictions on mobility. This is because changes in settlement structures would mean shorter distances to travel. There are also many attractive alternatives to passenger cars available, from public transport to cycles, e-bikes and sharing schemes. The Oeko-Institut's donation-funded project "City of the Future – Quality of Life in Inner Cities with Emissions-Free Transport" (in German language) identifies some of the far-sighted measures which enable cities to move towards sustainable transport. The expansion of public transport, cycling and walking, road safety training, traffic surveillance and parking management are just some of the measures which can increase urban quality of life for everyone.

And in other environmental sectors too – such as resource supply – a new mobility culture can have positive impacts.

6. Additional raw materials are used in the manufacture of electric cars – what is the situation with regard to their availability, recycling and substitution?

It is true that a rapid increase in demand may cause temporary shortages and drive up the costs of technology metals; however, no long-term resource scarcity is anticipated. Material efficiency, recycling and the substitution of raw materials are key strategies in resource use.

Compared with conventional vehicles, electric vehicles have a higher proportion of technology metals in their propulsion systems. Electric car batteries contain a number of these materials, notably lithium and cobalt, while the motors require rare earths. High demand is forecast for lithium in particular, but also for cobalt. In addition, lightweight materials are used in vehicle construction, including aluminium and carbon fibre reinforced polymer.

Temporary supply bottlenecks may occur if the quantities of raw materials – such as lithium – being extracted are insufficient to meet rising demand. This is shown in a study by the Oeko-Institut, which looked at a sustainable supply of raw materials for lithium-ion batteries (with an English summary) and was commissioned by Agora Verkehrswende. Nevertheless, sufficient resources will be available to meet growing demand for technology metals in the medium and long term. Innovative technologies which reduce specific and absolute resource demand are strategically significant, as is secondary material usage from recycling.

For example, recycling of rare earths from electric motors is feasible, as the research project "Recycling of Components and Strategic Metals from Electric Drive Motors (MORE)" (in German language) shows. The project focused on three recycling options: reuse of cleaned magnets, mechanical recycling of magnets for use in magnet production, and recovery of rare earths from used magnets. The pathways provided environmental benefits across all the categories studied, e.g. greenhouse gases, acidification potential and basic resource consumption.

Like the rare earths in electric motors, the key raw materials contained in lithium-ion batteries must be recovered through efficient recycling. Here, lithium, cobalt and nickel are the main focus of interest. Environmental audits conducted as part of two research projects – "Demonstration plant for a cost-neutral, resource-efficient processing of end-of-life lithium-ion batteries – EcoBatRec" and "Recycling of EV lithium-ion batteries" (LithoRec and LithoRec II) showed further potential for optimising the environmental performance of the recycling processes.

The recycling of electric vehicles should focus not only on batteries and electric motors but also on the power electronics, which contain precious metals. These raw materials should be recovered in specialist e-waste recycling plants, as the research project "Electric vehicle recycling 2020 – key component power electronics (ElmoReL 2020)" (in German language) showed. In the case of precious metals such as gold, silver and palladium, recovery rates of more than 90 per cent can be achieved if the relevant components pass through a fine sorting and separation stage first. This is evident from a comparison with conventional recycling using an auto shredder, which results in the loss of most of the precious metals (75 per cent and more).

Substitution can also ease the pressure on scarce resources. Substitution means the replacement of raw materials with others with similar properties. For example, neodymium-iron-boron permanent magnet motors can already be replaced by asynchronous motors, which are rare earth-free. This topic was investigated by the Oeko-Institut within the framework of the study "Substitution as a strategy for reducing the criticality of raw materials for environmental technologies (SubSKrit)" (in German language). Although substitutes already exist for rare earths in electric propulsion motors, a lithium-free battery for e-mobility is unlikely to be available in the foreseeable future. Lithium is therefore a particular focus of the current public debate about e-mobility.

7. Which environmental and social challenges are associated with resource extraction for e-mobility?

Environmental and social standards are not adhered to in resource extraction for e-mobility – and, indeed, for other applications – in a number of countries. International standards and compliance monitoring are therefore urgently required. The same applies, incidentally, to the extraction of fossil fuels such as coal and oil.

Even with optimum recycling systems and a high level of material efficiency, a significant share of raw materials for e-mobility will have to come from increased primary production.

Environmental damage in the primary extraction of these key resources tends to occur mainly at mining sites and is generally caused by poor environmental standards. It can include consumption of water resources, water pollution, tailing pond breaches, air and soil pollution and heavy metal contamination. A Policy Paper in English language produced for the international project "Strategic Dialogue on Sustainable Raw Materials for Europe (STRADE)" on the environmental impacts of primary production describes these risks in detail. Raw material extraction for e-mobility does not only focus on hard rock mining. Almost half of primary lithium production comes from salt lakes. One particular environmental risk associated with lithium extraction from salt lakes in South America is disruption of the hydrological balance in these already very arid areas.

Mining of rare earths has severe ecological impacts unless adequate precautions are taken to maintain high environmental standards. For example, rare earth deposits are almost always found in conjunction with significant radioactive materials, which become residual matter during processing. According to the Oeko-Institut's "Study on Rare Earths and Their Recycling" (in English language), mining of rare earths in China has already caused serious damage not only to the environment but also to the health of workers and local residents. Child labour and the financing of armed conflicts are some of the other negative socio-economic impacts potentially associated with the mining of metallic raw materials for electric vehicle construction or other applications, as described in another Policy Paper (in English language) produced within the STRADE project framework.

The example of cobalt can be used to illustrate that the extraction of raw materials which are not generally classed as conflict resources is also associated with environmental and social risks. The Democratic Republic of the Congo accounts for more than 50 per cent of global primary cobalt production. The political situation and weak governance in this country make it difficult to introduce core mining standards here. Some of the cobalt is produced by artisanal miners using simple non-industrial techniques. This informal production is often linked to child labour and poor working conditions.

Most of the cobalt is extracted as a by-product of industrial copper mining. These copper-cobalt deposits often contain minerals which form sulphuric acid on contact with air, releasing heavy metals which then leach into water resources.

In its own project "Germany 2049 – Transition to a sustainable use of raw materials" (in German language), the Oeko-Institut reveals how Germany's raw material footprint can be reduced, assigning a key role to transport. In its final report, the Oeko-Institut has crafted an agenda for achieving the raw material transition (*Rohstoffwende*) by 2049. The goal is to minimise the negative environmental and social impacts of demand for primary resources in Germany and worldwide.

8. Are electric vehicles accepted by users?

Most users are satisfied with their electric vehicles. There are complaints, however, about the lack of a public infrastructure for battery charging, the high costs and the limited choice of models. In general, concerns diminish substantially with familiarisation.

In extensive surveys conducted as part of the “ePowered Fleets Hamburg” project, the use of commercial e-vehicles received a positive response from the large majority of users and fleet managers. The vehicles scored particularly well on driving experience and comfort and on the key criteria of safety and reliability. According to respondents, it does not take long to acclimatise to an electric vehicle after switching. Fleet managers see one major advantage over conventional vehicles: e-vehicles require less maintenance. Indeed, according to a survey by the German Aerospace Centre (DLR), 97 per cent of private users are satisfied or very satisfied with their e-vehicle.

There are complaints, however, about the higher costs. The choice of e-vehicle models available on the market is also seen as inadequate; for example, there is a lack of transporters for commercial use and a limited choice of battery electric models in the mid- to high-end range. Most private users are looking for an all-round vehicle and are therefore concerned by the lack of estate cars and vans. However, the shortcomings of the public infrastructure for battery charging are seen as the main obstacle: although most drivers do not need to use it on a daily basis, it is seen as an important add-on. It is also noticeable that in the surveys conducted as part of the “ePowered Fleets Hamburg” project, drivers of electric vehicles regard the various potential obstacles as less important across the board, compared with people with no experience of e-mobility.

With certain groups of buyers who are interested in innovation and are environmentally aware, the existing disadvantages relating to cost, range and charging time are outweighed by the desire to make a positive contribution to mobility sector transition through their choice of vehicle. Indeed, when a new model by a US electric vehicle manufacturer was announced, hundreds of thousands of customers around the world said that they were willing to wait months for their vehicle and even to pay upfront.

The “ePowered Fleets Hamburg” (in German language) project found that a third of fleet managers surveyed would pay as much as an additional 10 per cent on the total costs of the vehicle over its lifespan compared with the costs of a vehicle with an internal combustion engine, and a further 26 per cent of fleet managers are willing to pay even more.

Incidentally, although Germany still has far fewer than 100,000 e-vehicles in its fleet despite subsidies of €3,000-4,000 being available to buyers, there is one major success story: even without government subsidies, the fleet of pedelecs (e-bikes) has grown to three million, amounting to 15 per cent of cycle purchases. E-bikes are not being purchased solely in lieu of conventional bicycles; they can also be used as a substitute for cars on commuter journeys and in urban goods transport.

9. When is an e-vehicle more economical than a vehicle with an internal combustion engine?

At present, electric vehicles are still more expensive to purchase – but cheaper to run – than comparable conventional vehicles. In terms of total costs, the balance sheet already favours e-vehicles in many cases – especially if they are used intensively.

As with many new technologies, e-vehicles are produced in small numbers at first, and this generates substantial additional costs by comparison with the mass market for conventional vehicles. However, it is already worth considering not just the vehicle purchase but the total costs of operation. For example, choosing a small electric vehicle from the current range can lead to a cost benefit of €2,500 after the eighth year of service life, mainly because the vehicle needs less maintenance and the running costs per kilometre are up to 65 per cent lower, according to the "Oeko-Institute's online calculator for private e-vehicles" (available in English).

In order to demonstrate the particular potential of e-vehicles for commercial use, the Oeko-Institut has published other online tools which allow comparison of individual vehicles (available in English) under various conditions and enable electromobility's fleet potential (in German language), including fleet optimisation, to be calculated and analysed.

The current additional costs of e-vehicles, as compared with vehicles with an internal combustion engine, are mainly due to battery costs. However, these costs have already fallen significantly in recent years, exceeding many expectations. A further substantial drop in the additional costs of electric vehicles is likely over the next few years.

The study on "The economic viability of electromobility in commercial applications" (in German language) looks at various vehicle types from urban buses to delivery vehicles, identifies potential areas of use and analyses a range of variables and factors influencing economic viability. For example, resale values, although hard to predict, are a major factor. Policy decisions, such as taxation of fossil fuels and the financing of renewables expansion, also influence the costs to the consumer.

In general, as with CO_2 emissions (see also Question 1), the more "fossil" kilometres are avoided through electric vehicle use, the smaller the costs of e-vehicles in comparison to conventional cars. High capacity utilisation – but also possible reductions in vehicle use through car sharing or smart fleet management – helps to drive down costs. In that respect, there is still major untapped potential, as the Oeko-Institut shows in the research on electric vehicle use in commercial fleets which accompanied the "ePowered Fleets Hamburg" (in German language) project.

10. Is e-mobility also an option for freight transport?

The expanding road freight transport sector urgently needs alternatives to diesel propulsion. In local transport, battery electric trucks and delivery vehicles appear to be a promising option. Alternatives are needed in long-distance transport due to its high energy demand. Overhead cable propulsion of trucks is a realistic option for the future. However, it is important not to lose sight of the need for a modal shift of freight from road to rail.

Road freight transport is continuously growing and is dominated by diesel. Climate-friendly alternatives need to be developed as a matter of urgency, for even with a strong modal shift to rail, which would be highly desirable in any case, a substantial proportion of goods will continue to be moved by road.

The use of electric vehicles in road freight transport is particularly promising due to the high number of kilometres travelled. However, it also poses major challenges. Delivery services, which are particularly affected by bans – currently under discussion – on diesel vehicles in inner-city low-emission zones, have recently become key drivers of electromobility. However, there is still a lack of series production vehicles from the large manufacturers in many cases. As a result, an electric delivery vehicle developed by a start-up caused a stir and was listed in the Top 10 price-subsidised e-vehicles in 2017.

In long-distance transport, however, range and load capacity pose particular challenges which, even in future, are unlikely to be met by electric vehicles powered purely by batteries. A promising technology for long-distance road haulage is the use of electric trucks powered by overhead cables that provide enough energy for long-haul highway journeys. The total costs to the economy of switching to carbon-neutral long-distance road haulage are lowest if sections of the highway network are electrified with the installation of overhead cables, enabling trucks to run on electricity, according to a study entitled "Determining an expert strategy for the energy supply of the transport sector up to 2050" (in German language). By contrast, the total costs of alternative scenarios based on regenerative hydrogen or synthetic fuels (power-to-gas, power-to-liquid) to 2050 are twice as high. The reason is that by comparison with fuel and electricity costs, the costs of setting up an overhead cable infrastructure, amounting to as much as 1.5 million euros per kilometre, play a minor role according to the overall analysis to 2050.

The German Government has recognised the potential of overhead power line technology. On behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), two sections of highway in Hesse and Schleswig-Holstein are being electrified with a view to trialling the technology under real-world conditions from late 2018. A development strategy for the overhead power line system in Germany and possible market launch, business models and barriers to their introduction are currently being studied as part of the project "Valuation and implementation strategies for heavy duty vehicles powered by overhead lines" (in German language), led by the Oeko-Institut. This comprehensive study compares trucks powered by overhead cables and their associated infrastructure with other alternative propulsion technologies and also with diesel, focusing on costs, energy and resource consumption, and greenhouse gas emissions. The results are expected in early 2019.

While the prospect of highway electrification is exciting, it is important to bear in mind that rail is the simplest and most efficient form of e-mobility in the freight transport sector. However, further efforts are required to electrify the network: currently, only 60 per cent of Germany's rail network is equipped with overhead power lines. By contrast, frontrunner Switzerland's entire rail network runs on electricity.

11. What is the role of e-mobility in bus transport?

Electric buses still play a relatively minor role in Germany, but offer major potential, as the example of China impressively demonstrates. However, their rollout in Germany has so far failed due to operational problems and an inadequate supply of vehicles.

Of the 80,000 buses on Germany's roads, just over 100 are electric. However, e-mobility in the urban bus sector – especially in urban areas – has a vital role to play due to the high levels of air pollutants, such as nitrogen oxides, which currently exceed permissible limits. Long-distance buses, on the other hand, face similar challenges as road haulage, particularly with regard to range. Due to their specific characteristics, local public bus operations are suited to battery electric propulsion. In principle, on fixed route services, the power requirement can be accurately estimated based on predicted speed, additional consumption for amenities such as air conditioning, and available infrastructure for battery charging. Based on this information, the vehicle can then be individually configured.

However, the challenges – studied by the Oeko-Institut within the framework of the "Innovative and systematic strategies for more energy efficiency in local public transport" (in German language) project – are considerable: every day, buses need to cover distances exceeding 300 km in some cases and must provide a reliable service – including in winter, when heating can account for as much as 50 per cent of fuel consumption. In cities, there are often only a few hours available at night when vehicles can be charged at the depot. Furthermore, most of the vehicles currently available are still prototypes; some leading manufacturers do not yet supply electric buses. As a consequence, the costs of a battery electric bus are roughly 20 per cent higher than the costs of a diesel bus, partly because purchase costs are approximately twice as high, as the Oeko-Institut shows in the study "Economic viability of electromobility in commercial applications", commissioned by the German Federal Ministry for Economic Affairs and Energy (BMWi) (in German language).

Without generous subsidies, the scope for transport companies to electrify their fleets is therefore very limited, unless fares are increased at the same time. In addition, there are uncertainties regarding the question of which technical solutions will be adopted: charging with or without a cable, only at the depot or also in transit? Will there be a partial return of the classic trolley bus? Would it not be better to invest in trams?

Nevertheless, there are signs that the electric bus trend is picking up speed in Germany too. This is evident from an initiative, supported by the major transport companies, to promote the procurement of emissions-free vehicles and agree joint technical standards. Transport companies are investing in new electromobility-friendly depots, and battery manufacturers are expanding their capacity to mass-produce batteries for electric buses.

The example of China shows that with a high level of awareness of the air quality problem, combined with a consistent strategy and generous subsidies, electric buses can quickly emerge from their niche. According to figures from the International Organization of Motor Vehicle Manufacturers (OICA), there were already more than 300,000 electric buses on Chinese roads in 2016.

12. How progressive is the e-mobility development in Germany in comparison to the international situation?

When it comes to sales of e-vehicles, the German market is by no means a frontrunner. Other countries provide more support for e-mobility, impose more restrictions on drivers of conventional vehicles, set longer-term goals and, as a result, have already achieved higher market shares.

Even among European countries, Germany is not a frontrunner. In terms of the e-vehicle fleet share, new registrations and subsidies, countries such as Norway, the Netherlands and Austria are further ahead. This is evident from a Report by the European Environment Agency (EEA) based on studies by the Oeko-Institut (in English language). France and the United Kingdom too, both of them countries with a domestic automotive industry, have – in relative terms – higher subsidy and registration figures and recently made headlines when they announced plans to ban all new petrol and diesel cars and vans from 2040.

One success factor, in addition to financial support, appears to be the benefits for users of electric vehicles compared with other vehicle owners; for example, they are exempt from restrictions or charges applicable to vehicles with internal combustion engines (London), are permitted to use bus lanes (Oslo), enjoy free parking (some German cities) or are fast-tracked in the vehicle registration system (Beijing).

In addition, there is a growing awareness that vehicle manufacturers also benefit from stable conditions, such as quota systems, which are in place in many US states, planned in China and under discussion in the EU. However, the motives behind the measures to promote e-mobility are by no means purely ones of environmental policy. It is no secret that by regulating its domestic market, China is keen to build its manufacturers' capacities to operate globally as well.

It is not always a level playing field: unlike Germany, in countries such as Norway buyers must pay substantial import taxes and registration duties on vehicle purchases; exemption of those taxes and duties is only viable as an incentive scheme in such settings. Generous subsidies can also have unwanted effects: in the Netherlands, for example, there was a glut of plug-in hybrids which rarely ran on electricity, and subsidy scandals have been reported from China.

Nonetheless, stable frameworks and clear funding incentives can create a mass market. This has happened in Norway, for example, where in June 2017, electric vehicles (including non-plug-in hybrids) accounted for the majority of new registrations for the first time. A similar development can be observed in the bus sector in China (see also Question 11).

In the longer term, there is a risk that vehicle development and production will shift to locations with the highest demand. This could pose a threat to the German car industry in particular, unless Germany reverses the trend in vehicle sales soon.

13. What does the expansion of e-mobility mean for the future of the German car industry?

The German car industry is heavily dependent on exports, so it is particularly important for the future of the industry that it does not miss out on current trends. The setting of ambitious long-term frameworks can provide important impetus for innovation.

The possible impacts of e-mobility on the car industry are a contentious issue in public and academic debate. Sometimes, however, this does not tell the full story: for example, if the numbers of parts installed in electric motors and internal combustion engines are compared and presented as an indicator for job losses.

In fact, a car does not consist solely of the drive system, whose manufacture – according to Jörg Hofmann, chairman of the metal industry trade union IG Metall – occupies around 30 per cent of employees in the car industry. The rest – interior, infotainment, bodywork, electrics, safety features, etc. – will be affected to a very limited extent or not at all by a switch to a different type of powertrain. However, there may be an impact on employment due to the reduced need for maintenance and replacement parts, potentially resulting in job losses at car repair shops.

The impact of the market shift towards electric propulsion on employment in Germany will ultimately depend mainly on the extent to which the vehicles are developed and manufactured in Germany. The automotive industry currently faces a time of great uncertainty and upheaval. Disruptive technologies – in other words, innovations with the potential to supplant existing technologies – and business models, including new sharing concepts, new stakeholders and competitors, more intensive locational competition and possible leaps in productivity, all play a role here. Today's automotive industry is not yet fully aligned to global sustainability. This should be seen as both a challenge and an opportunity. Inaction and business as usual are not an option: the longer we wait, the wider the technology gap will become, increasing the risk of structural collapse later, with all its negative consequences. It is already clear that in some global markets, notably China, there is a growing emphasis on e-vehicles. If Germany's automotive industry misses out on this trend, jobs will be at risk.

What is needed, then, is an industrial strategy to actively manage the structural transition early on. Research, development and (higher) education focusing on new technologies must be strengthened to build skills for the future. In order to create the stability needed for forward planning and investment, but also to provide clear signals guiding investment into new infrastructures – particularly the charging infrastructure – early communication is recommended, and measures and clear criteria for the future must be established in law. For example, at EU level, there is already discussion of coupling CO_2 standards for new vehicles with an e-vehicles quota for the period from 2020.

The "Mobile Baden-Württemberg" (in German language) study, led by the Oeko-Institut, shows that even without the challenge of e-mobility, the German automotive industry faces a time of great uncertainty and upheaval, due to disruptive technologies and business models, new stakeholders and competitors, more intensive locational competition and possible leaps in productivity, etc. The employment effects will very much depend on how market and location shares evolve. A switch to e-mobility, then, does not have to mean a decrease in employment.

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