Low-Carbon Cars In Germany

A summary of socio-economic impacts

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Disclaimer

The stakeholders who contributed to this study shared the aim of establishing a constructive and transparent exchange of views on the technical, economic and environmental issues associated with the development of low-carbon technologies for cars. The objective was to evaluate the boundaries within which vehicle technologies can contribute to mitigating carbon emissions from cars in Germany. Each stakeholder contributed their knowledge and vision of these issues. The information and conclusions in this report represent these contributions, but should not be treated as binding on the companies and organisations involved.

Berlin, October 2017

Executive Summary

The German auto industry is a global leader in technology innovation and will continue to play a leading role in tackling climate change and urban air pollution. This project has confirmed that improving the efficiency of cars and deploying Zero Emissions Vehicles (ZEVs) can make a significant contribution to meeting Germany's ambitious CO_2 reduction target for transport in 2030 and towards 2050 and the Paris Agreement.

While this study has not analysed impacts on competitiveness, participants agreed that the German auto industry needs to remain at the cutting edge of innovation of low-carbon vehicle technologies in order to remain competitive during this transition.

The transition from petroleum-based energy sources to renewably sourced energy is good for Germany's economy and for net employment. Replacing imported oil with domestically-produced energy will keep many billions of euros recirculating in the German economy. The transition to these energy sources will also create new jobs, for example in manufacturing and installing the charging infrastructure, but will ultimately reduce jobs in manufacturing of combustion engines. Profound understanding of the changes to training and skillsets is needed to facilitate a just transition.

However, Germany is unlikely to achieve its ambitious CO_2 reduction target for transport in 2030 solely via changes to new vehicles. Sustainable low-carbon mobility needs a systemic approach, taking into account solutions and transport modes beyond the automotive sector. New technologies, such as low-carbon fuels, and digital innovations, like shared & connected mobility, will play a key role in this task. This means all solutions that can contribute to achieving the decarbonisation goals by 2050 should be considered, and they should be promoted where effective and efficient.

Total costs for motorists of owning ZEVs could converge, under certain scenarios, to that of combustion vehicles until 2030, and in some particular use-cases (e.g. taxis) will reach cost-parity even much earlier. To make the transition to low-carbon mobility successful, governments will need to encourage this convergence and should consult with industries and other stakeholders.

Charging infrastructure is a condition for a quick market uptake of EVs, and investment therefore needs to be accelerated. The implementation of a rapid charging infrastructure in Germany will cost several billion euros by 2030. A determined and joint effort of the industry, government and civil society is needed in order to deploy sufficient charging infrastructure. Timing, location, capability, interoperability and ease of use are key issues. Electricity grids will need to be reinforced and modernized as part of sector coupling, but these costs can potentially be reduced by implementing smart charging to moderate peak electricity demand.

The transition to low-carbon mobility causes a wide range of impacts to employment across several sectors. Employment in the automotive sector will remain stable until 2030 in our central scenario (where climate goals are met through a balanced mix of hybrids, plug-in vehicles and increasingly efficient ICEs). After 2030, the transition to e-mobility will increase employment in sectors such as construction and infrastructure, but will ultimately impact the whole automotive value chain. Predictions from 2030 onward face multiple challenges requiring profound analysis. The future location of battery manufacturing will have some impact on the economic outcome. If Germany wants to maximise the value from the transition to low-carbon mobility, it should seek to encourage domestic battery production by providing a supportive policy environment.

Introduction

During 2016, the German government set a target of reducing transport CO_2 emissions by 40-42% by 2030. At the same time, the European Union's "Strategy on Low Emissions Mobility" foresees a fundamental shift away from petroleum towards greener energy sources. And the Paris Agreement seeks to hold average global temperatures to well below 2 degrees Celsius. It is clear that change is coming.

It is inevitable that much of this change will be achieved via the adoption of new vehicle technologies. For Germany, an economy heavily invested in automotive production, such goals will have profound and far-reaching consequences. With this in mind, the European Climate Foundation (ECF) convened a project to examine the main social, environmental and economic impacts of a technology-led transition to low-carbon cars. While this study focuses on vehicle technologies, we also acknowledge that the transition to low-carbon mobility will also require many other solutions, such as low-carbon liquid fuels and greater use of shared mobility. Further research is needed to understand the full potential, especially for cutting-edge solutions such as e-fuels. To help inform the assumptions and review the emerging evidence, the ECF involved the following organisations:

- Germany's three largest car manufacturers; two international car manufacturers; and four suppliers from the automotive value chain.

- Three companies involved with the supply of energy and charging infrastructure in Germany.

- Germany's main auto workers union

- Three German NGOs for environmental and consumer protection

This expert panel met on six occasions to advise an analytical team, which was tasked with answering the following key questions:

- To what extent can clean car technologies contribute to meeting Germany's 40-42% transport CO_2 reduction goal by 2030?

- What is the range of possible impacts on consumers from changes to vehicle purchasing costs and overall vehicle running costs?

- How is Germany positioned to capture the value of future vehicle technologies, such as lightweight materials, and batteries?

- How much would Germany need to invest in charging infrastructure for the agreed vehicle technology scenarios, including reinforcing the electricity grid?

- What is the likely range of overall impacts on German GDP and employment?

It is also worth noting three potential impacts that this study has NOT attempted to quantify:

- It has not tried to measure the impact on the competitiveness of the German auto industry, either from outpacing or from lagging behind the global transition to clean mobility.

- It has not tried to measure changes to the number of cars that might result from potential changes in mobility patterns.

- And it does not provide a detailed analysis of the changes in employment within the automotive sector itself.

As such, the main result of this study is a broad overview of the likely impact of a structural change to German mobility whereby there is an increase in efficiency; a change in vehicle technologies and energy infrastructure for cars, and a shift from imported oil to domestically produced electricity and hydrogen.

Methodology

The modelling approach used in this project is described in detail in the technical report, and is summarised in Figure 1. An expert panel was convened to help construct a series of plausible technology deployment scenarios, considering historic evidence of diffusion rates for low-carbon technologies, as well as the range of existing projections for future technology diffusion. The panel also advised on the most relevant input data on mobility, vehicles, energy, infrastructure and economy. These are described in later chapters.

The agreed datasets were then fed into a stock model, which determined changes to Germany's overall stock of capital assets and energy consumption per sector on an annual basis under each of the scenarios. Finally, the outputs from the stock model were fed into the macro-economic model E3ME.

The E3ME model embodies two key strengths relevant to this project. The model's integrated treatment of the economy, the energy system and the environment enables it to capture two-way linkages and feedbacks between these components. Its high level of disaggregation enables relatively detailed analysis of sectoral effects. E3ME delivered outputs on changes to household budgets, the energy trade balance, consumption, GDP, employment, CO_2, NOx and particulates.

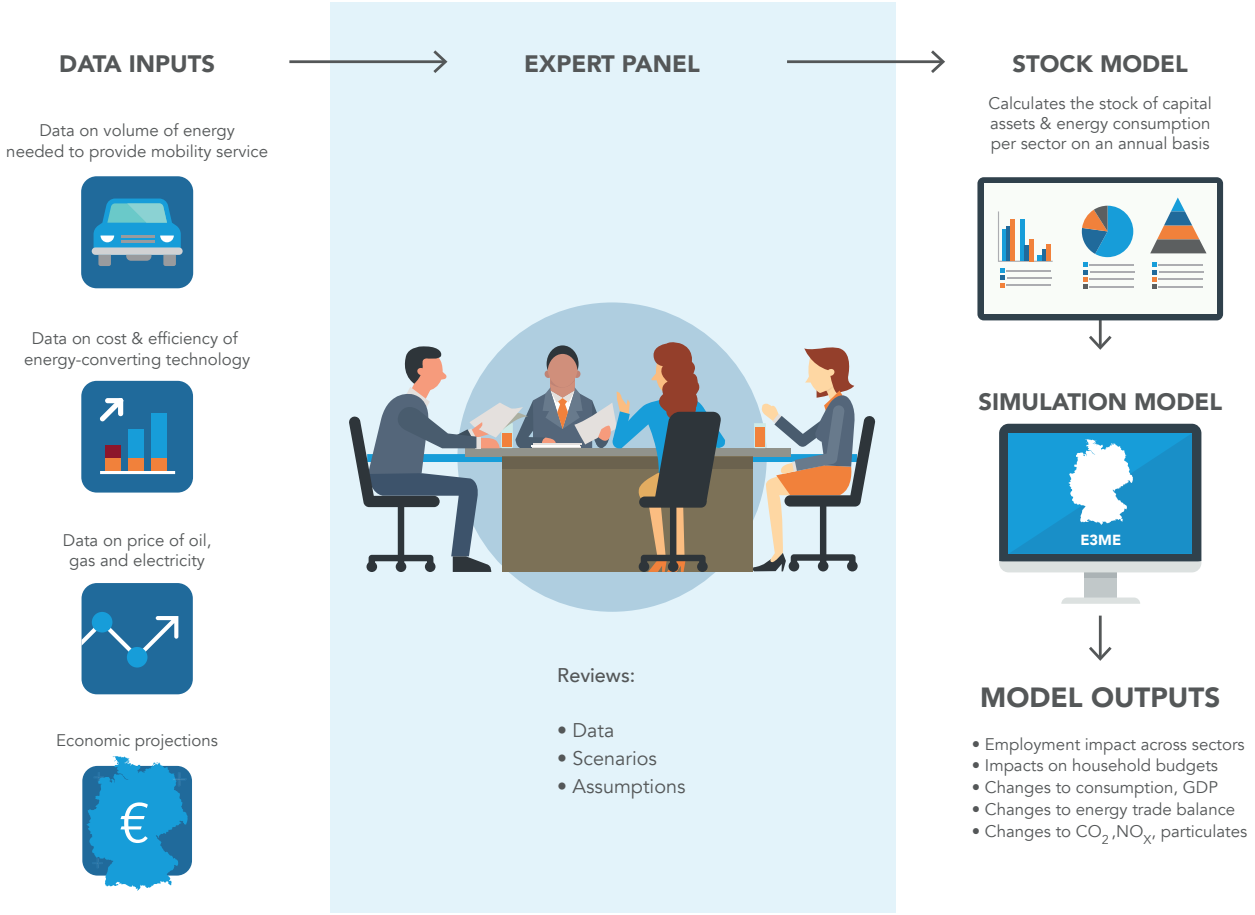


Figure 1. An overview of the modelling approach

Environmental Impacts

Question: *To what extent can clean car technologies contribute to meeting Germany's 40-42% CO2 reduction goal for transport?*

There is a wide range of uncertainty about future deployment of zero-emissions technologies, which will be impacted by changes to technology costs, energy costs, the level of taxes and incentives, and consumer preferences. However, this expert panel has agreed a central vehicle technology scenario that is considered plausible, achievable and broadly in line with the goals of the Paris Agreement, when combined with other measures to reduce transport CO_2.

In this central scenario TECH (Figure 2) the German car fleet changes from one that is dominated by diesel and gasoline vehicles in 2017 to one in which by 2030 nearly 40% of new cars sales are Zero Emissions Vehicles (namely plug-in hybrid electric vehicles, battery electric vehicles, fuel-cell electric vehicles) and the remainder are largely hybridised (both mild- and full-hybrids). The deployment of ZEVs is consistent with the range of previous forecasts and takes account of historical diffusion rates for new automotive technologies.

In our central TECH scenario, CO_2 emissions from cars are reduced from around 99 MT per annum in 2017 to about 12 MT per annum in 2050 (Figure 3). At the same time, a substantial co-benefit is achieved: Emissions of particulate matter from vehicle exhausts would be cut from around 5,000 tonnes per annum in 2017 to below 500 tonnes in 2050. This is achieved via a combination of increased efficiency and switching the energy source from diesel and gasoline to low-carbon electricity and hydrogen. While this trajectory achieves a very substantial reduction in CO_2 by 2050, it does not on its own achieve Germany's goal of reducing transport CO_2 by 40-42% by 2030.
One reason for this is that while there is a rapid

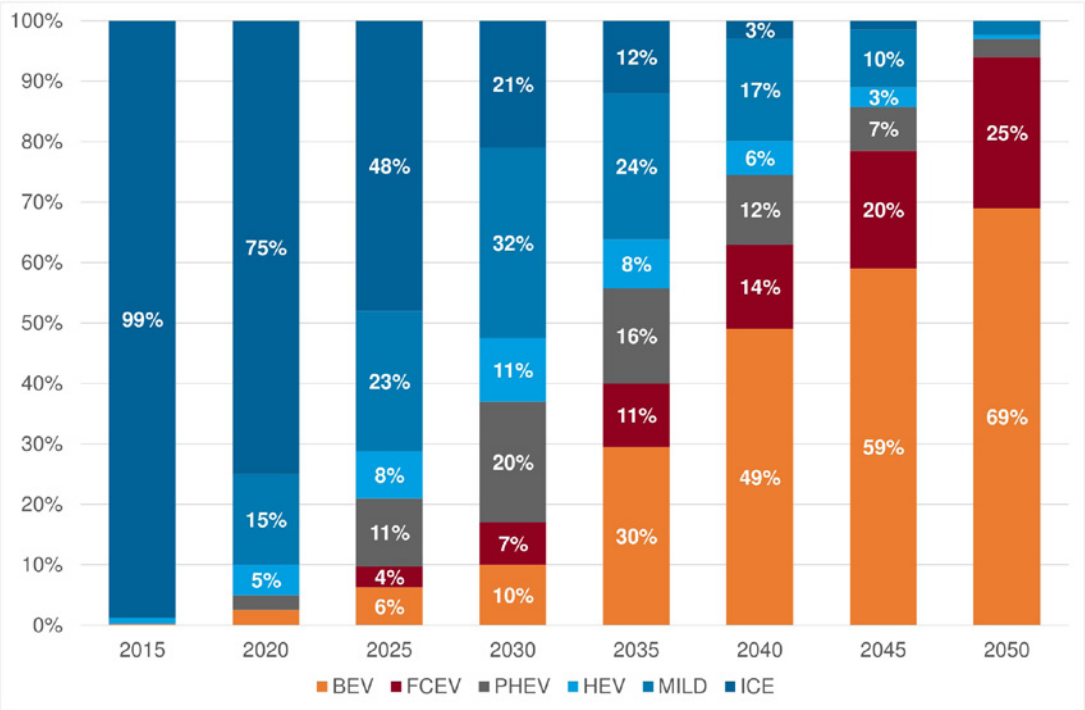


Figure 2. The central scenario for deployment of new vehicle technologies in new car sales represents an averaging of projections by the expert panel.

change to the technology mix in new vehicle sales, the technology mix in the overall fleet changes comparatively slowly. Vehicle lifetimes in Germany are around 15 years, and the average age of vehicles on the road today is 9 years. However, previous analysis undertaken for the ECF indicates that this scenario is capable of meeting the goals of the Paris Agreement if combined with a range of other measures to reduce transport CO_2, such as more efficient trucks and buses, advanced low-carbon fuels etc.

Various commentators have argued that diesel and gasoline engines should be eliminated from new car sales by 2030 to achieve environmental goals. In order to explore this issue further, a scenario was developed that reached 100% plug-in vehicles by that date. This scenario does achieve Germany's goal of decarbonising transport by 40-42% by 2030, without any other improvements to the mobility sector. However, it does also appear to be more challenging to implement than our central TECH scenario, both in terms of technology deployment rates and in terms of socio-economic impacts. Typically, low-carbon vehicle technologies have taken 15 years or more to diffuse (see Figure 7). The socio-economic implications are explored in later chapters.

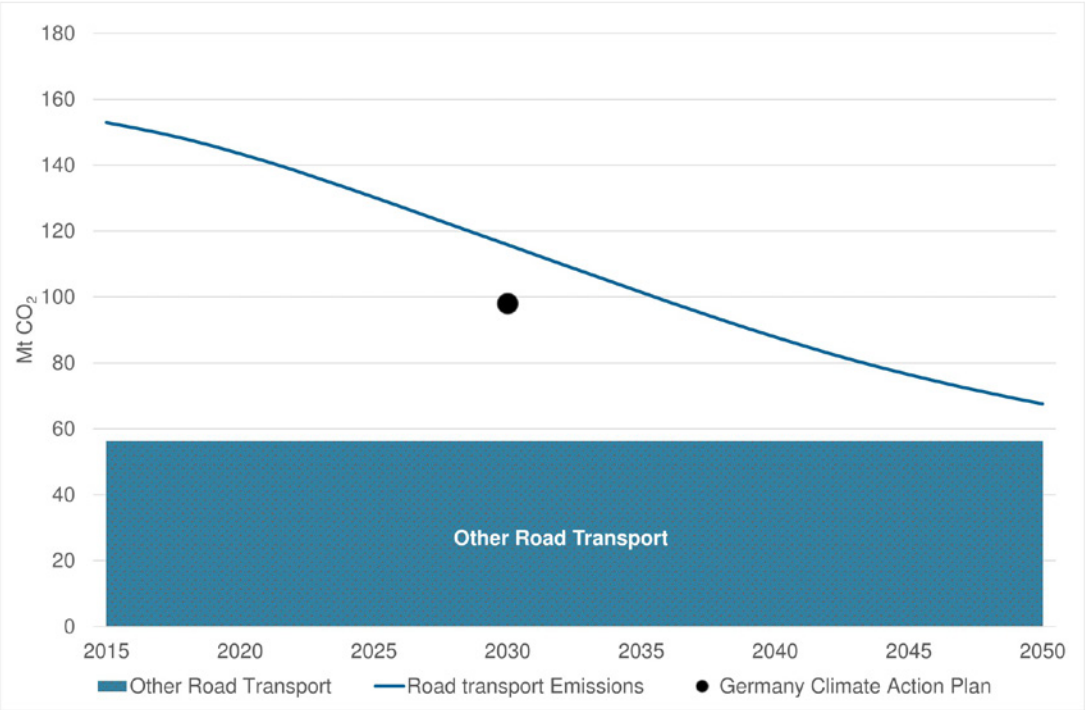


Figure 3. German road transport CO2 emissions in the TECH scenario

Consumer Impacts

Question: *What is the range of possible impacts on consumers from changes to vehicle purchasing costs; and overall vehicle running costs?*

There is a wide range of views on the cost of vehicle technologies to reduce CO_2 emissions. Projections of the cost of improving the efficiency of diesel and gasoline cars vary widely (Figure 4). At the top end of the range of estimates is work undertaken by IKA, while at the bottom of the range are estimates by the ICCT. A more central view is provided by Ricardo-AEA in analysis conducted for the European Commission in 2015.[1] We have chosen this Ricardo data for the central assumptions on vehicle technology costs in our analysis, but we have also tested the impact if costs turn out to be higher or lower, in line with the views of either the IKA or ICCT.

The modelling of battery electric systems takes into account the cost of cells, wiring harnesses, containers and management systems, as well as performance improvements over time. Our baseline estimates are higher than some bullish cost projections recently published. For example, our analysis is more conservative than GM's recent estimate that the Chevrolet Bolt battery is $145/kWh at the cell level or GM's roadmap projection of a cell cost of $100/kWh by 2022. We are also more conservative than recent estimates that battery packs from the Tesla Gigafactory could reach $125/kWh by 2020.

Fuel cell cost assumptions for fuel cell electric vehicles are based on discussions with car manufacturers and a review of published data (such as the US Department of Energy data). Costs are assumed to fall from the high values in today's low volume models to approximately

[1] "Improving understanding of technology and costs for CO2 reductions from cars, and LCVs in the period to 2030 and development of cost curves," 28 July 2015 draft version, Ricardo AEA (2015)

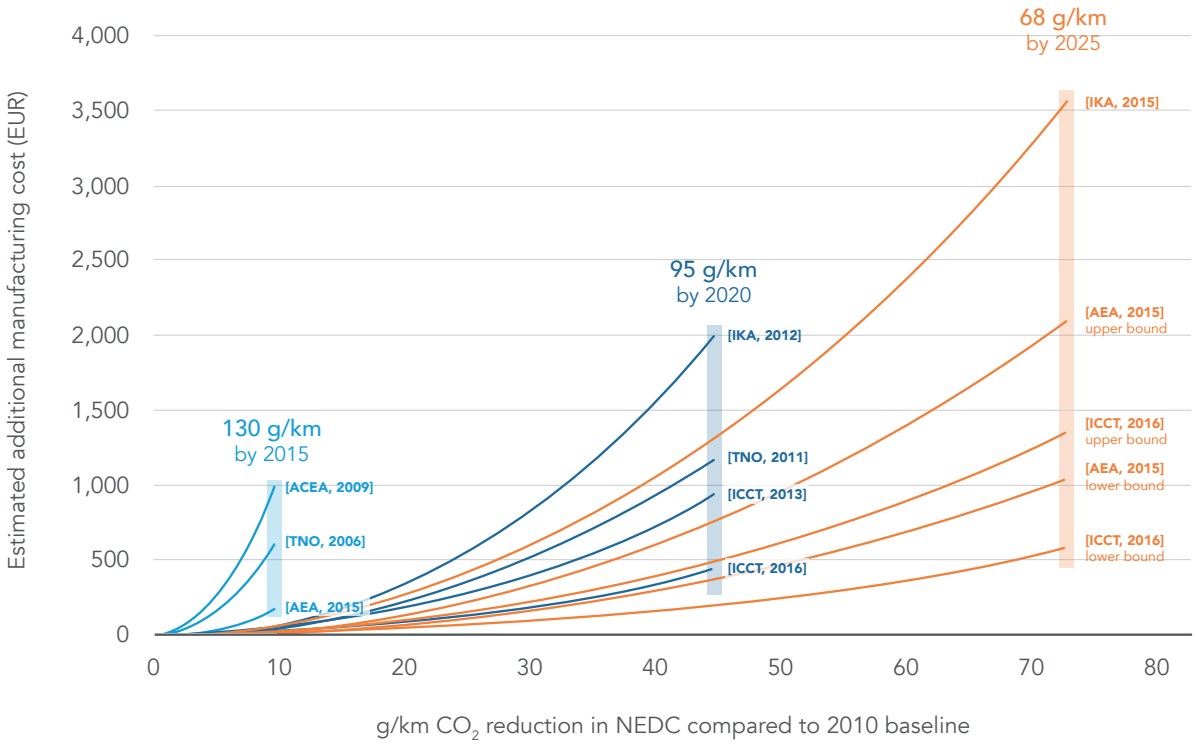


Figure 4. Cost estimates for technologies to reduce CO2 from gasoline and diesel engines

€100/kW in 2020, and €60/kW in 2030, subject to strong increases in production volumes to hundreds of thousands of systems per year per manufacturer. High- and low-cost scenarios have also been modeled.

The cost of technologies to reduce CO_2 from cars will reduce over time as scale economies are achieved, but the aggregate costs will increase as more technologies are added to reach tighter CO_2 limits. Figure 5 shows how vehicle purchase costs are likely to evolve in future to meet climate objectives in our TECH scenario. In 2020, battery-electric and fuel-cell electric vehicles are projected to be significantly more expensive than diesel and gasoline vehicles and their hybrid variants. But by 2030, the difference in price will be narrowed as diesel and gasoline cars get more expensive to meet environmental goals and as zero-emissions cars get cheaper as they start being manufactured at scale. In the German context, there is a convergence in costs in our central case, but not complete parity by 2030. Changes to the purchase costs are just one element of the overall impact on consumers. It is also important to look at the total cost of owning a vehicle for the first owner, whose purchasing decision will determine whether the low-carbon technologies enter the German vehicle fleet or not. To understand this requires that over the initial ownership period we also consider not only the purchase price, but also the costs of fuelling the vehicle, the financing costs, the charger cost if it is an electric vehicle, and the amount for which it can be resold at the end of the ownership period. Figure 6 shows this perspective over a 4-year ownership period, according to our central case.

The main finding is that by 2030 there is strong convergence in the cost of owning and running all types of vehicles in our central case, and this convergence is much stronger than for the purchase price alone. However, it is also notable that there is a relatively wide range between the most optimistic

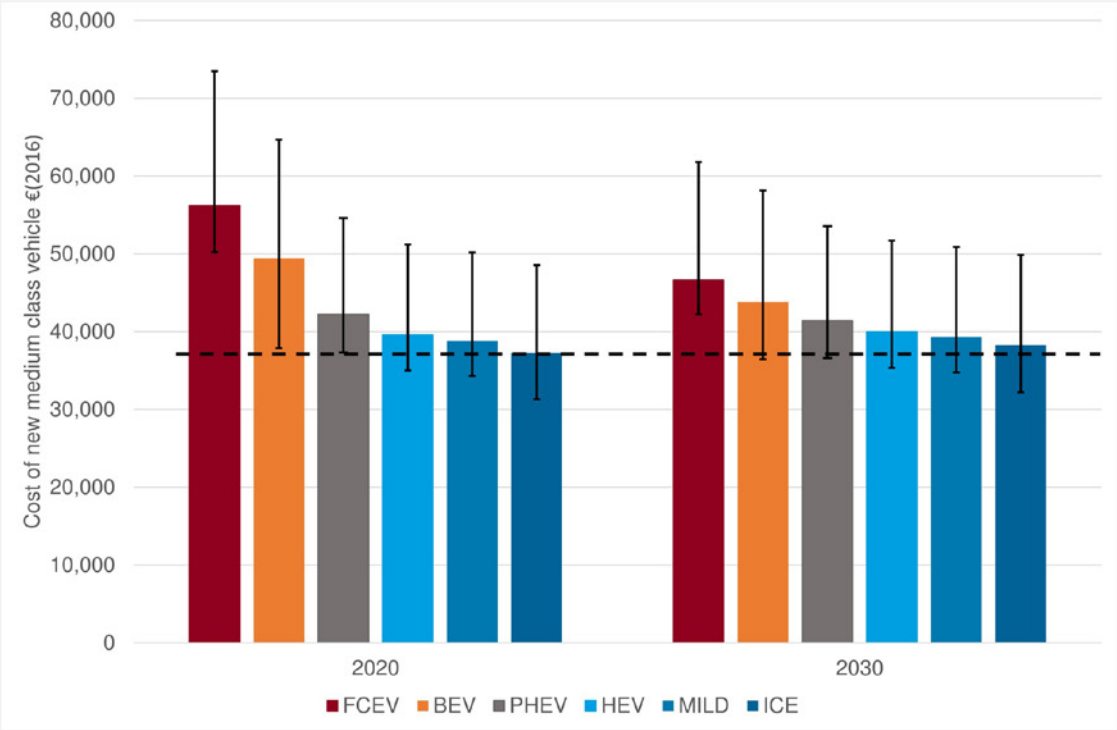


Figure 5. Aggregate capital and financing costs for mid-sized cars in the TECH scenario

and most pessimistic assumptions (high-case vs low-case). These high-case and low-case estimates reflect different projections of the cost of diesel, gasoline, electricity and the low-carbon vehicle technologies, as well as the cost of borrowing to buy the vehicles.

It is important to note how these uncertainties might impact on consumer adoption of different technologies. For example, if low-carbon technologies for petrol and diesel cars are at the high end of the range of uncertainty, and battery-electric cars turn out to be at the lower end of the range, then the transition might happen rapidly. By contrast, if innovation leads to cheap improvements to gasoline and diesel vehicles, but battery cost reductions turn out to be slower than currently forecast, this transition will prove more challenging. And while we have presented average values in Figure 6, it is often more relevant to focus on use cases. Some use cases, such as inner-city deliveries and taxis, will achieve cost parity between technologies comparatively early. Others, such as time-sensitive motorway driving (e.g. corporate executives), will achieve cost parity much later.

There is also uncertainty about how energy for mobility will be taxed in future. As government revenues from the taxation of diesel and gasoline are reduced, it seems plausible that the Treasury might look to tax other energy sources for mobility, most notably electricity and hydrogen. On the other hand, the German government has set an ambitious CO_2 reduction goal for the transport sector and German car manufacturers are investing heavily in ZEVs. It therefore seems unlikely that taxes will be set in such a way that significantly impedes the deployment of these technologies.

Taxation and incentives are important policy levers for achieving the low-carbon transition. Our analysis assumes that these are deployed effectively, such that the low-carbon technology scenarios are successfully achieved. At the same time, we acknowledge the current uncertainty and we highlight the importance of industry, government and civil society working together to find consensus on the optimal approach. This study has calculated that a road tax of around 2 cents per km would be needed to compensate for the loss of fuel duty revenues in the TECH scenario.

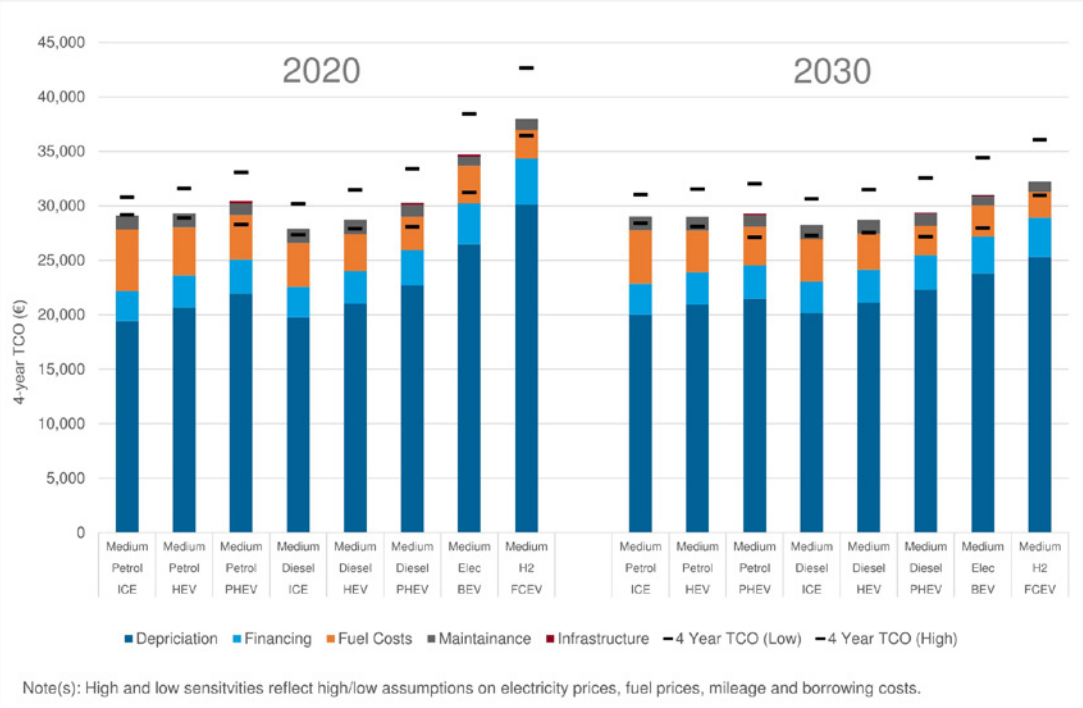


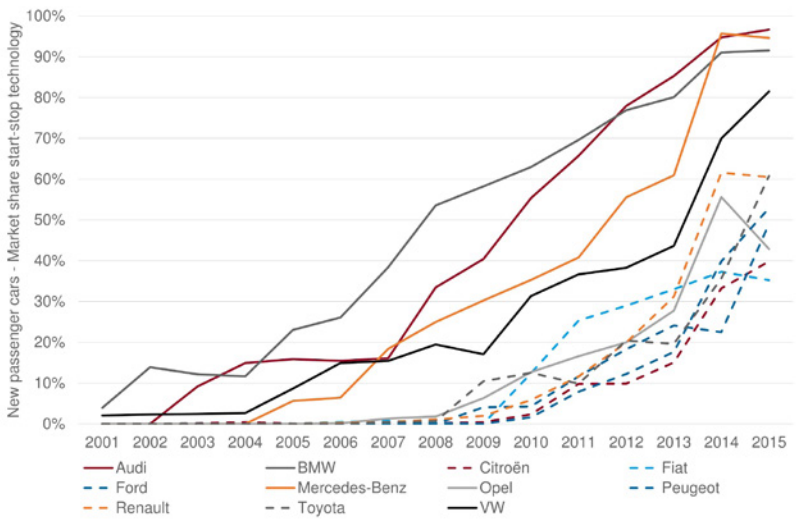
Figure 6.
Total cost of owning and running a mid-size car with various power trains in the TECH scenario in 2020 and 2030

New Value Chains

Question: *How is Germany positioned to capture the value of future vehicle technologies, such as lightweight materials, and batteries?*

Germany is a world leader in producing diesel and gasoline vehicles. Figure 7 shows how German companies led the charge towards stop-start systems and gasoline direct injection technologies due to their efficiency advantages. This is just one of many similar examples, and it thus seems plausible that German companies could compete effectively in the deployment of the next wave of fuel-efficient technologies, for example the 48V mild-hybrid system. This supports the assumption in this study that Germany's share of the market for technologies to improve diesel and gasoline engines remains unchanged in the period studied.

By contrast, one cannot automatically make the same assumption about Germany's share of the market for some of the entirely new technologies that will be needed during this transition. While German companies are well established in the production of electric motors, and several are involved at the cutting edge of fuel-cell development, there are questions about the future location of production of batteries and lightweight materials. For lithium-ion battery cells in particular,



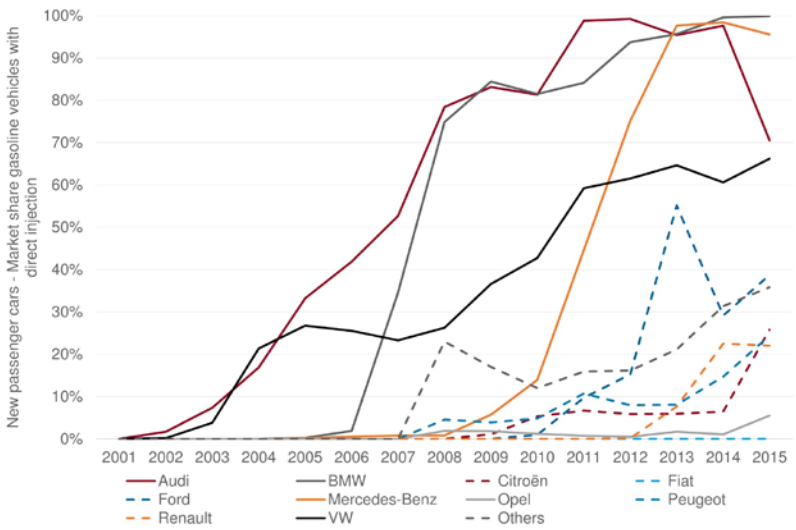


Figure 7. Diffusion of stop-start and gasoline direct injection technology by brand (source: ICCT)

Asian companies currently dominate the market. The future evolution of market share has important implications for the impact of this transition on jobs and growth in Germany.

In order to understand these issues more clearly, we examined the value chains for vehicle battery production and for lightweight materials. Lightweight materials are expected to be an increasingly important part of a transition to low-carbon mobility. Future car structures will have to be much lighter to compensate for the heavier drive trains in hybrid and fully electric vehicles. There will likely be multi-material designs, with aluminium, high strength steel, plastics, and carbon-fibre reinforced plastics, all likely to play a role. The Energiewende will ensure low-carbon electricity in Germany, which in future will help minimize the carbon footprint of lightweight materials. All these materials have a history of production in Germany. With batteries the challenges are greater.

The battery value chain can be disaggregated into various steps, the most important being cell production; assembling cells into battery packs; and assembling packs into modules and then integrating them into the vehicles. By examining the competitive strengths of German companies, we found they were relatively well placed to capture the value of these last 2 steps. However, cell production currently comprises around 60% of the overall value in a vehicle battery (Figure 8), and it is this area that is currently dominated by Asian producers.

We then looked at the potential for German companies to gain market share in cell production in the future. This depends on factors such as future labour costs and skillsets, energy costs, corporate tax rates, borrowing costs etc. The broad conclusion was that when it comes to current battery cell chemistries, incumbent cell producers in Asia have the advantage because they can cheaply expand existing production sites. Opportunities emerge for Germany, however, when a switch is made to new battery chemistries, if a supportive policy environment can be put in place. At this point, existing manufacturing sites can become more of a burden than an asset, and new market entrants might gain the competitive advantage, if they can bring a product to market at the required quality and price.

Given the uncertainty about future manufacturing of battery cells, we have had to model a range of possible futures: 1) 100% of battery cells are imported; 2) 100% of battery cells are produced in Germany; 3) 50% domestic and 50% imported. This last scenario forms the central case for our economic modelling.

The results of the modelling are presented later in this report (Figure 12), but for now it is sufficient to note that the location of battery cell manufacturing has some impact on Germany's GDP. If Germany wants to maximise the value from the transition to low-carbon mobility, it should seek to maximise domestic battery cell production by providing a supportive policy environment. However, the production of battery cells is highly automated, so the impact on employment from the location of cell manufacturing is less significant than the impact on GDP.

2014 Best-in-Class PHEV LIB Value Chain

	Raw materials	Processed Materials	Electrodes	Cells	Battery Pack	TOTAL
Share	N/A	29%	5%	26%	40%	100%
Currently Shipped	GLOBALLY	GLOBALLY	REGIONALLY	GLOBALLY	LOCALLY	
Success Factors	• **Indigenous resources** • Low export restrictions or limitations	• **Critical to quality** • **Demand assurance** • **Cost of capital** • **Production cost inputs**: e.g. regulatory, energy	• **Critical to quality** • **Processing know-how**: eg. coating thickness uniformity, solvent & moisture content	• **Critical to quality** • **Processing know-how**: eg. stack uniformity, drying, formation, electrolyte additive	• **End-product knowledge and integration know-how** • **Proximity to customers**: shipping costs, exchange of technical specifications	

Figure 8. A disaggregated view of the vehicle battery value chain

Infrastructure Costs

Question: *How much would Germany need to invest in charging infrastructure for the agreed vehicle technology scenarios, including reinforcing the electricity grid?*

To try to understand the infrastructure investment needs for this transition in Germany, we start by assuming that each EV sold has, on average, either a residential wall box or a workplace charging post installed. In addition, we have consulted widely with companies investing in this area and concluded that there will be roughly two public charging posts in urban areas for every 10 EVs on the road.

For rapid charging, there are two elements that impact the required number of charging points. The first is the minimum geographic coverage needed to provide full mobility to EV drivers on long journeys. For reference, there are 12,645 km of autobahn in Germany, and to provide rapid charging sites on each side of the autobahn, with a spacing of 50km, this implies that around 504 rapid charging sites are needed. This compares to approximately 390 motorway service areas in Germany today. In addition to motorways, there are approximately 40,000km of national roads, implying a need for approximately 800 sites at a spacing of 50km. On this basis we assume that around 1,300 rapid charging sites will be needed.

It should also be considered that the rapid charge network should also serve sufficient vehicles per day without unacceptably long queues. The details of our calculations are included in the technical report for this study, but in summary we assume that after an initial deployment of 1000 rapid charge points before 2020, the number of rapid charge points is in proportion to the number of battery electric vehicles in the fleet, with a ratio of approximately 200 battery electric vehicles per charging point. This takes into account peaks in traffic flows both during the day and in holiday versus non-holiday periods to avoid significant queues during peak times. It should be noted that these rapid charger assumptions are based on the arrival of relatively high range vehicle (300km and 500km for medium and large cars respectively), and the use of home or destination charging where possible in preference to en-route rapid charging.

Having calculated the infrastructure density required, we have multiplied this by the projected cost for installing each type of charger. The main finding is that up to around €8 billion of cumulative investment in EV charging infrastructure could be required in Germany by 2030 in our TECH scenario (Figure 9), although the figure might be lower if more efficient business models are found. Under the TECH RAPID scenario, where gasoline and diesel cars are phased out by 2030, this reaches €20 billion of cumulative investment.
Such numbers can appear prohibitively high, but to put them in context, Germany's new national infrastructure plan foresees €270 billion of investment by 2030. It is also notable that the German government's commitment to spending on charging infrastructure (the Ladeinfrastruktur project) falls short of the public infrastructure investment requirements in the long term under both the TECH and TECH RAPID scenarios.

Investments in hydrogen refuelling stations are based on the deployments announced by Hydrogen Mobility Germany, which expects 100 refuelling stations to be deployed by 2018, 400 before 2025 and c. 1000 by 2030 (subject to the speed of the vehicle rollout). The number of stations in 2040 and 2050 uses a similar ratio of vehicles to stations as 2030 and scales this in proportion to the fuel cell vehicle fleet.

Understanding the investment needs in infrastructure also requires an exploration of the upgrades that will be needed to the electricity system. Previous analysis has shown that there is a large difference between a situation in which EVs are charged immediately when they arrive at their destination and a situation where charging

is managed to avoid creating excessive loads on the system. If EV owners charge on arrival at home or at work (unmanaged charging), this would significantly increase evening electricity peak demand, resulting in increased network and generation capacity requirements, as well as high electricity production costs to meet the additional EV charging demand. On the other hand, smart charging strategies could largely avoid these impacts and enable EVs to deliver valuable services for balancing out variability in the electricity system.

The level of EV deployment in our TECH scenario is 5.7 million EVs in 2030, rising to 25.4 million in 2050. With unmanaged charging, this leads to an increase in peak demand of 5.5GW in 2030 and 21GW in 2050, which is significant compared to a typical system peak demand of approximately 65GW without EV charging.

Though there are costs to implementing smart charging, these can in theory be more than offset by the value created by connected EVs providing services to the network operator. Such services involve remotely switching EV charging on and off to help manage peaks and troughs in electricity supply, and to help maintain a stable frequency of electricity. These services will become increasingly important as Germany makes the transition to a renewables-led electricity system. It should also be noted that these services can be achieved through normal, uni-directional charging, and capturing many of the benefits does not necessarily need bi-directional "vehicle-to-grid" capability. The modelling shows that smart charging can largely prevent any increase in peak demand in 2030. By 2050, instead of an increase in peak demand of 21GW, smart charging can limit the increase to just 3GW. This has important implications for the cost of the electricity system.

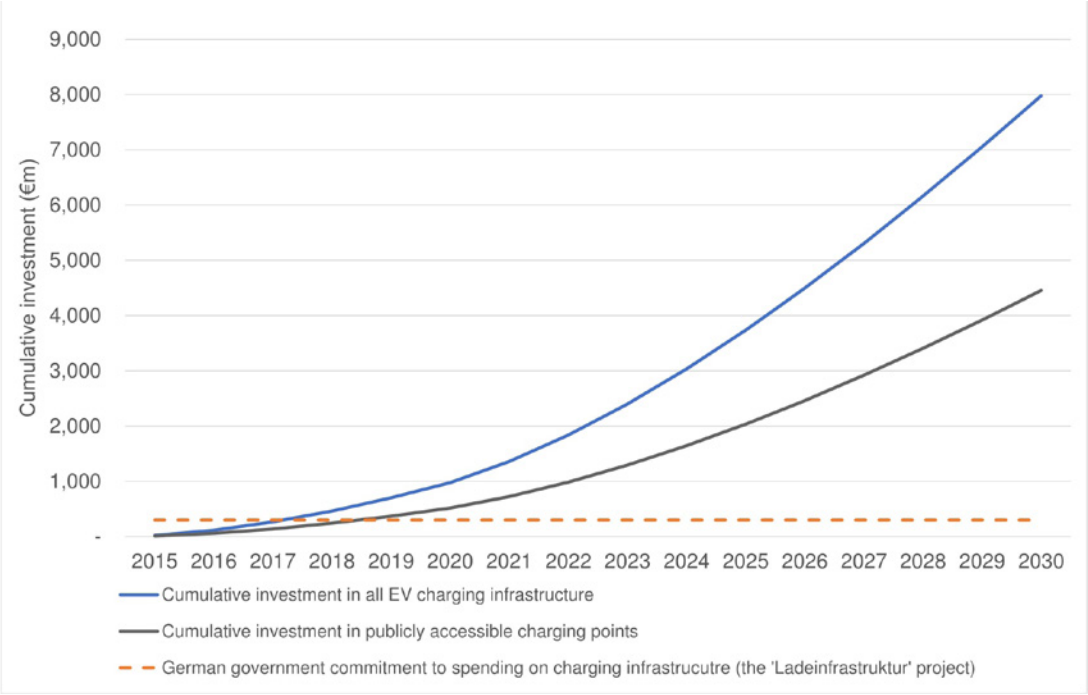


Figure 9. Cumulative investment needs for chargers to service the vehicle fleet defined by our TECH scenario

Infrastructure Costs

According to the analysis undertaken in this project, under an unmanaged approach to vehicle charging, Germany's grid operators would need to spend €350 million per year by 2030 to reinforce the network (Figure 10). By contrast, if uni-directional smart charging were implemented, the benefits provided to the grid would outweigh the costs of additional hardware, communications and telemetry, leading to a net benefit across the system of €140 million per year in 2030. By 2050, the net benefit of smart charging would be around €110 million per year, compared to an EV system cost of €1,350 million per year for unmanaged charging.

A note of caution should be made at this point, because the value of smart-charging can only be realised if EV owners can be convinced to hand over control of charging their vehicle to the grid operator. For that they will likely require some financial incentive. We can gain an indication of the size of financial incentive that is possible by calculating the value of smart charging on a per-vehicle basis. At the start of the transition, such services to the grid are scarce and this value can be worth several hundred euros per vehicle per year.

However the value is diluted over time as more EVs connect to the grid and start saturating demand for grid-balancing services. By 2030, the smart-charging benefits per EV would be around €100 per year, reducing to around €80 per year in 2050. In order to develop this opportunity, transaction costs will need to be kept to a minimum and therefore efficient commercial models will be vital. As Germany engages in this transition, further analysis and dialogue on the optimal approach to grid reinforcement would be beneficial.

Another solution for maximising this opportunity could be through bi-directional, or vehicle-to-grid, charging. This is because bi-directionally charged EVs are able to offer their full charge capacity for the duration of their available charge window, subject to the constraint of being fully charged at departure time. According to this analysis, a 3kW bi-directional charger could generate revenues of around €390 per electric vehicle per year, which after accounting for the costs would lead to a benefit of around €140 per vehicle per year. Higher charging power of 7-10 kW could create even greater opportunities.

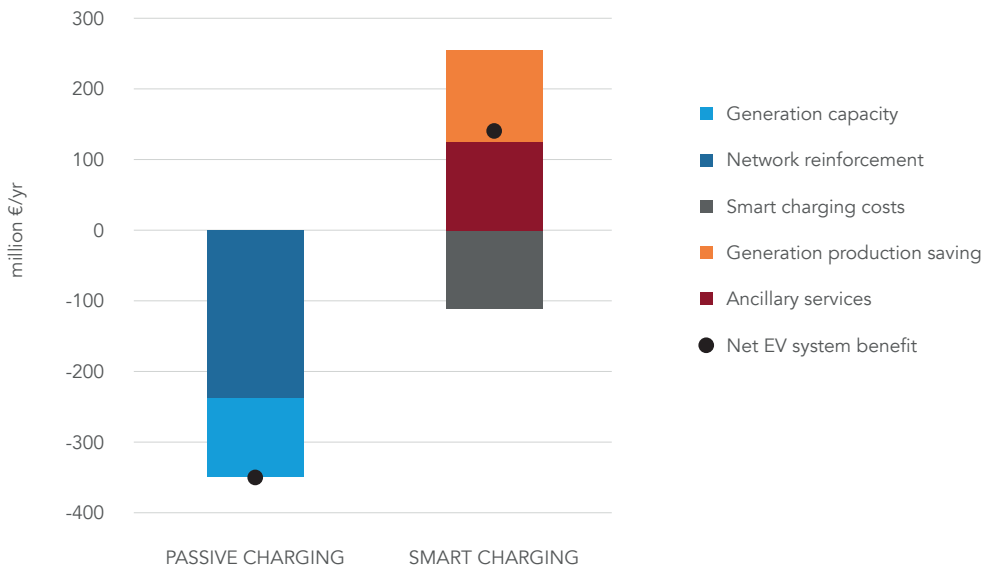


Figure 10. Investment needs for reinforcing the German electricity grid under both smart-charging and un-managed charging scenarios

Economic Impacts

Question: *What is the likely range of overall impacts on German GDP and employment?*

While there is uncertainty about many of the factors within this transition, we have tried to capture this uncertainty within the range of assumptions used for the macro-economic modelling. This has allowed us to identify the main shifts in value that would occur within the German economy during the transition to low-carbon mobility.

Firstly, the shift towards hybrids, plug-in hybrids and fuel-cell vehicles during the 2020s generates additional value for Germany, both from cars sold domestically and from exports to other countries pursuing the decarbonisation agenda. Investment in charging infrastructure also creates value. This is offset by the increasing penetration of battery-electric vehicles, which are likely to generate slightly less value for Germany than the petrol and diesel cars they replace, depending on the degree to which battery cells are imported.

Secondly, the shift away from petroleum, which is imported from outside Germany, towards electricity and hydrogen, which are largely produced domestically, means that Germany captures a greater share of the value from energy used in mobility. Figure 11 shows the evolution of energy use in the TECH scenario. Petrol and diesel consumption is strongly reduced during the 2020s as a result of existing EU CO_2 standards, and after that as a result of anticipated climate policies to meet the Paris Agreement, as foreseen in our TECH scenario.

The third main economic impact is that the vehicle fleet becomes increasingly efficient, due to more hybrids, and because electric motors are inherently efficient in their own right. This occurs both as a result of existing climate policies (CPI scenario), and as a result of increasing electrification and hybridisation to meet future climate policy goals. This leads to lower mobility costs for German households, allowing them to shift their spending away from mobility budgets towards other areas that typically have more domestic value-added.

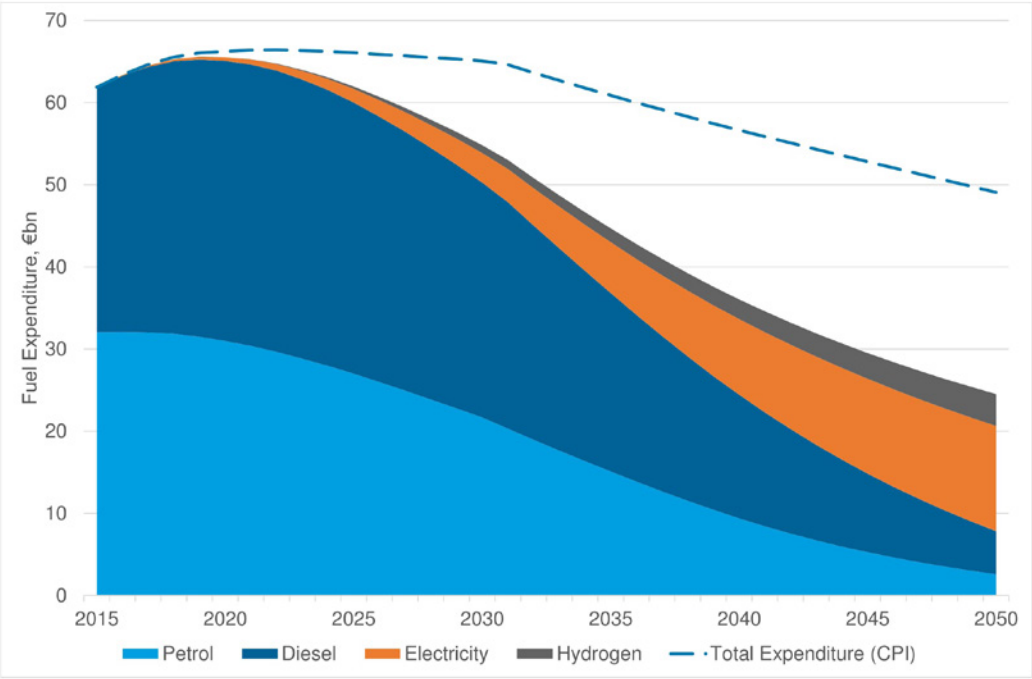


Figure 11.
Energy expenditure for mobility under our TECH scenario

Using the macro-economic model E3ME, we have measured the net economic impact of this transition, compared to a reference case in which cars remain unchanged from today. The economic impact is sensitive to the location where battery cells are produced in future, as shown in Figure 12. It is also sensitive to changes in the future oil price, because this alters how much the avoided spending on oil imports is worth.

It is also logical that a global transition away from oil will lead to lower oil prices globally, and thus oil prices will be higher in a high-carbon world than in a low-carbon world. This would increase the value that Germany could capture by switching from imported oil to domestic energy sources. Thus, a global transition to a low-carbon economy, as foreseen in the Paris Agreement, delivers a greater GDP benefit for Germany than a national transition. This is also reflected in Figure 12. Overall, there is a net increase in German GDP as a result of making the fleet of cars more efficient to meet current climate policy goals, equivalent to an additional 0.4% of total GDP in 2030 (CPI vs REF). Further innovation to meet future climate goals would start to further increase national GDP after 2025, equivalent to a further 0.1-0.2% of GDP in 2030 (TECH vs CPI), depending on the assumptions used. The GDP impact is greater if we assume climate policies are implemented globally, leading to lower global oil prices than in the Reference case.

The impact on employment, while linked to the overall economic impact, is somewhat different. To measure the impact on employment, we also need to take account of the different employment intensities in the various sectors that are affected. There is a trend for increasing automation of the auto industry, leading to lower jobs overall, regardless of the low-carbon transition. Building battery-electric vehicles is expected to be less labour-intensive than building the gasoline and diesel vehicles they will replace. Meanwhile, building hybrids and plug-in hybrids is expected to be more labour intensive. Our modelling shows

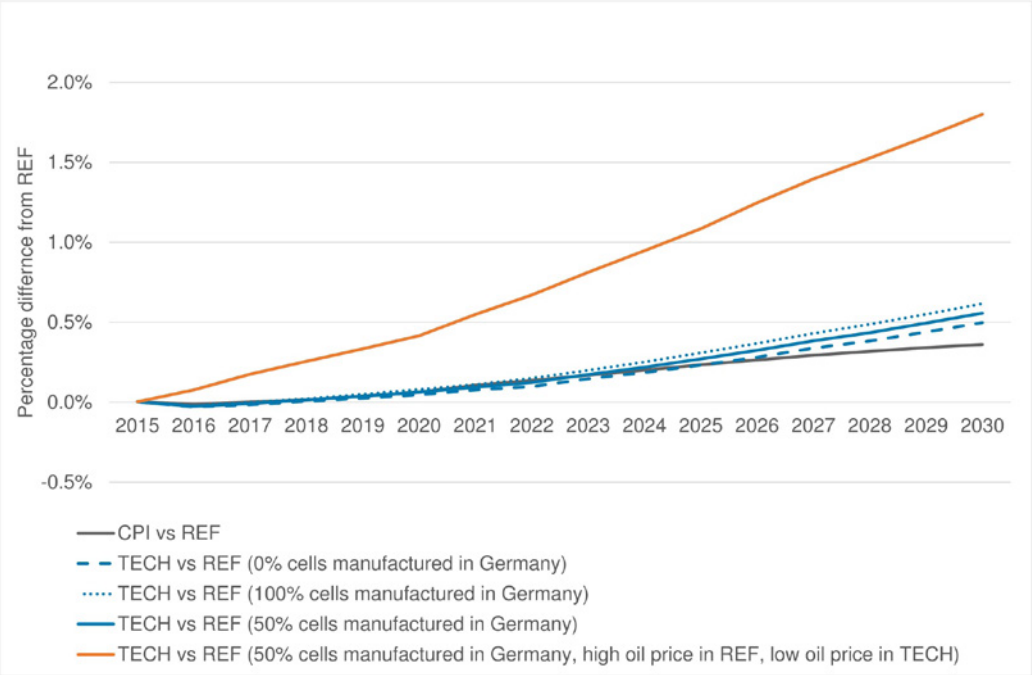


Figure 12.
The impact on Germany's GDP of a transition to low-carbon cars

that the net employment impact for the auto sector from this transition will depend on the balance achieved between these various technologies, and the degree to which they are imported or produced in Germany.

Figure 13 shows the evolution of jobs in Germany as a result of the transition to low-carbon cars in 2030 and 2050 under our central TECH scenario, relative to the Reference case. As a result of the economic shifts described above, there is a net increase in employment in the following sectors: construction, electricity, hydrogen, services and most manufacturing sectors. Employment in the fuels sector is reduced. Employment in the automotive manufacturing sector is increased until 2030, but decreases thereafter in our central TECH scenario.

In our TECH scenario, net auto sector jobs are increased in 2030, because diesel and gasoline engines are built to greater levels of sophistication and efficiency to meet climate goals; and because of the increasing deployment of hybrids; plug-in hybrids and fuel-cell vehicles, which also contain increasing technological complexity. However, by 2050, the net impact on jobs starts to enter negative territory in our TECH scenario, because hybrids are increasingly replaced by battery-electric vehicles, which are more simple to build and therefore generate less jobs.

We have also explored a scenario in which plug-in hybrids remain dominant for longer (TECH PHEV). In such a case, German workers continue to benefit from building more complex vehicles for longer, and the net employment impact in the auto sector remains positive in 2050. While it is tempting to conclude that this indicates that Germany should prioritise plug-in hybrids to maximise employment, this should be evaluated carefully. If Germany were to place a major industrial bet on plug-in hybrids, but then car-buyers in Germany and its export markets were to favour battery electric vehicles, this would create risks of stranded assets. Nonetheless, the analysis does support the assertion that a transition to plug-in hybrids, if embraced by consumers, is beneficial for German auto sector employment.

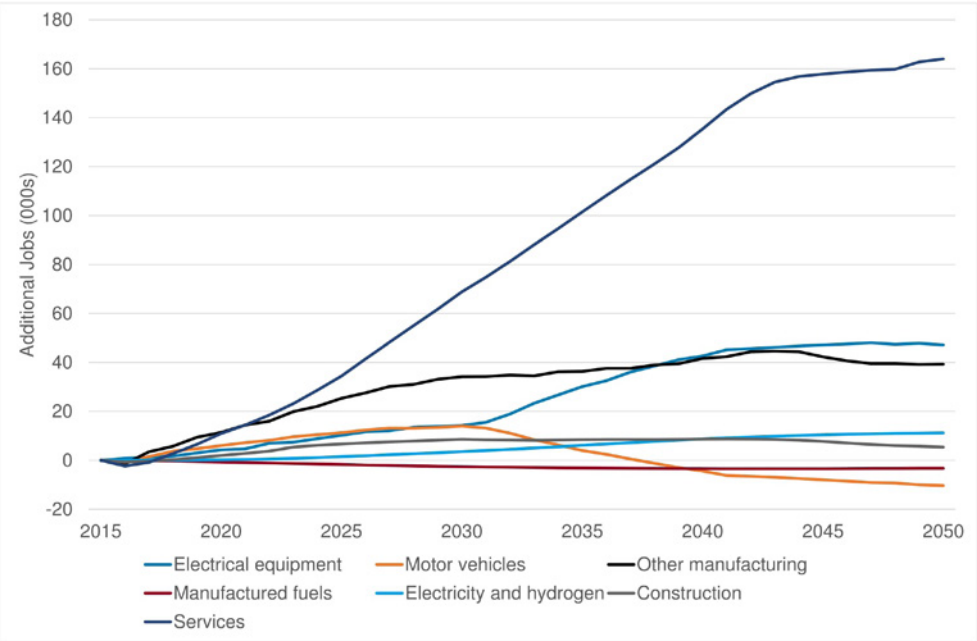


Figure 13.
The employment impact per sector in Germany of the transition to low-carbon cars (thousands)

Employment impacts within the German auto sector are an important issue and deserve further analysis. The benefit of using a macro-economic modelling approach is that it allows us to assess the economy-wide impacts of this transition, but there are limits to the level of detail that can be provided. For the low-carbon transition to be successful, care will need to be taken of those who will lose their jobs in technologies that become redundant. We thus recommend further analysis to explore how a "just transition" can be achieved in the auto sector, where these changes will take place against an overall background of increasing automation, which causes progressively lower employment.

Another important issue brought to light in this analysis is the reduction in future fuel tax revenues in Germany. This will firstly be caused by improved vehicle efficiency – The agreed EU CO_2 targets for 2021 will lead to a fuel tax revenue shortfall of around €6 billion in Germany by 2030. And the deployment of ZEVs, as foreseen in our TECH scenario would reduce fuel tax revenues by a further €7 billion. However, as described above, the structural shifts created by this transition lead to an economic boost, and taxation of this additional economic activity will entirely offset the accompanying reduction in fuel tax revenues by 2030, according to the analysis conducted in this project (Figure 14).

While economic modelling shows this to be the case, it is unlikely to be so clear from the perspective of the German treasury, which will simply observe dwindling fuel tax revenues. Nonetheless, it is worth noting these two important trends during the transition to low-carbon mobility. And as stated earlier, this highlights the importance of industry, government and civil society working together to find consensus on the optimal approach.

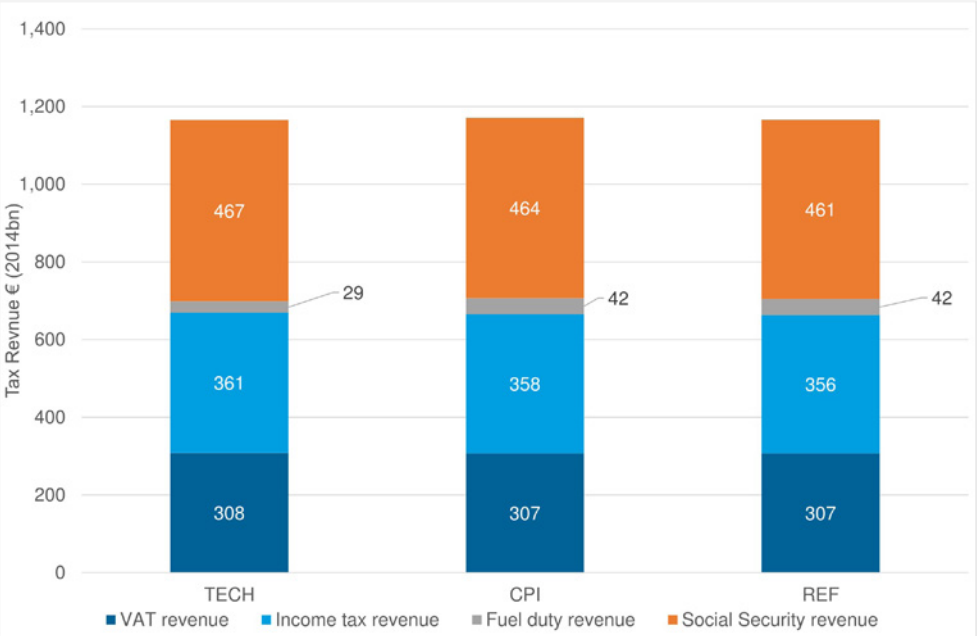


Figure 14.
German government tax revenues in 2030 in our REF and TECH scenarios

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