# INTEGRATING BATTERY ELECTRIC VEHICLES INTO THE GERMAN ELECTRICITY MARKET

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## ABSTRACT

This paper gives an overview of challenges for integrating electric vehicles (EV) into the German electricity sector. The focus of the paper is on the electricity market in 2030, which has two advantages. Firstly, the higher share of volatile wind power generation makes electricity storage more important. Secondly, trends within the vehicle market in recent years do not make a rapid switch to overwhelming EV power demand likely.
Three charging principles are presented: (1) uncontrolled unidirectional, (2) controlled unidirectional, and (3) controlled bidirectional or vehicle to grid (V2G). Especially with regard to the third principle two different electricity markets are illustrated, in which EV might provide their V2G service: the electricity storage market for storing superfluous energy during the night and the control reserve market for stabilizing the grid voltage and frequency.
It becomes apparent that EV batteries are better suited to the control reserve market.

*Keywords: Elektric vehicles, vehicle-to-grid, Germany*

# INTRODUCTION

Renewable energies, especially from wind power and photovoltaic, feature a volatile and particularly uncontrollable energy supply during a given 24 hour period. Today, electricity supply is much more flexible[1] and adjustable according to the current electricity demand by households and industries as it has been few decades ago. In the future, however, the high share of renewable energies might lead to a mismatch in the electricity supply and demand. The electricity supply from renewable sources is dependent on environmental circumstances. Therefore, from the current point of view, a constant energy demand cannot be met without fossil power plants unless significant energy storage capacities are established.[2] This leads to new challenges in the storage of electricity and regulation technology for stabilising the frequency and voltage of the grid.

At the same time, vehicle manufacturers are searching for alternatives to fossil fuels and it has become very promising that electric vehicles can overcome many drawbacks of vehicles with internal combustion engines – e.g. concerning the climate change issue and the security of energy supply in the transport sector.

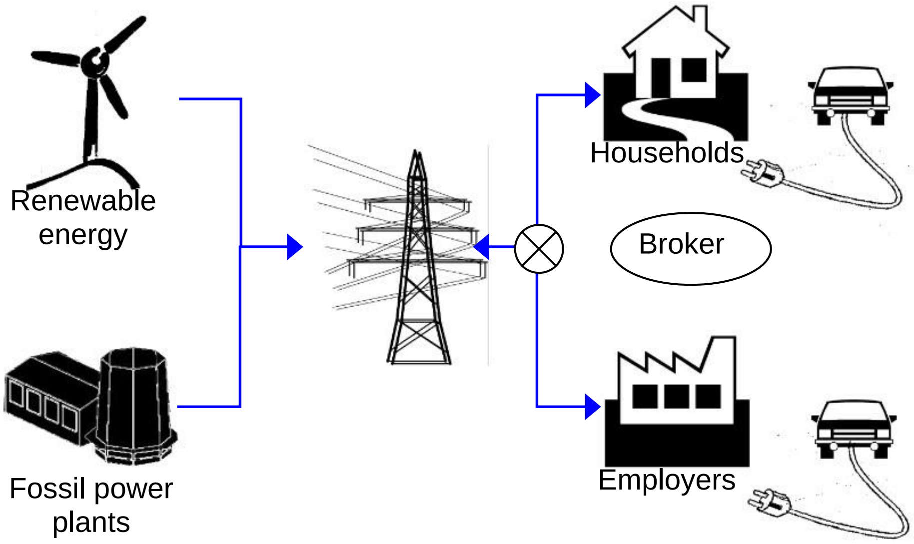
It seems obvious and attractive to combine these two issues in the energy and transport sector: parked battery electric vehicles (BEV)[3] serve as storage power stations for the energy sector. This idea is smart as the peak energy demand is usually at early noon (cooking) and in the evening (cooking and leisure), when in Germany most of the vehicles (more than 90 %) are parked at the work place or at home (GMP, 2009).

The principle is simple (see Figure 1): BEVs are parked and plugged into the local electricity grid. Usually, the battery of the vehicle will be charged instantly. But, in considering the future electricity market, where electricity prices might vary over time on a minute-by-minute basis, it might be meaningful to delay the charging of the battery for some minutes or even to further discharge the battery via the cable connection, in order to profit from higher electricity prices. For the regulation of the whole vehicle fleet it could be meaningful to introduce new business models – e.g. a broker for charging and discharging management of BEVs (Vehicle-to-Grid, or V2G) who optimises the charging of batteries according the electricity prices of the electric supply companies and to provide regulation ancillary services for stabilizing the electricity grid with respect to security and quality (i.e. frequency and voltage) of energy supply. This pooling of vehicles has the advantage that the availability of batteries for storage services increases and the low price elasticity of electricity demand in Germany (Bower et al., 2001) might be enhanced by a professional broker.

[1] However, strong constraints consist due to high energy losses for the start up processes of fossil power plants (Klobasa, 2009:120).

[2] We assume from today's perspective, that demand side management approach does not significantly change the electricity consumption behavour of households.

[3] We will focus our analysis in the following on BEV, as their battery capacity is higher than for Hybrid Electric Vehicles. Therefore they are more suitable in the context of electricity storage.




With ⊗: Regulation of the electricity for charging vehicles

Figure 1 – Sketch of V2G (own source)

Some authors have already shown that V2G could already be profitable, conditional on some assumptions. For example, Kempton et al. (2001) argued that in California V2G was already profitable in 2001. Furthermore, Lund and Kempton (2008) demonstrated for Denmark that an introduction of EVs and V2G allows an efficient integration of much higher levels of wind electricity with an accompanying decrease of $CO_2$ emissions. This secondary effect of decreasing $CO_2$ emissions is important too, as the transport sector, the second largest emitter of greenhouse gases, is the only sector in the European Union (EU27), which increased its emissions with regard to 1990 (Eurostat, 2008). Besides the huge growth of $CO_2$ emissions in aviation (+80 %), this increase is mainly caused by road transportation. Concerning the share of overall (direct) $CO_2$ emissions from transport in the EU-27, road transport plays a crucial role because it is responsible for more than 70 % (Eurostat, 2008). When considering only inner European transport, the share of road transport exceeds 90 % of the transport emissions (Eurostat, 2009). Most studies forecast a further increase in transport emissions until at least 2020 (e.g. EC, 2008a).

Even though the $CO_2$ emission reductions through EVs are strongly dependent on the energy mix, the reduction potential is significant – especially when compared with other fuel alternatives (Jochem, 2009:64ff).[4] The marginal abatement costs of electrification are rather high, however (BDI, 2007:41). According to Machat and Werner (2007), even the current specific average $CO_2$ emissions per MWh in Germany (600 grams of $CO_2$) leads to an emission reduction of about 20 % for passenger cars. This is however not sufficient to meet the European target of 2015 of 130 grams $CO_2$ per km. A higher share of wind power in Germany would undoubtly lead to a much higher emission reduction potential.

[4] Only fuel cells can almost reach this emission reduction potential, but for higher costs (see, among others, Jorgensen, 2008).

Hence, besides this storage feature of BEVs, many other aspects (e.g. environmental[5], economic independence[6], and business driven factors[7]) favour a broad penetration of electric vehicles. But although these aspects with regard to the relevance of the market penetration of BEVs exceed the storage feature by far, they are not examined in this paper. Similarly, it does not provide suggestions concerning the ongoing discussion of an acceleration of the market penetration of BEVs.

The paper considers the potential for regulation ancillary services for stabilizing the (local) electricity grid with respect to frequency and voltage and the storage of electricity to provide additional electricity during peak hours.[8]
The following section provides an introduction to the current German energy sector. Afterwards, an outlook for German electricity supply to 2030 is given. Then, the current challenges of electric vehicles and their penetration potentials in the German transport sector are sketched. Finally, the usage of the storage capacity of BEVs and how they might contribute to an accelerated penetration of renewable energies in the energy supply framework are discussed. A conclusion then recapitulates.

# THE GERMAN ENERGY SECTOR

Before natural gas and nuclear power plants challenged the dominance of coal and lignite power plants the German electricity production was dominated by combustion of (mainly) domestic resources. Before 1990, renewable energy power plants besides hydropower did not account for significant shares on the energy generation. Today, the German electricity sector is dominated by fossil and nuclear power plants which provide 85 % of the current net electricity generation. Currently, renewable energies have a share of only 15 % (see Figure 2). In 2008, hydro power plants supplied about 26.7 TWh of electricity. Wind power became the largest electricity provider amongst the renewable energy sources. In 2008 wind power generation provided about 40 TWh electricity for the German market. Other renewable energy sources are for example photovoiltaik, geothermical energy, biomass, biogas, waste; together they have a share of 5 % of the German electricity supply.

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[5] Besides $CO_2$ emissions, the transport sector emits carbon monoxide (CO), nitrogen oxides ($NO_X$), volatile organic compounds (VOC) and other particles (PM) which are hazardous for human health and the environment. These emissions can also be reduced (at least locally) by BEV. However, due to tyre and brake pad abrasion, small parts of particles will remain. Even noise problems in cities would be reduced, especially for cars driving slower than 60 km per hour, as for faster velocities other driving noises dominate (Wietschel and Dallinger, 2008).
[6] EU Member States are highly dependent on imported transport fuels – in 2005 the oil dependency of the EU-27 was 82.3 % with more than two thirds of imports coming from the Middle-East and Russia (EC, 2008b).
[7] E.g. electric supply companies have incentives to increase their electricity sales. The average household has an energy share for transport of about 30 % (AGEB, 2009).
[8] This article neither considers potential penetration rates of EV in the vehicle market, nor electricity production of hybrids or fuel cell cars via their combustion engines (as e.g. Kempton et al., 2001).

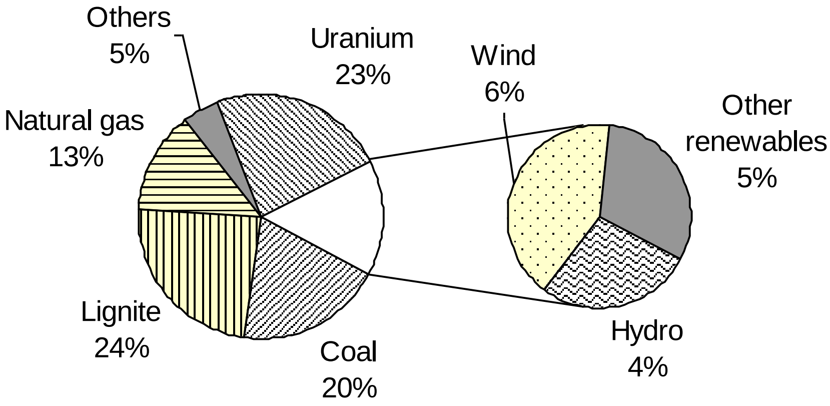


Figure 2 – Share of German net electricity generation in 2008 (637.6 TWh) (Destatis, 2010)

At any time the produced electricity must match its demand to provide electricity with constant frequency and voltage quality. Therefore, power plants constantly vary their operations corresponding to the current demand. But not all power plant types are able to alternate their load equally well. Typically, power plants are classified in base, middle and peak load power plants. Peak load power plants such as gas fired and pump storage power plants are most suitable for load variations. These load variations are called control reserve, classified in tertiary (or minute), secondary, and primary (or spinning) control reserve (Figure 3). Within the control reserve markets the suppliers have to hold the provided reserve during the whole defined time period; if the reserve is required, it has to be available at full capacity immediately (about 5 seconds) until up to five minutes in the primary control reserve market. In the secondary control reserve market the suppliers have to replace the primary reserve within 30 to 300 seconds and must guarantee the capacity for up to 15 minutes. Capacities in the tertiary control reserve market have to be available 15 minutes after the disturbance. The provided capacity might be provided for several hours. For all of these reserve markets, negative and positive balancing power is traded. Negative balancing power is needed for unexpectedly high power feed-in or low demand, while positive balancing power is required for unexpectedly low power production or high demand. Sufficient control reserves are essential for a secure electricity system. The corresponding capacity prices differ widely in the different reserve markets from 70 (for electricity absorption in the tertiary market) to 350 (for electricity delivery in the primary market) Euros per MW provided (Oberschmidt and Klobasa, 2008). The additional work price (really consumed electricity) ranges from 4 to 90 Euro per MWh.

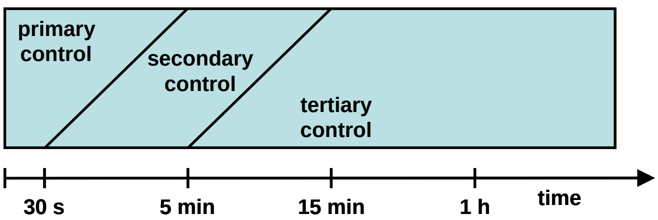


Figure 3 – Operation of control reserve types in different time periods (Rosen, 2007)

Providers of the different control reserves have to fulfil the warranty requirements for the security of energy supplies. The requirements range from technical competences and operative conditions to economic capacity of the potential provider of control reserve, and differ depending on the control reserve types (VDN, 2005).

## The German energy sector in 2030

In the next decade nuclear power plants will be mothballed due to governmental restrictions in Germany. Due to the European Emission Trading Scheme (EU-ETS), primarily gas fired and renewable energy power plants will compensate for these losses in electricity generation. The increase in installed renewable energy capacities, especially wind power generation, will lead to an increase in the volatility of electricity generation in 2030. Gas fired power plants will also be more dependent on the actual generation of wind turbines. Nevertheless, the German import dependency on fossil fuels will remain (see Figure 5). Equally, the $CO_2$ emission reduction targets under the EU-ETS will lead to a higher urgency for emission reductions to maintain the foreseen emission reduction path. But with increasing renewable energy capacity the ability of the power plant portfolio to respond to load variations will reduce due to the stochastic feed-in of power from wind turbines and solar power plants.[9] While a prognosis of electricity from photovoiltaik is rather uncomplicated, the electricity from wind power is very unstable. In Figure 4 a sketch of the empiric volatile feed-in from wind turbines is given for the year 2007. It is obvious that the capacity differs from nearly zero to about 18 GW in a very volatile manner.

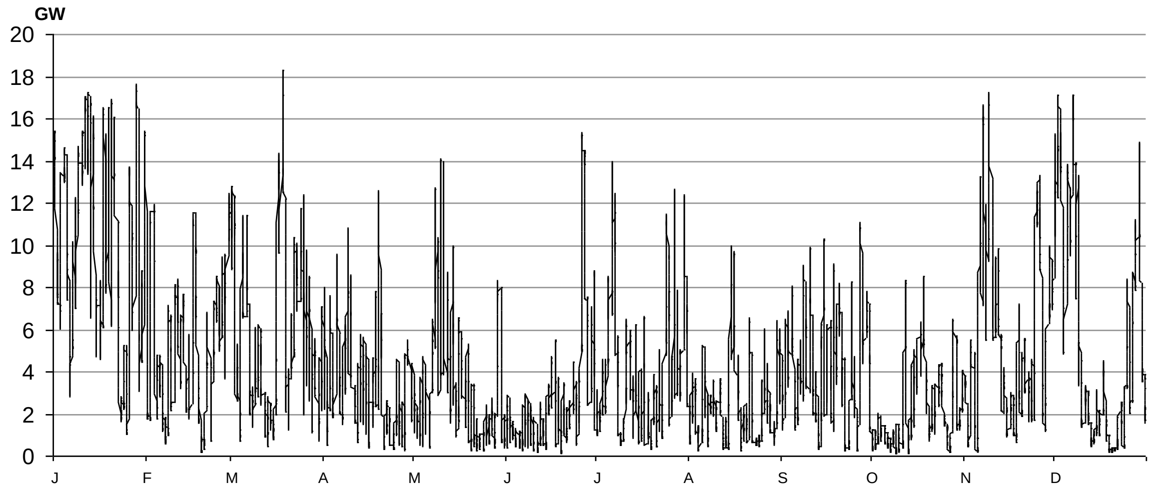


Figure 4 – Wind feed-in in Germany in 2007 (mean hourly values in GW) (Data of German grid operators, 2010)

According to the outlook for the European energy supply by the European Commission (EC, 2008a), the German electricity demand increases from 517 TWh in 2005 to 620 TWh in 2030. This corresponds to a growth until 2030 of about 20 % or roughly 0.7 % per year. The gross electricity production share of renewable energies nearly doubles from 11 % in 2005 to 21.3 % in 2030. Nevertheless, thermal power plants still hold the majority of the German

[9] Nevertheless, besides this increasing volatility some countermeasures (e.g. demand side management etc.) can be applied to compensate for these amplitudes (see, among others, Dany, 2000).

power plant portfolio with 67 % of the net generation capacity (Figure 5). Coal and gas fired power plants hold the largest and second largest share, respectively, of net generation capacity until 2030. Wind power generation provides the third largest fraction with 23.2 %. All other energy resources together supply no more than 12 % of the total net generation capacity in Germany in 2030.

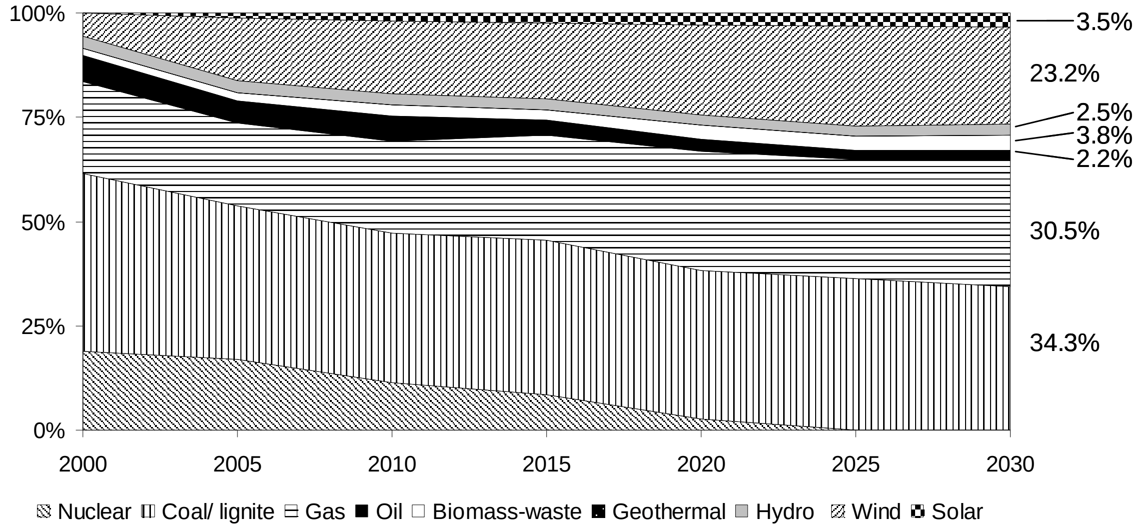


Figure 5 – Development of power plants net capacities in Germany (EC, 2008a)

Especially the increased share of wind power generation leads to an increased volatility in the electricity supply. This obviously leads to a greater need for electricity storage capacities and more volatile electricity prices. In the following section it is analysed whether BEVs are suitable to provide profitable electricity storage capacities.

# ELECRIC VEHICLES

When automobiles first appeared, in the late 19th century, electric vehicles were in some ways superior to vehicles with integrated combustion engines. In particular, electric vehicles were valued for their silent and smooth driving. For example, in 1900, the share of EVs in the US was about 38 %; 40 % were steam driven and 22 % were driven by petrol; in New York the share of electric vehicles was even 50 % (Sammer et al., 2008). Furthermore, the first passenger car reaching 100 km/h (about 60 mph) was an electric vehicle (Larminie and Lowry, 2003). But, an unsatisfactory range led to a rapid extinction of electric vehicles.
Still, the most critical sticking point of electric vehicles is the range – i.e. the battery life. Fuel cells are still far from being cost-effective and batteries do not provide satisfactory operating distances within an acceptable budget or weight/space demand.
Currently, the most promising technology seems to be the lithium-ion (Li-ion) battery, which features an energy density of about 170 Wh/kg and is consequently superior to nickel metal hydride (NiMH) and other current battery technologies (Kalhammer et al., 2007). Various authors have confirmed that current batteries already fulfil the usual requirements of electric driving, including daily distances and lifetimes of passenger cars (e.g. Axsen et al., 2008, Kalhammer et al., 2007). According to Peterson et al. (2009), current Li-ion cells (i.e. A123

systems ANR26650M1 cells) are even appropriate to provide V2G services for many years[10]. The costs of these cells are still not competitive with conventional combustion technologies, however, but the development in recent years suggests a continuing reduction of battery production costs (Biere et al., 2009).

Concerning the national electricity grid interaction, BEVs are said to provide electricity at about \$0.30/kWh$_{el}$ for current lead-acid and Li-ion batteries. For nickel metal hydride (NiMH) and nickel cadmium (NiCd) batteries this value is significant higher (Kempton et al., 2001, and Beurskens et al., 2003). However, these values strongly depend on the underlying assumptions. The prices by pump-storage hydro power plants or thermal and compressed air storage systems are about \$0.03/kWh$_{el}$ (Beurskens et al., 2003). Though, when taking the volatile prices on the European electricity exchange stocks (e.g. the EEX) and the local terrain requirements as well as the high investments for storage power plants into account, V2G might in fact be an attractive alternative.[11] Hence, C2G is underpinned by its low capital costs, fast variability, and low maintenance costs (Tomić and Kempton, 2007).

The prognosis of the penetration of BEV in the German transport sector is linked to the question of different vehicle types. In principle, every car that is capable of driving with an electric engine alone is said to be an EV. According to this definition, hybrid electric vehicles (HEV) containing internal combustion engines (ICE) and electric engines are EVs, too. HEVs can be distinguished between micro, mild, and full hybrids. The micro HEV includes a small electric engine beside a usual ICE, which allows the ICE to be switched off during short stops at traffic lights: when the driver pushes the accelerator again, the electric engine accelerates the vehicle for the first few metres, and the ICE resumes after a comfortable restart without hindering the remaining traffic. The mild HEV includes a more powerful electric engine which can recuperate the kinetic energy into electricity while the vehicle decelerates and can support the ICE during strong accelerations. The full HEV allows pure electric-powered driving and consequently includes charging capability to recharge the enhanced electricity consumption. As their battery should be regularly charged, most full HEV have a conventional plug for household sockets – the so called plug-in HEV or PHEV.[12]

Hence, the battery type and capacity is strongly dependent on the BEV type and its envisaged operation area. A small vehicle mainly for city use would require only about 0.12 kWh per kilometre, which leads to a sufficient battery capacity of about 20 kWh (Kalhammer et al., 2007). But huge vehicles with a larger range need much higher capacities, with batteries of more than 60 kWh if no range extender is considered. The costs and weight of these batteries are still too high.

However, the pure data on transport demand suggests that BEVs suffice to accomplish more than 95 % of our daily trips (GMP, 2009). But most surveys obtain very different results when people are asked about their personal evaluation (Zumkeller et al., 2005). The analysed data of actual trips (GMP, 2009, and Infas and DIW, 2004) show that two out of three trips are shorter than 10 km and 80 % of trips are shorter than 50 km. The parking times are mostly

[10] Peterson et al. (2009) conclude that after several thousand days in V2G service the cell capacity of applied Li-ion batteries is still above 95 %.

[11] On the European Energy Exchange the electricity prices varied between -500 and 100 € per MWh in 2009 (EEX, 2010).

[12] The abreviation PHEV should not be confudsed with the sometimes used abreviation PEV (which is used for pure electric vehicles in contrast to HEV).

long enough to recharge the battery and, furthermore, during the day at most 21 % of vehicles are being driven whilst all others are parked; during the night more than 99 % of vehicles are parked (Infas and DIW, 2004).[13] For all other trips, where a BEV is not appropriate (e.g. holidays) a well appointed car sharing alternative might be sufficient and desirable for most households.

However, the increased energy demand through the electrification of passenger cars might lead to shortages in electricity during the evening hours. An uncontrolled electricity demand for passenger cars would currently lead to the demand structure during a typical working day shown in Figure 6.[14] It is evident that the demand of these electric passenger cars will enhance the electricity shortage during evening hours, as the demand increases during the day and peaks at the same hour as it does today. This profile can be significantly influenced by the charging rate. If the charging rate for the vehicles is increased, the morning slope (between six and nine o'clock) is much steeper and the load curve is much higher during the day. Hence the conventional peak load (at about 18 o'clock) is increased, and in the early morning hours (before 6 o'clock) the electricity demand for EVs is almost zero.

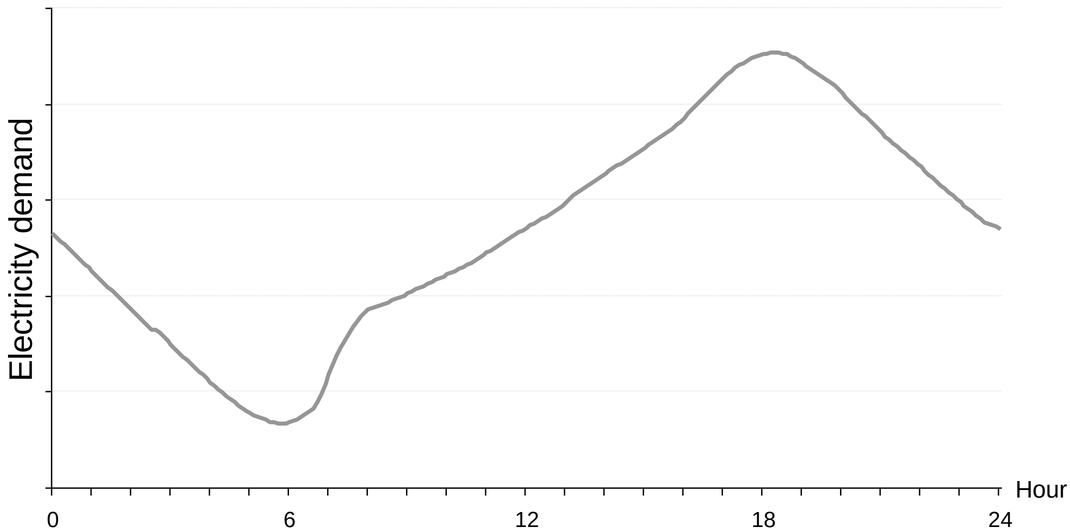


Figure 6 – Electricity demand structure of private EVs during the day (own figure)

Hence uncontrolled charging is disadvantageous. Therefore, an adjustment of the charging schedules seems reasonable. Fundamentally, three different charging processes are conceivable:

- uncontrolled unidirectional (1),
- controlled unidirectional (2), and
- controlled bidirectional (3) or vehicle to grid (V2G) charging.

(1) Usually electronic equipments do not have a time control over the electricity demand, e.g. the plug in of a mobile phone leads immediately to the charging of the battery. But between

[13] Needless to say, not all vehicles can be plugged in during their parking (e.g. people, who park in the streets – "street lamp parkers"), but during the night 63 % of German car owners usually park their cars in a garage or on a private parking space (Destatis, 2009).

[14] This figure is calculated with GMP (2009) data and it is assumed that each car is plugged in when the trip ends, and the charging begins immediately with a charging capacity of 3.68 kW.

17 and 18 o'clock, thousands of vehicles will arrive at home, and if they immediately plug in their EV, the electricity demand will be strongly multiplied during these already highly loaded evening hours – especially in the winter season (see Figure 7). This uncontrolled unidirectional charging might lead to a shortage in electricity supply during the evening hours.[15]

(2) If, however, the moment of the plug in is temporally separated from the charging process (controlled unidirectional charging), the shortage in the evening hours is avoided. However, due to the higher share of wind power generation a further disequilibrium of electricity demand and supply is expected, which makes a further optimisation of vehicle charging more attractive.

(3) This leads to controlled bidirectional charging which allows the car owner to trade electricity when using the battery as an electricity storage system. The required infrastructure (an electric bush to plug-in the car, a smart meter, and the possibility of feeding in electricity to the grid) at the charging station allows charging and discharging according the effective and flexible price for electricity, which reflect the actual scarcity or surplus of electricity in the grid.

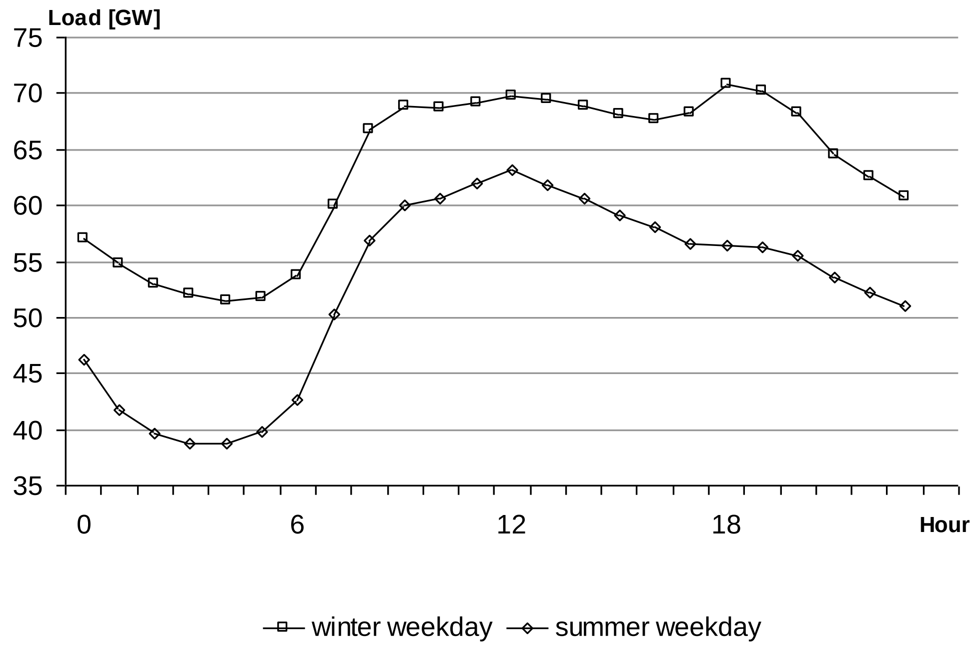


Figure 7 – Typical winter and summer load curves in Germany (ENTSO-E, 2010)

V2G enables the time shifts in electricity demand and supply to be harmonised. In an extreme position, a constant electricity demand of about 30 GW is foreseeable for Germany (Heider et al., 2009), if enough BEVs provide V2G services during the day. This might considerably change the power plant portfolio.

[15] This shortage is strongly limited by the charging rate, which mainly depends on the domestic grid capacity. In Germany the fuse in a common household is rated at 16 A. As the circuit's voltage is 230 V, the resulting maximum power capacity in Germany is limited to (230 times 16) 3.68 kW. In reality the charging rate might be about 3.5 kW.

However, the BEV must compete with other electricity storage systems such as pump-storage hydro power plants, thermal and compressed air storage systems, electrolysis (hydrogen) or other stationary battery technology. As mentioned above, Li-ion batteries are much more expensive than pump storage hydro power plants or thermal and compressed air storage systems by a factor of 10 to 30 (Beurskens et al., 2003) – depending on the storage requirements, the costs of the technology and the assessment of investments for the Li-ion battery (which is available anyway by plugged in BEVs).

When neglecting the investment costs of the battery (as it is purchased for travelling and not for storage), BEVs are well suited to storage capacities if their lifetime is sufficient to withstand the additional charging cycles. The lifetime of Li-ion batteries is strongly dependent on the depth of discharge and charging rate[16]. Full loads, complete emptying or fast charging do negatively influence the lifetime of Li-ion batteries. If this advice is heeded, the lifetime of current Li-ion batteries exceeds the lifetime of the vehicle (Peterson et al., 2009, and Jorgensen, 2008).

If the households should be integrated in the storage capacity (or control reserves) market, a rethinking of the German electricity payment system is required. Today most German electricity customers receive an invoice for their electricity consumption once a year with a monthly advance payment. This has the advantage of constant payment during the year. This is convenient as households pay a constant electricity price to the electric utility. However, if this constancy is abandoned, the accounting period should be shortened to a week or month, in order to encourage households to adopt their electricity consumption according to the current electricity price. Weekly accounting makes the adaption of electricity demand according to hourly prices for households more attractive, as they directly see the result of their behaviour. This might increase the price elasticity of electricity. Currently, in Germany, only a small price differentiation is encountered overnight.[17] Smart metering, which is obligatory for new or renovated houses in Germany after 2010, is a first step towards electricity charging on an hourly basis (graduated tariff). Houses with photovoltaic or combined heat and power systems already satisfy another requirement of V2G – the possibility to feedback electricity into the grid. However, with the electricity price reduction overnight, no significant profit is possible by applying V2G today. But for brokers, pooling many BEVs is already profitable – according to the adage that “every little helps” (Heider et al., 2009).

# ELECTRIC VEHICLES FOR STORAGE OR CONTROL RESERVES?

As depicted above, due to the higher wind power generation share, the electricity storage demand will be increase by 2030. The storage demand refers on the one hand to storage capacity for shifting superfluous electricity by wind power generation during the night to the following day and from one windy week to a windless week or season, respectively. On the

[16] As shown above, the charging rate in a German household is usually limited to 3.68 kW, but fast charging stations with 20 or even 40 kW are discussed, and in California already 6 kW charging stations are established (Kempton et al., 2001).
[17] The electricity is cheaper during the night, which is attractive for night-storage heater users. Only a few households use this tariff in Germany.

other hand it refers to the control reserve for ensuring a stable electricity supply. As stated above, the second issue is especially relevant for the V2G approach.

First, looking at the (long term) storage capacity in 2030, it becomes obvious, that due to the daily and seasonal differences in electricity supply of wind power generation, an enhanced capacity will be required. If we assume, that the absolute increase of wind power generation is about 47 % between 2010 and 2030 and its share increases by 6 % (from 17 to 23 %; EC, 2008a) it has to be assumed that the volatility in the market and its prices will further increase, too.[18] Currently, the electricity storage system (i.e. pump storage) amounts to about 11 $GW_{el}$ (German federal grid agency, 2008). To absorb the increased volatility by wind power generation, the storage capacity in the grid should be expanded by at least 50 % (see German Energy Agency, 2005). This means that in 2030 a storage capacity of about 17 $GW_{el}$ might be reasonable even if other countermeasures for levelling out the volatility and a grid expansion (German Energy Agency, 2005) are introduced and accomplished, and assuming an additional average storage capacity of 6 $GW_{el}$ and if it is also assumed that this additional capacity is provided only by BEVs, where each BEV has an average battery capacity for V2G services of about 10 kW about 600,000 plugged in BEVs would be necessary – less than two percent of the current global German vehicle fleet. Similarly, Heider et al. (2009) assumed a maximum storage capacity of 140 GW for the whole German passenger vehicle fleet (by taking into account that only 30 % of BEVs are plugged in). These numbers of EVs in 2030 are not unrealistic. However, pump storage power plants do store the electricity for several days or even weeks (Möst, 2006:32). And this is not very meaningful for EVs, as they are usual daily used. Storing (superfluous) energy for some days is not efficient, as the battery capacity can not be used entirely during these time period. Hence, BEVs cannot help with the (long term) storage issue – it represents too little storage capacity and is too expensive. A further extension of the grid and other storage systems (i.e. pump storage) would be more reasonable (German Energy Agency, 2005).

Secondly, looking at the second issue for V2G, the control reserve, it becomes obvious that the characteristics of V2G are very suitable for providing (in particular primary and secondary) control reserve (see Kempton and Tomić, 2005). For this the EV should provide the required electricity simultaneously for up to five minutes for primary control reserve and up to 15 minutes for the secondary control reserve. They can provide positive as well as negative reserve instantly without a notable time delay. The daily volume in Germany for the primary and the secondary market amounts for positive and negative control reserve to about 0.6 GW and 3 GW, respectively (Riedel and Weigt, 2007:11; Swider, 2006:11). Assuming an average capacity of 10 kW per EV for V2G services and a maximum charging rate of 3.5 kWh it is obvious, that at least 300 plugged-in EVs are needed per bid if we assume that a bid for 1 MW is allowed within the primary and secondary control reserve.[19] This can be hypothetically provided for 2.5 hours. Obviously, a change in the charging rate will reduce the demand on EVs correspondingly. Furthermore, if we assume that the additional demand on secondary control reserve will increase to 5 GW, about 1.5 million EVs (4 % of the German passenger car fleet) would be required to provide this additional request. For the tertiary

[18] This volatility remains even for off-shore wind power plants, but might be reduced slightly due to enhanced wind prognosis tools (Klobasa, 2009).
[19] Today the smallest bid in the primary and secondary control reserve market in Germany is limited to 10 MW (German federal grid agency, 2007).

control reserve the amount of energy within the batteries might not suffice to guarantee several hours of applying electricity. Hence, EVs are inferior to gas fired power plants in this issue.

Assuming a considerable improvement of battery technology, and their availability (i.e. corresponding market penetration), they are competitive to other storage technologies. In this context BEVs can provide assistance to a higher share of regenerative energies such as wind power or photovoltaic. Even a relatively small number of vehicles (a few million) distributed in the grid might help to regulate the reliability within the local grid when they are adequately managed by brokers. The profits for the vehicle owner due to V2G are hard to forecast, however, as they are strongly dependent on the depreciation costs of the battery, the price volatility in the future electricity market as well as the mobility behaviour of the household. Neglecting legal and acceptance concerns by households, several vehicles are professionally pooled by a broker, who optimises the charging of the fleet leads to considerable profits. Kempton et al. (2001) suppose that in the US already in 1998 up to $ 3000 annual net profits per BEV were possible.

From the current point of view, the development of the last months in the field of EVs is too heterogeneous to make reliable forecasts of the German market. But system analytic research and precise monitoring of the developments in the fields of battery technology, wind energy, politics and individual behaviour of households and companies might help to bring more clearness to potential developments of the future. For this an interdisciplinary and applied approach is necessary. For the sake of the dream of zero emission transport a further research is indispensable.

## CONCLUSIONS

When analysing the development of the German energy market in recent years and until 2030, it becomes apparent that the electricity supply is getting more and more volatile. This leads at the same time to more volatile prices and to an increased demand for electricity storage and control reserve. Electricity storage systems store superfluous energy (e.g. during windy nights) to provide electricity during the daytime. The control reserve market includes positive and negative energy and stabilizes the grid voltage and frequency by providing the right amount of energy at the right time. For this the reserve market keeps a huge amount of electricity in readiness – even if only a small share is needed. The price for electricity is higher in the control reserve market and the provided energy is not necessarily released. However, the pure commitment fee is compensated in any case. This makes it very desirable for battery storage systems.

At the same time, the German vehicle sector expects an increasing fleet share of EVs. These seem to be plugged into the grid for most of the day. Hence, batteries might be used for control reserve services if the necessary infrastructure (smart meters, energy recovering system, etc.) is installed. This is advantageous not only for the control reserve but also due to the fact that an uncontrolled charging system might lead to shortages in electricity supply during the daily peak load hours (i.e. in the evening). A lagged charging system can overcome this shortcoming, but a V2G technology would be most suitable – at least when neglecting costs. For optimising and controlling the charging a broker (for the fleet) seems reasonable. Even if EVs have higher costs for providing electricity today, they can provide positive as well as negative control reserve instantly without a significant time delay at the location where it is most required. These advantages are without controversy from a technological point of view. This might be even more appropriate when in the future the service life of batteries exceeds the lifespan of vehicles without boosting costs. In this case V2G would be an appreciated auxiliary income for the vehicle owner. But, so far they are not competitive with other storage technologies, except for some applications in the primary and secondary control reserve.

In conclusion, due to the increase in wind supply in Germany, a higher storage and control reserve demand in the future can be expected. This makes the probability of an increased involvement of households in the electricity market more likely – how this would be manifested is strongly dependent on the future battery development and the change in householder behaviour. The latter is characterised through a very heterogeneous and partly irrational behaviour with respect to vehicle purchases (Jochem, 2009). Hence, the forecasting reliability of conventional simulation models with representative individuals is limited. Spatial multi agent simulation models (e.g. Sensfuß, 2008, or Jochem, 2009) might overcome these shortcomings.

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