Schill, Wolf-Peter; Gerbaulet, Clemens; Kasten, Peter

Article

Electromobility in Germany: CO2 balance depends on charging electricity

DIW Economic Bulletin

Provided in Cooperation with:
German Institute for Economic Research (DIW Berlin)

Suggested Citation: Schill, Wolf-Peter; Gerbaulet, Clemens; Kasten, Peter (2015) : Electromobility in Germany: CO2 balance depends on charging electricity, DIW Economic Bulletin, ISSN 2192-7219, Deutsches Institut für Wirtschaftsforschung (DIW), Berlin, Vol. 5, Iss. 17, pp. 235-242

This Version is available at:
http://hdl.handle.net/10419/110200

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.
The German government plans to significantly increase the deployment of electric vehicles. What impact would this have on the country’s power system and carbon emissions? This question was addressed as part of a European research project analyzing various scenarios up to 2030. One of the key findings of the study is that total annual power consumption of the four to five million electric vehicles (depending on the scenario) would be small. However, recharging the vehicles, particularly in an uncontrolled charging mode, which involves the car being fully recharged as rapidly as possible after being connected to the electricity grid, would result in problematic peak loads in the power system. The type of additional power generation required for electric vehicles also largely depends on the charging mode. For example, a charging mode that minimizes system costs would use a particularly high share of power from hard-coal- and lignite-fired plants, which, in turn, would result in an above-average level of specific carbon emissions of the charging electricity. If the electricity and transport sectors are both considered, it becomes evident that the introduction of electromobility would result in a significant net reduction in carbon emissions only if linked with an additional expansion of renewable energy sources compared to current plans.

One of the German government’s stated goals is to increase the use of electric engines in the field of motorized private transport.1 The aim is for Germany to have a fleet of one million electric road vehicles (EVs) by 2020 and six million by 20302 and, parallel to this, for Germany to become both the “lead market” and “lead supplier” in the field of electric mobility by 2020.3 In order to meet these targets, one of the steps taken by the German government was to establish the National Electric Mobility Platform (Nationale Plattform Elektromobilität, NPE). Following a phase of market preparation (up to 2014) and market launch (up to 2017), the plan is to reach the mass market by 2020.4 In September 2014, the German cabinet passed a new electric mobility law to underpin the market introduction of EVs.5

The introduction of electric mobility is accompanied by a number of challenges: for example, the range, weight, and life of vehicle batteries all still require significant improvement. Purchasing an EV also remains a relatively expensive undertaking for customers while the range of available models is limited and the level of acceptance...
European Research Project Examines Impact of Electric Mobility

A European research project studied the possible impact of future EV fleets on the German power system and CO₂ emissions in the transport sector. One of the key areas of interest was the effects of electric mobility on German power plant dispatch and the resultant net CO₂ emissions, in each case on the basis of various assumptions regarding the EV charging mode.

The Institute for Applied Ecology (Öko-Institut) initially developed two market scenarios illustrating the expansion of the charging infrastructure is also needed.

At the same time, however, electric mobility has the potential to open up a wide range of opportunities in the medium and long term. For instance, EVs could enable us to use domestic renewable energy sources without having to rely on biofuels. Moreover, electric drives are generally considerably more efficient than combustion engines. They also produce only low levels of local air pollution and no CO₂ emissions. However, it is possible that these emissions might be shifted, at least to a certain extent, occurring when the electricity is generated instead. Last but not least, there is also the hope that the optimized grid integration of EVs will make a positive contribution to improving the flexibility of the power system.

Among car users remains largely uncertain. Further expansion of the charging infrastructure is also needed.

sion of EVs up until 2030 and derived the corresponding time profiles for hourly vehicle usage and charging options. DIW Berlin then calculated the impact of these EV fleets on the German power system using a power plant dispatch model. The results of this calculation, in turn, provided essential input parameters for a transport sector model developed by the Öko-Institut and used to calculate the net CO₂ emissions of the electricity and transport sectors.

**Scenarios for Development of Electric Mobility in Germany**

The Öko-Institut developed two scenarios for electric mobility in Germany for the period up to 2030, covering pure battery electric vehicles (BEVs) as well as plug-in hybrid electric vehicles (PHEVs) and range extender electric vehicles (REEVs) (see Box 1). A business-as-usual (BAU) scenario envisages a continuation of the current policy framework conditions. In contrast, the Electric Mobility+ (EM+) scenario assumes additional policy measures promoting electric mobility. These measures include higher taxes on fossil fuels, ambitious emissions standards for new vehicles, and the introduction of a feebate system based on emissions for all new vehicle registrations. Representative mobility data for Germany were used to calculate vehicle use. The purchasing decision between different engine technologies is simulated using a conjoint analysis of a survey of 1,500 buyers of new cars.

The main factors affecting the purchase and use of EVs include acquisition costs, running costs, charging infrastructure requirements, charging times, and the frequency of longer journeys which go beyond the BEV range. Around 50 percent of car owners in core cities do not have a parking spot on their own property and would therefore constantly have to rely on a public charging infrastructure in order to use an EV. The share of car owners without a parking spot on their own property falls to 30 percent in suburbs and rural areas. On average, each vehicle makes around six journeys of longer than 150 kilometers every year. Using the Poisson probability distribution, we can assume that the probability of a BEV being driven beyond its range more than four times a year is over 70 percent.

The survey indicated a high level of acceptance of electric mobility. The market potential of EVs derived from the survey during the period under observation was approximately 50 percent of new vehicle registrations in the BAU scenario and around 60 percent in the EM+ scenario. According to the survey, the level of acceptance of PHEVs and/or REEVs is higher than for BEVs. A simulation of the future market shares of EVs uses a diffusion factor to take other obstacles into account such as the required expansion of production capacities and the currently rather limited selection of EV models. Accordingly, the market share of new EV registrations is below market potential.

In the two scenarios, the market share of new EV registrations will be approximately five to six percent in 2020, increasing to 20 to 25 percent by 2030. PHEVs and REEVs account for considerably higher market shares than BEVs. The overall EV fleet size is around 0.4 million (BAU) or 0.5 million (EM+) by 2020. According to the BAU scenario, by 2030, the EV fleet will expand to just under four million and, according to the EM+ scenario, to approximately five million cars, equating to 13 percent of the total number of passenger cars (see Figure 1). 12

**Figure 1**

**Stock of electric vehicles in the scenarios**

In million cars

<table>
<thead>
<tr>
<th>Year</th>
<th>BAU</th>
<th>EM+/RE+</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>2030</td>
<td>3.5</td>
<td>5.0</td>
</tr>
</tbody>
</table>

BEV: Purely Battery-Electric Vehicles.


© DIW Berlin 2015

---

8 For a more detailed description of the scenarios, see P. Kasten and F. Hacker, Two electromobility scenarios for Germany: Market development and their impact on CO₂ emissions of passenger cars in DEFINE (Berlin: November 14, 2014).

9 Vehicles that produce high specific emissions are subject to a surcharge when purchased whereas financial assistance is provided for the purchase of vehicles with low specific emissions.


11 Survey respondents were repeatedly asked to choose between various vehicle types which differed by drive type, performance, CO₂ emissions, and purchasing and fuel costs. See K. Götz et al., Attraktivität und Akzeptanz von Elektroautos. Arbeitspaket 7 des Projekts OPTUM: Optimierung der Umweltentlastungspotentiale von Elektrofahrzeugen (Frankfurt/Main: October 2011).
The impact of the EV fleets outlined in the Öko-Institut scenarios on the German electricity system is analyzed using a power plant dispatch model developed by DIW Berlin (see Box 2). The model minimizes power plant dispatch costs, factoring in the necessary charging requirements for EVs. The model distinguishes between two extreme charging technologies for 2020 and 2030: the share of lignite-fired generation in the charging power of EVs tends to be overestimated, particularly for cost-optimized vehicle charging.

In the case of plug-in hybrid electric vehicles, the decision about the driving mode—electric or with the conventional internal combustion engine—is not modeled in detail: instead, it is generally assumed that the share of electric power in vehicle use ought to be increased to a maximum.

With regard to the network integration of EVs, controlled EV charging was analyzed (grid-to-vehicle), but not the option of feeding electricity from the vehicle battery packs back into the grid (vehicle-to-grid). Various studies indicate that vehicle-to-grid could be particularly relevant for the control reserve market segment; this is not explored here, however.

The Transport Emissions and Policy Scenarios (TEMPS) model developed by the Öko-Institut is used to quantify the energy demand and greenhouse gas emissions of the transport sector for various scenarios, depicting changes in transport demand, vehicle fleet, and fuel use. Using key mobility parameters (number of trips, trip distances, modal split of passenger and freight transport, and transport distances), transport demand scenarios for passenger and freight transport are determined and used in the model as input parameters. The technology database documents the possible technical developments of the respective mode of transport up to 2050 according to vehicle category and powertrain. The future development of vehicle efficiency is calculated using a model for new vehicle registrations and the existing vehicle fleet, meaning the effect of CO₂ emission standards or measures to promote the use of alternative technologies on the existing vehicle fleet in Germany can be analyzed.
strategies (see Box 1): in the uncontrolled charging mode which is completely user-driven, EVs are fully recharged as quickly as possible immediately after being connected to the charging station. In the optimized charging mode, however, which is completely cost-driven, vehicle charging can be delayed subject to the constraints of the vehicles’ hourly usage and charging profiles, which minimizes the charging costs arising in the electricity system. The model also allows simulating (semi-optimized) charging strategies which are user-driven to a certain extent and where only some of the battery capacity must be recharged as quickly as possible as soon as the vehicle is connected to the power grid.

Energy Consumption of EVs Marginal But Charging Power Can Be Critical

The annual energy requirements for future EV fleets are minimal compared to total power demand. In 2020, depending on the charging strategy, electric mobility requires only 0.1 to 0.2 percent of total electricity demand. By 2030, these shares increase to 1.2 to 1.6 percent or seven to nine terawatt hours (TWh).15

In contrast to the yearly energy consumption of EVs, their hourly charging power could, however, become very high. Charging rates fluctuate considerably from one hour to the next and there are substantial differences between the user-driven and cost-driven charging modes. Purely user-driven charging occurs primarily during the daytime and evening (see Figure 3). This may result in a significant increase in the power system’s peak load which could have serious consequences for system security. According to both the BAU and the EM+ scenarios, a completely user-driven charge mode would mean that, in 2030, there would be several hours when the assumed power generation capacities (based on the Grid Development Plan) would be completely exhausted.16

In the cost-driven mode, on the other hand, the evening peaks of the charging profile are shifted to the nighttime when electricity demand is low and to the hours over midday when solar power generation is high. The average charging profile for the cost-optimized mode is considerably more balanced overall than for the fully user-driven mode and it consequently also results in a much less pronounced increase in demand during peak load periods.

15 In comparison, in 2012, final energy consumption by Germany’s electrified trains was just under nine terawatt hours for passenger transport and between three and four terawatt hours for freight transport. See IFEU, Auswertungen des Modells.

16 The solvability of the model in these peak hours is ensured using a stylized, very expensive peak load technology. In the real world, an according level of load shedding, the provision of a capacity reserve, or the import of electricity from abroad would be required.

The capacities of wind power and photovoltaics strongly increase.

Figure 2

Installed power generation capacities

In gigawatt

0 50 100 150 200 250

2010 2020 2030

Natural gas Oil Other

Wind onshore Wind offshore Run-of-river Biomass

Pumped storage Hydro

Lignite Coal

Nuclear


© DIW Berlin 2015

Fully user-driven charging primarily takes place during evening hours.

Figure 3

Average charging power over 24 hours in 2030

In gigawatt

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

Fully user-driven 50 percent user-driven Fully cost-driven

Exemplary for the scenario EM+


© DIW Berlin 2015

Compared to fully uncontrolled charging, even semi-optimized charging where, for example, only half of the battery capacity must be recharged immediately after connecting to the power grid, results in a much smoother average charging profile.

Power Generation for Electric Vehicles Depends on Charging Mode

The different charging profiles are associated with corresponding changes in power plant dispatch. EVs may,
on the one hand, increase the utilization factor of emissions-intensive power generation technologies such as lignite- and hard-coal-fired plants and, on the other, consume temporary surplus energy from intermittent renewable energy sources.

In the 2030\textsuperscript{17} Electric Mobility\textsuperscript{*} scenario (EM\textsuperscript{*}), a cost-driven charging strategy increases the utilization of hard-coal- and lignite-fired plants significantly in comparison to a reference scenario that does not include EVs (see Figure 4). In the case of fully user-driven vehicle charging, the vehicle is often charged at times when lignite-fired power plants are running to full capacity, meaning the additional power needed comes mainly from natural-gas-fired combined cycle plants as well as coal-fired-plants and, to a lesser extent, from lignite plants.

In both cases, the use of renewable sources of energy is only slightly higher, since these sources produce very little surplus energy; this means that virtually all the wind and solar power generated, as anticipated in the scenarios, can already be adopted by the energy system in the scenario with no EVs. Here, cost-optimized charging allows for a slightly larger increase in the utilization of renewables, since in this case vehicle charging can be shifted to times where there is surplus electricity from wind and solar power.

### Charging Power Causes Above-Average Greenhouse Gas Emissions

The specific CO\textsubscript{2} emissions from the additional energy demand for EVs depend both on the power plant fleet and the charging strategy applied. If the use of EVs increases the utilization of emissions-intensive power generation plants such as lignite- and hard-coal-fired plants, the specific CO\textsubscript{2} emissions also increase. Conversely, if EVs can be charged with additional renewable power-remissions will decrease. In the 2020 and 2030 BAU and EM\textsuperscript{*} scenarios, additional coal-fired power generation dominates the emissions balance. This applies, in particular, to cost-driven charging. Consequently, specific emissions resulting from the increased energy demand caused by EVs ("charging power") are — irrespective of the charging mode — higher than those for the entire power mix (see Figure 5).\textsuperscript{18}

---

\textsuperscript{17} The effects are most evident in this scenario. In the BAU 2030 scenario and in the 2020 scenarios, the results are similar in quality, albeit less pronounced.

\textsuperscript{18} The effects observed depend heavily on the structure of the power plant fleet and the relevance of renewable curtailment. In future, the emissions balance of cost-driven charging could be far better if emissions-intensive power plants are removed from the system and renewable curtailment becomes more significant.
In another scenario called Renewable Energy+ (RE+), the introduction of electric mobility is directly linked to the further expansion of renewable power generating capacities beyond the scope set forth in the Grid Development Plan. These additional capacities are selected such that the total annual power generation from these sources covers the electricity demand for EVs exactly. For example, if the electricity demand for EVs were to be covered solely by additional solar PV installations, the 2030 scenario (EM+) would require around 13 to 14 gigawatts of capacity more than the 59 gigawatts already anticipated. In this scenario, the specific emissions resulting from vehicle charging are near zero.

**Additional Renewable Power Capacities Have Positive Effect on Net CO₂ Emissions from EVs**

The introduction of electric mobility essentially shifts CO₂ emissions from the transport to the power sector.19 Accordingly, electric mobility will have a beneficial net CO₂ emissions balance only if, by using electric vehicles rather than vehicles with a combustion engine, the road traffic emissions reductions exceed the increase in emissions caused by the generation of the additional electricity needed. An analysis based on the TEMPS model (see Box 2) taking account of the CO₂ emissions in the power sector shows that the net emissions balance of EVs largely depends on the assumptions made.

According to the 2030 BAU scenario, the CO₂ reductions in the traffic sector achieved by EVs are more than offset by the increase in emissions in the power sector. Depending on the charging mode, the overall CO₂ emissions are 1.0 or 1.6 million tons higher than in a scenario with no electric mobility (see Figure 6). This equates to approximately one percent of the CO₂ emissions of passenger cars in Germany today.20 In the EM+ scenario, in contrast, net CO₂ emissions are 1.3 or 2.1 million tons lower, or up to two percent of the passenger cars’ CO₂ emissions in Germany today. It must be said, however, that these reductions are achieved because in the EM+ scenario — unlike in the scenario with no electric mobility (or the BAU scenario)— the CO₂ limits for conventional passenger cars are assumed to be far stricter. In both scenarios, the specific CO₂ emissions resulting from the additional electricity demand for EVs will be greater in 2030 than those produced by internal combustion vehicles. This means that the expected efficiency gains or emissions reductions for conventional pas-

---

19 Any changes in mileage or size range structure of the vehicle fleet are not taken into account here. It is assumed that mileage is constant in all scenarios.

20 In 2010, the direct CO₂ emissions from passenger cars in Germany amounted to 110 million tons.
controlled charging where the EVs are fully charged as rapidly as possible after being connected to the power grid. Due to limited power generating capacities, in future it may be necessary to limit purely user-driven charging by means of regulation, at the very latest when vehicle fleets reach the size assumed in the 2030 scenarios. Even improving the charging strategy from a fully user-driven to an at least partly cost-driven mode could lead to substantial improvements.

Second, the model results show that optimized vehicle charging not only facilitates the integration of renewable energy sources into the power system but can also increase the utilization of hard-coal- and lignite-fired power plants. If the government aims to politically introduce electric mobility in connection with the use of renewable energy sources, steps must be taken to ensure that renewable energy capacities are further expanded beyond the levels set down in existing scenarios. With regard to CO₂ emissions, this is particularly important as long as the installed capacities of emissions-intensive power plants are still sizable and, what is more, these plants are increasingly under-utilized in the context of the German energy transition. As to the energy system, it is of no consequence whether the additional power generated from renewable sources is consumed entirely by the EVs themselves by means of a dedicated charging strategy, or whether some of the additional power generated is used to cover other power demand.

Third, cost-optimized vehicle charging can only help reduce emissions if the external costs of these emissions are factored in to the wholesale electricity price accordingly. Otherwise, cost-optimized charging can lead to above-average specific CO₂ emissions that are even greater than those for uncontrolled charging. Failure of policy-makers to put an appropriate price on CO₂ emissions would render other emissions-oriented charging strategies necessary which may be feasible in theory but which are very unlikely to be implemented in practice.

What is important, however, is that electric mobility is not introduced with a view to short- and medium-term CO₂ emissions effects only. In fact, electric vehicles can bring about a host of other advantages such as lower local emissions from other air pollutants and reduced dependency on mineral oil in the transport sector. In particular, electric mobility offers the opportunity to use energy gained from domestic renewable sources without the utilization of biofuels. In the long-term, beyond 2030, battery-driven EVs pave the way for alternative drive concepts and fuels and open up new possibilities for near-zero-emissions vehicles powered by renewable sources of energy.

Wolf-Peter Schill is a Research Associate of the Department Energy, Transportation, Environment at DIW Berlin | wschill@diw.de
Clemens Gerbaulet is a Research Associate of the Department Energy, Transportation, Environment at DIW Berlin | cgerbaulet@diw.de

Peter Kasten is a Senior Researcher in the Division Infrastructure & Enterprises at Öko-Institut | P.Kasten@oeko.de

JEL: Q42; R41; Q54

Keywords: Electric vehicles; power system modeling; carbon emissions.