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Electric vehicles: Charging into the Future

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Electric vehicle drives offer a number of advantages over conventional internal combustion engines, especially in terms of lower local emissions, higher energy efficiency, and decreased dependency upon oil. Yet there are significant barriers to the rapid adoption of electric cars, including the limitations of battery technology, high purchase costs, and the lack of recharging infrastructure. With intelligently controlled charging operations, the energy needs of potential electric vehicle fleets could be covered by existing German power plants without incurring large price fluctuations.

Over the long term, electric vehicles could represent a sustainable technology path. In the short to mid-term, however, exceedingly optimistic expectations should be avoided, especially with respect to the reduction of greenhouse gas emissions. Electric vehicles as such will not be able to solve all current problems of transportation policy. Yet they may constitute an important component of a larger roadmap for sustainable transportation.

Against the backdrop of growing climate change concerns and a high level of dependency upon scarce fossil energy resources, many countries are currently advancing the research, development, and market introduction of electric vehicles.[1] In 2009, the German government presented a *National Development Plan for Electric Mobility*, which is motivated by technology, energy, and transportation policy considerations. The plan formulates the goals of reaching a total of one million electric cars by 2020 and developing Germany into a *lead market for electric mobility*. Within the scope of Germany's second economic stimulus package (*Konjukturpaket II*), which was passed in 2009, 500 million euros will be invested between 2009 and 2011 in research, development, and market preparation in the areas of battery technology, components, and network integration. In addition, there are ongoing field trials in eight German model regions to test recharging procedures, practicality, and user acceptance of electric vehicles. At a summit meeting of government and industry representatives held at the German Federal Chancellery in May 2010, a *National Platform for Electric Mobility* was created, consisting of seven working groups. The platform aims to provide technological leadership for key components and to improve industry-wide cooperation.

1 See also Schill, W.-P.: Elektromobilität in Deutschland – Chancen, Barrieren und Auswirkungen auf das Elektrizitätssystem. Vierteljahrshefte zur Wirtschaftsforschung, 2/2010.

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Table 1

Electric Drive Technologies for Vehicles

	Specific Characteristics	Battery Storage Capacity in Kilowatt Hours
Micro and Mild Hybrid	Combustion engine with electric accessories or electric auxiliary drive	less than 1
Full Hybrid	Two power trains: combustion engine and electric drive. Pure electric operation possible for short distances.	1 to 3
Plug-In Hybrid	Like a full hybrid, but with a larger battery and the possibility of recharging at the power grid. Pure electric operation possible for longer distances.	6 to 15
Battery-Electric Drive	Pure electric power train. Battery recharging at the power grid. Alternatives: additional serial combustion engine (range extender) or switchable batteries.	15 to 20 for city cars, up to 60 for large cars
Electric Motor with Hydrogen Fuel Cell	Operating power is generated on board from hydrogen by a fuel cell. Coupling with a battery is possible.	No battery or a small battery

Source: Compiled by DIW Berlin. DIW Berlin 2010

Different Forms of Electric Mobility

Essentially all vehicles with electric drives could fall into the category of *Electric Mobility*, including rail vehicles directly connected to the power grid – i.e. local and long-distance trains, which have already been electrified for decades. In the current debate, however, the term *Electric Mobility* is primarily used for motorized individual transport, i.e. passenger cars and scooters. It describes the supplementation or complete substitution of today's internal combustion engines by electric power trains. There are a number of different drive concepts, ranging from slightly hybridized combustion engines to fully electric vehicles (Table 1). Micro, mild, and full hybrid vehicles combine a conventional combustion engine with electric drive components and a low-capacity battery. Yet they obtain their energy exclusively from conventional fuels. Plug-in hybrid vehicles allow charging the battery at the power grid, such that a portion of the car's energy consumption can be covered by grid power. By contrast, pure battery-electric vehicles obtain their energy exclusively from the power grid. Vehicles with hydrogen fuel cells fall into the category electric mobility only in a limited sense, since they generate their operating power from hydrogen on board. In the following, this report focuses on battery-electric passenger cars.

Advantageous Features of Electric Drives

A significant advantage of electric drive vehicles is that they hardly emit any local air pollutants such as nitrogen oxides or particulate matter. In addition, noise emissions are lower compared to combustion engines.[2] As a result, electric cars are especially attractive for inner city transport, low emission zones, and environmentally sensitive areas. However, air pollutants may be released at the site of electricity generation – in particular, CO_2. Drawing on realistic driving cycles and a *well-to-wheel* approach, CO_2 emissions of battery-electric vehicles are lower than those of comparable cars with diesel or gasoline engines.[3] This is even true if the current German electricity mix is used, which contains a large share of coal. Its CO_2 intensity will decrease in the future, especially through the further deployment of renewable energy. This will directly improve the emissions performance of future electric vehicles. With regard to overall German CO_2 emissions, the future expansion of electric vehicles and the associated increase in electricity demand will require an additional expansion of renewable energy – otherwise, the use of renewable electricity in the transportation sector will merely replace its use in other electric applications.

Aside from emissions advantages, electric drives are significantly more energy efficient than combustion engines, and also more efficient than hydrogen fuel cells. From a *well-to-wheel* perspective, the energy efficiency of gasoline or diesel engines is only 18 to 23 percent. By contrast, electric engines already achieve around 30 percent efficiency, even with Germany's current electricity mix.[4] Here as well, foreseeable energy efficiency improvements in power generation would directly benefit future electric vehicles. Electric vehicles could thus contribute to the conservation of primary energy resources.

Furthermore, electric vehicle drives make it possible to use a broad energy resource base. Conventional engines largely rely upon fossil fuels, which can be replaced by biofuels only to a small extent. In 2007, more than 90 percent of German final energy consumption in the transport sector was supplied by petroleum products.[5] In contrast, power for electric vehicles can be generated from practically all primary energy sources. This could potentially diminish economic and political dependency upon oil imports as well as associated macroeconomic imbalances and price risks.

2 See Pehndt, M. et al.: Elektromobilität und erneuerbare Energien. Heidelberg, Wuppertal, 2007.

3 Well-to-wheel includes the overall process chain from primary energy generation to the turning of the vehicle's wheels. For detailed calculations, see Erdmann, G.: CO2-Emissionen von Batterie-Elektrofahrzeugen. Energiewirtschaftliche Tagesfragen 59 (10), 2009, 66–71.

4 Wietschel M., Dallinger, D.: Quo Vadis Elektromobilität? Energiewirtschaftliche Tagesfragen 58 (12), 2008, 8–16.

5 German Federal Ministry of Economics and Technology. Berlin 2008.

Significant Barriers Remain

Battery technology currently represents the largest barrier for the rapid deployment of electric vehicles. Compared to conventional fuels, even the most advanced lithium ion batteries only have a small energy density.[6] Consequently, even large and heavy batteries only permit a limited operating range. Yet it should be noted that daily travel distances of most users are small: in 2004, half of all commutes by employed individuals in Germany were shorter than ten kilometers, about 80 percent were shorter than 25 kilometers, and more than 90 percent were shorter than 50 kilometers.[7] So the operating range of currently available electric vehicles would already be sufficient to cover the majority of commuter travel.

Battery capacity restrictions require electric vehicles to be more light-weight and to be motorized more efficiently in comparison to conventional cars. From this perspective, the ongoing German trend to build ever heavier and more powerful vehicles seems quite problematic. In 2008, the average engine power of all newly registered cars in Germany was between 81 and 90 kW (110-122 HP). Only seven percent of newly registered vehicles were below 50 kW (68 HP), which is in the range of currently available, practical electric vehicles.[8] Given this market environment, the deployment of electric vehicles seems to be restricted to specific market niches at the moment. The use of an electric vehicle as the primary mode of transportation in private households thus seems improbable. Electric vehicles are more likely to be deployed as secondary cars or as fleet vehicles. For instance, the vehicle fleets of certain government agencies, delivery services, or carsharing providers may be well-suited for electrification.

Further research is clearly needed, not only with regard to the energy density of lithium ion batteries, but also with regard to their longevity, temperature sensitivity, safety, and recyclability. Yet the availability of lithium, a primary battery component, is unlikely to be jeopardized in the foreseeable future, even though current supply sources are strongly concentrated in South America, especially in Chile.[9]

An additional weakness of current batteries is their high cost: a battery for a plug-in hybrid vehicle with an energy storage capacity of ten kilowatt hours currently costs 8,000 to 10,000 euros, which is as expensive as a basic conventional small car.[10] On the other hand, battery-electric vehicles do not involve the expense of a conventional power train. In addition, recharging costs are low compared to conventional fuels. Therefore, the economic feasibility of electric cars depends largely upon their usage profile and their mileage. For the foreseeable future, cars with relatively small batteries and high annual mileage are likely to be economically most feasible.[11]

The creation of a sufficient number of charging stations and the need of protecting them from misuse and vandalism represent a major infrastructure barrier. This problem could be solved if private electric vehicles were charged at their owners' homes using existing household power connectors. Yet this is only possible if suitable personal parking spaces are available. As setting up additional recharging infrastructure is costly, this currently seems to be most viable for the case of fleet vehicles which are parked at central sites, for example parking garages. In contrast, a widespread deployment of public charging stations is not foreseeable in the mid-term. Another unresolved problem is the national and international standardization of charging, connection, and billing technologies.

Electric mobility also faces socio-cultural barriers. In particular, the flexibility of electric vehicle usage is lower compared to conventional cars due to their smaller operating ranges and longer recharging times. Even if charging durations could be reduced by means of higher charging rates, it is unclear at this time if users would tolerate such restrictions to the flexibility of car use. Moreover, empirical studies show that consumers remain fundamentally skeptical about energy technologies which they consider new and untested, especially if they are also capital-intensive.[12]

6 Gasoline has an energy density of around 12 kilowatt hours per kilogram. Current lithium ion batteries fall about two orders of magnitude short of this level.

7 German Federal Ministry of Transport, Building and Urban Development: Verkehr in Zahlen 2009/2010. Vol. 38, Hamburg 2009.

8 German Federal Federal Motor Transport Authority: Fahrzeugzulassungen Neuzulassungen Motirisierung Jahr 2008. Flensburg 2009.

9 See Angerer, G. et al.: Lithium für Zukunftstechnologien: Nachfrage und Angebot unter besonderer Berücksichtigung der Elektromobilität. Karlsruhe 2009.

10 Hackbarth, A. et al.: Plug-in Hybridfahrzeuge: Wirtschaftlichkeit und Marktchancen verschiedener Geschäftsmodelle. Energiewirtschaftliche Tagesfragen 59 (7), 2009, 60–63.

11 Detailed calculations are also offered by Biere, D. et al.: Ökonomische Analyse der Erstnutzer von Elektrofahrzeugen. Zeitschrift für Energiewirtschaft (2), 173–181.

12 Sovacool, B., Hirsh, R.: Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition. Energy Policy 37 (3), 2009, 1095–1103.

Table 2

Electric Vehicle Scenarios for Germany

Inventory in millions of electric cars

	Low scenario ("Pluralismus-Szenario")			High Scenario ("Dominanz-Szenario")		
	2020	2030	2050	2020	2030	2050
Plug-in Hybrids	0.4	3.5	6.8	1.5	11.5	22.0
Pure Battery-Electric Vehicles1	0.1	0.3	0.6	0.1	0.4	21.6
Total	0.5	3.8	7.4	1.6	11.9	43.6
Cumulative Daily Electricity Consumption2 in Gigawatt Hours	2.1	13.7	34.2	6.8	48.0	219.2
Cumulative power rating in Gigawatt Hours	2.5	17.5	40.0	8.0	55.0	425.0

1 Including electric scooters and small city cars.
2 Under the assumption of equally distributed car usage throughout the year.

Sources: Wietschel, M., Dallinger, D; calculations by DIW Berlin. DIW Berlin 2010

The expansion of electric cars will take place quite slowly. Even under the rather improbable high scenario, their number will hardly reach twelve million by 2030.

Market Shares of Electric Vehicles Will Remain Small

In general, the German passenger car fleet is replaced at a very slow rate. Whereas the overall number of German cars is about 41 million, the annual number of new car registrations was between three and four million during recent years. Thus, even a high proportion of electric vehicles among new registrations would result in a slow penetration of the vehicle inventory. Yet high electric vehicle shares at new registrations are unlikely given the barriers previously described.

Existing scenarios on the future expansion of electric vehicles are highly variable, as there are so many uncertainties regarding future technological, infrastructural, and economic conditions. Table 2 shows the results of a study that projects two different development paths through 2050.[13] In a scenario with a high market penetration of electric vehicles (called "*Dominanz-Szenario*"), the German vehicle fleet will be almost entirely replaced by electric cars. In an alternative scenario with lower market penetration ("*Pluralismus-Szenario*"), which seems more realistic given the barriers discussed above, different types of drives coexist over a long time. The number of plug-in hybrids exceeds the number of pure battery-electric vehicles for a long time due to higher operating ranges attainable with hybrid vehicles and due to lower requirements for setting up recharging infrastructure. The table also shows that the fleet penetration of electric vehicles rises only very slowly in the nearer future, even in the optimistic scenario.

Electricity Market Impacts: Controlled Recharging Leads to Moderate Effects on Quantities and Prices

Electric vehicles increase electricity demand. Yet the timing of additional demand can potentially be managed. The overall energy demand of future electric vehicle fleets is relatively small compared to total national electricity consumption. For example, assuming annual road mileage of 10,000 kilometers per car and consumption of 20 kilowatt hours of electricity per 100 kilometers, the one million electric cars hoped for in Germany would increase annual electricity consumption by about two terawatt hours. This is quite modest compared to the total annual electricity demand of about 600 terawatt hours.[14]

Thus, the *total energy demand* of electric vehicles will not overburden the electricity system in the foreseeable future. In contrast, even a relatively small number of electric cars could lead to periods of problematic *electrical power demand* in case of uncontrolled charging because of the high cumulative power rating of electric vehicles.[15] A number of studies have investigated the impact of electric vehicle loading upon the power grid under the assumption that electric vehicles would be used for commuting in significant numbers and that the vehicle owners would plug them in for recharging after returning home from work. It has been shown that such uncontrolled recharging would increase the existing evening peak load, during which available generation capacities are scarce.[16] At night-time, however, there is plenty of free power plant capacity. Shifting vehicle loading into off-peak hours is thus essential even for a small electric vehicle fleet in order to avoid problematic peak loads. Load shifting would not only be necessary for maintaining network stability, but would also make economic sense, as existing power plants and network capacities could be utilized more efficiently. In addition, wholesale electricity market prices are significantly lower at night-time compared to daily peak load hours.

13 Wietschel M., Dallinger, D., et al. It is one of the few existing studies on the long-term development of the German vehicle fleet that differentiates between various types of vehicle drives through 2050 under different framework conditions.

14 AG Energiebilanzen: Stromdaten Jahr 2009. Berlin 2010.

15 Power is defined as energy per time unit. In the electricity sector, a frequently used energy unit is gigawatt hours; power is accordingly indicated in gigawatts.

16 See. Blank, T. et al: Zusätzlicher Energie und Leistungsbedarf für Elektrostraßenfahrzeuge. Energiewirtschaftliche Tagesfragen 58 (12), 2008, 50-52; and also Birnbaum, K. et al.: Elektromobilität: Auswirkungen auf die elektrische Energieversorgung. BWK 61 (1/2), 2009, 67–74.

Box

Notes on the Model Calculations

The calculations draw on an expanded version of the ElStorM electricity market model. In the model, electricity producers maximize their profits, whereas costs for recharging electric vehicles are minimized. The model represents the German wholesale market with an hourly resolution. It focuses on currently installed conventional German power plants, as these plants are generally responsible for wholesale price formation at the German power exchange. The model takes a number of generation technologies into account, including lignite, nuclear, coal, natural gas, run-of-river hydro, oil, as well as pumped hydro storage plants. Wind power is excluded for technical reasons: Currently, German wind power feed-in is regulated with a feed-in tariff. Consequently, it only has a small and indirect impact on market outcomes at the power exchange. In addition, fluctuating levels of wind power feed-in would make it more difficult to interpret the model results.

Exogenous model parameters include power generation capacities, variable generation costs, elastic reference demand on the wholesale market, and a constant daily electricity demand for recharging vehicles, which is assumed to be freely distributable over the course of the day. Endogenous model results include hourly generation levels of different technologies, hourly electricity prices, as well as the timing of electric vehicle recharging.

For a typical winter week (reference data from January 2009), four different model runs were performed based upon different hypothetical electric vehicle fleets. These include the fleets of 2, 12, and 44 million cars projected by the optimistic high scenario for 2020, 2030, and 2050, respectively. The cumulative daily recharging needs as well as the cumulative power rating of the hypothetical vehicle fleets were derived from the described scenario. As the calculations are based upon the existing German power plant fleet, no inferences should be drawn about the future development of the electricity market. Rather, we investigate the effects of future hypothetical electric vehicle fleets on today's electricity market. Over the medium and long term, the German generation mix will change significantly, especially because of further expansion of fluctuating renewable energy sources. It remains to be investigated which impacts such structural changes might have on future electric vehicle scenarios.

At the German Institute for Economic Research (DIW Berlin), we used an expanded version of our electricity market model ElStorM to analyze the quantity effects and price effects of electric vehicle loading for different vehicle fleets, assuming a controlled, cost-minimizing recharging strategy during a typical winter week.[17] The analysis is based on the hypothetical vehicle fleets projected for 2020, 2030, and 2050 in the high scenario (Table 2), which represents an upper boundary for an electric car deployment path to be expected. A fundamental assumption of the model is that vehicle owners are able to take advantage of fluctuating hourly wholesale electricity prices. They minimize the cost of recharging the cars by loading them during low-price off-peak periods. The model is based upon the current German conventional power plant fleet because these plants play a key role in determining prices at the German wholesale market. The regulated feed-in of wind power is not taken into consideration (Box).

Model results for the examplary week (168 hours) show that optimal vehicle recharging takes place during night-time hours (Figure). Even in the extreme scenario with almost 44 million electric vehicles, recharging could take place almost entirely during off-peak periods.

With intelligently managed recharging, the additional electricity demand for electric cars could be generated by existing conventional power plants without requiring additional peak-load capacity. Comparing each scenario to the reference case without electric cars, we find that electricity prices would only increase during off-peak periods, but not during peak periods. In the simulations with two and twelve million electric cars, the effects upon wholesale electricity prices are small as long as cost-minimizing recharging strategies are employed. In the extreme case of 44 million electric vehicles, however, prices increase such that off-peak price levels essentially disappear.

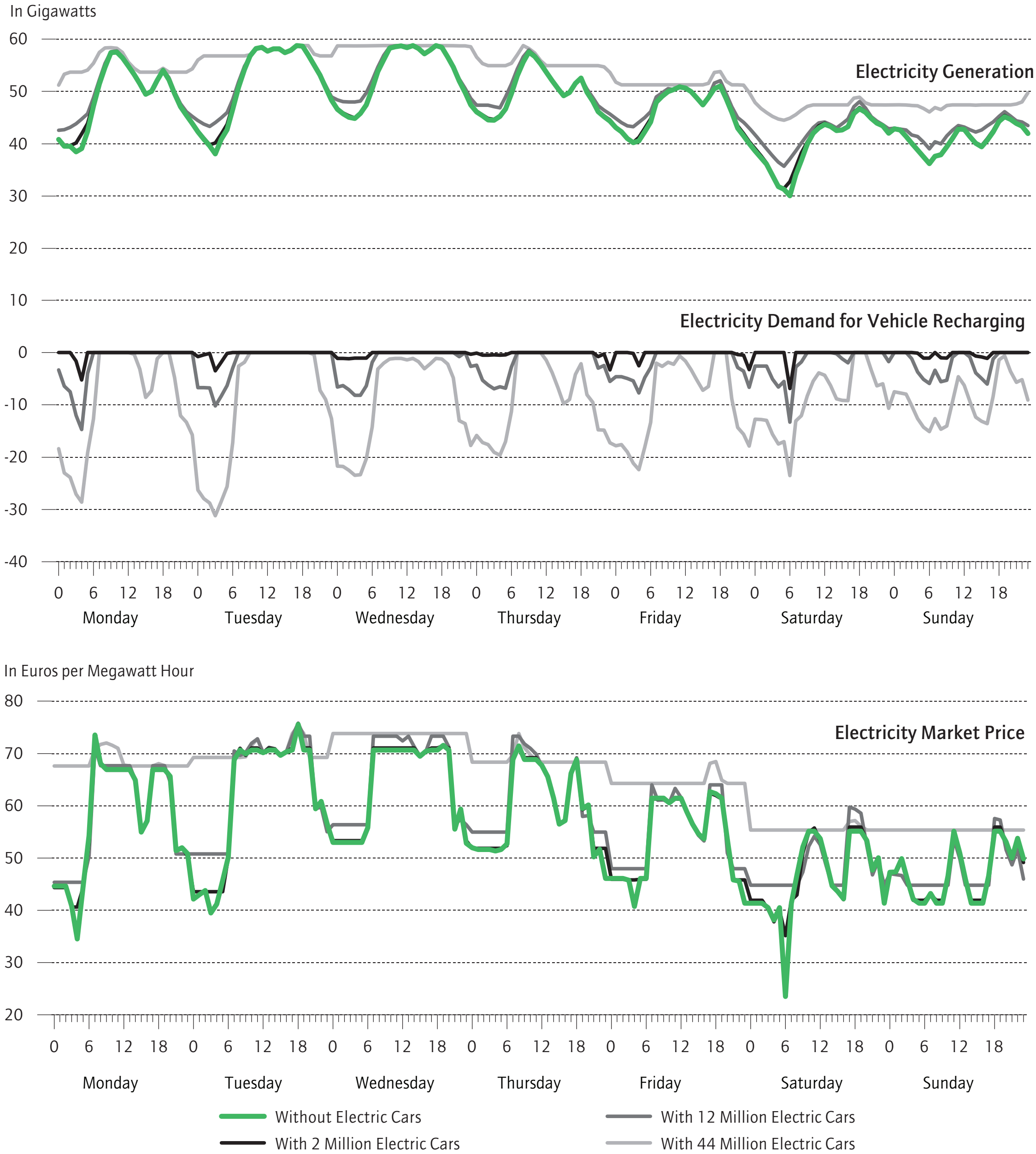
Without taking renewable energy generation into account, the additional electricity demand of electric vehicles would primarily lead to a greater utilization of coal-fired power plants. In the simulation with twelve million vehicles, almost 90 percent of the additional demand—compared to the reference case—would be covered by hard coal and lignite plants. Therefore, calculations on the emission performance of current electric vehicles should draw on

17 For a description of the basic model, see Schill, W.-P., Kemfert, C.: The Effect of Market Power on Electricity Storage Utilization: The Case of Pumped Hydro Storage in Germany. DIW Discussion Paper No. 947, 2009.

Figure

Electricity Generation, Vehicle Recharging, and Electricity Market Prices for Different Electric Vehicle Fleets

Weekly pattern for a typical week in the winter of 2009



Source: Calculations by DIW Berlin. DIW Berlin 2010

An inventory of twelve million electric vehicles could be charged at night-time without any problem. Even for an almost complete electrification of the German passenger car fleet, peak prices would not necessarily rise in the case of controlled charging.

the emissions of coal-fired power plants rather than on the average German power plant mix.

The model results show that the electricity demand for vehicle loading in Germany could be covered by existing conventional power plants. Yet this would not be a reasonable strategy if transportation-related greenhouse gas emissions are to be reduced substantially. Pursuing ambitious climate protection goals demands to avoid any increase in the utilization of coal-fired power plants, and particarly to avoid new coal plant construction.[18] Instead, future electric car deployments require an according expansion of renewable energy generation.

Additional Possibilities with *Vehicle-to-Grid*

Implementing what is known as the V*ehicle-to-Grid* (V2G) concept promises to realize substantial synergies between the vehicle fleet and the electricity system. The basic idea of V2G is to integrate parked electric vehicles into the power grid with a bidirectional grid connection. This would not only permit controlled recharging of vehicle batteries, but would also allow for feeding back stored electricity into the power grid in times of high demand.[19] The concept makes use of the fact that vehicles are not on the road during most hours of the day. A widespread implementation of the V2G concept would significantly increase the connected load of the grid: if only a quarter of today's approximately 41 million vehicles in Germany were electrified and integrated into the electrical network with a power rating of 15 kilowatts per car, then the cumulative power rating would amount to around 150 gigawatts, which was available as short-term generation or load capacity. This value actually exceeds today's entire German power generation capacity of around 147 gigawatts. However, the potentially high cumulative power rating of future electric vehicle fleets stands in contrast to the comparatively small storage capacity of car batteries. For this reason, the V2G concept is especially promising for high power, time-critical applications. This includes the provision of reserve power, which is necessary to balance short-term deviations between planned electricity generation and actual demand in the power grid. In contrast, V2G seems rather unfeasible for storage-intensive applications such as peak power supply or storage of excess wind power.[20] Before the V2G concept can be widely implemented, many remaining questions need to be addressed regarding standardization and operation of the required infrastructure as well as possible adverse effects upon vehicle batteries.

Conclusion

In recent discussions about alternative drive technologies, the focus has been on electric vehicles. Compared to internal combustion engines, electric drives offer several advantages, including nearly zero local emissions, potentially low overall CO_2 emissions, increased energy efficiency, and the possibility to draw on a broad base of energy resources. If domestic renewable energy sources are used, electric vehicles not only promise substantial CO_2 emission reductions but also independence from imported fossil fuels. Moreover, potential synergies between the vehicle fleet and the electricity system could be realized if electric vehicles were intelligently connected to the power grid. Substantial barriers, however, remain for the rapid and widespread adoption of electric vehicle drives, including the limitations of current battery technology and high costs. In addition, it is important not to underestimate infrastructure-related and socio-cultural barriers.

Due to ongoing political support in many countries and significant activities in the private sector, it is unlikely that the topic of electric mobility represents just a passing fad, as has partly been the case with fuel cells and biofuels in the past. Yet a significant market penetration of electric vehicles would only appear to be realistic over the long term. Given the obstacles identified herein, it is clear that electric vehicles will at best become important in some specific market niches over the next few years. This fact is underscored by the German policy goal of having one million electric vehicles on the road by 2020. The target appears to be quite ambitious given present technical and economic hurdles, although it would only constitute two percent of the current German car fleet. Against this background, it makes sense to think about electric vehicles as a promising long-term technology path that should not be overburdened by unrealistic short-term and medium-term hopes and expectations. Politicians should avoid rushing into short-sighted actions, but instead should aim to set an appropriate long-term course for electric vehicles.

From a technology policy perspective, the promotion of research and development is essential. However, support should be technologically unbiased, as it is not yet foreseeable which drive technology will turn out to be most feasible over the long run. Because of the mentioned barriers, electric vehicles are currently not ready for the mass market. Direct purchasing incentives should accordingly be considered at a later point in time, if at all. The German Academy

18 See Kemfert, C., Traber, T.: Nachhaltige Energieversorgung: Beim Brückenschlag das Ziel nicht aus dem Auge verlieren. Wochenbericht des DIW Berlin Nr. 23/2010.

19 The V2G concept was first described by Kempton, W., Tomic, J: Vehicle-to-Grid Power Fundamentals: Calculating Capacity and Net Revenue. Journal of Power Sources 144 (1), 2005, 268–279.

20 See also Lund, H., Kempton, W.: Integration of Renewable Energy into the Transport and Electricity Sectors through V2G. Energy Policy 36 (9), 2008, 3 578–3 587; and Andersson, S. et al.: Plug-In Hybrid Electric Vehicles as Regulating Power Providers: Case Studies of Sweden and Germany. Energy Policy 38 (6), 2010, 2751–2762.

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of Science and Engineering recently promoted the idea that Germany should not strive to become a *lead market*, but rather to become a *lead supplier* of sustainable electric vehicle components.[21] Policy makers could indirectly promote the market introduction of electric cars by supporting the set-up of charging infrastructure or by purchasing electric vehicles for government vehicle fleets. It is also important to reconsider the future taxation of recharging electricity. Gas station prices for fossil fuels include a high energy tax component in Germany, which is justified in part by the need to finance transportation infrastructure. It should be determined to what extent recharging electricity should also make such a tax contribution in the future, or whether it should be tax-supported in the long term.

From the perspectives of energy and environmental policy, it is important not to raise unrealistic expectations, especially regarding electric vehicles' possible contribution to short-term CO_2 reductions in the transport sector. As the German car fleet will continue to be dominated by conventional vehicles for a long time to come, energy improvements and CO_2 reduction measures for internal combustion engines should by no means be neglected. In addition, natural gas vehicles should be promoted more actively, as they cause relatively low CO_2 emissions and could also be fueled with biogas in the future.[22] Without a doubt, the introduction of electric vehicles should be linked to the expansion of renewable electricity generation. Otherwise, the use of renewable electricity in the transport sector would simply substitute its use for other applications. The potential contribution of electric vehicles to the network integration of fluctuating renewable energy sources should not be overestimated. The use of other electricity storage technologies, demand-side measures, and network expansion seem to be more suitable for achieving this goal.

From a transportation policy perspective, it is clear that the mere replacement of internal combustion engines by electric drives does not represent the sole solution for existing problems – for example, with regard to road fatalities or increasing land consumption. For this reason, electric cars should be seen as one building block of a more comprehensive, sustainable transportation policy that goes beyond motorized individual transport. Even with large numbers of electric vehicles, it will remain essential to pursue urban planning that reduces traffic and shifts it towards carriers that are more resource-efficient and more environmentally friendly. Specifically, the attractiveness and user friendliness of public transportation—which has already been electrified for a long time in the case of rail transport—should be further improved.

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21 German Academy of Science and Engineering: Stellungnahme: Wie Deutschland zum Leitanbieter für Elektromobilität werden kann. Munich 2010.

22 See Engerer, H., Horn, M.: Erdgas im Tank für eine schadstoffarme Zukunft. Wochenbericht des DIW Berlin Nr. 50/2008.