E-Mobility and its future effect on demand and flexibility

Chances and challenges 2035 from a transmission system operator's perspective

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***Abstract*— Germany is currently in the middle of the energy transition ("Energiewende"). An important future question is how to foster the decarbonization of other sectors to fulfill the ambitious CO2-reduction targets in Germany laying ahead. Especially the electric mobility sector is expected to play a major role in sector coupling and could provide new features within the energy landscape.**

The impact of electric vehicles on demand profiles (in addition to small storages and other flexibilities) in a demand forecast methodology with electric vehicles including the distribution of the demand across Germany were developed and the results taken into a scenario framework of the 50Hertz Energiewende Outlook 2035 to show the impacts on the electricity markets, the generation mix and necessary grid extensions.

With the developed methodology the effect of electric vehicles on demand and flexibility, as well as the accompanying chances and challenges are modelled from a transmission system operator's perspective for 2035 scenarios.

But in this article not only Germany is in the focus: Based on the international business experience of the authors the status of e-mobility in Qatar and Japan from a grid perspective is outlined.

Keywords: demand forecast; flexibilities; regionalisation, scenario building, Germany, Qatar, Japan,

INTRODUCTION

Germany is currently in the middle of the energy transition ("Energiewende"). Over 30 percent of national power consumption is already covered by renewable energy sources (RES). An important future question is how to foster the decarbonization of other sectors to fulfill the ambitious CO2-reduction targets in Germany laying ahead.

Especially the electric mobility sector is expected to play a major role in sector coupling and could provide new features within the energy landscape. In figure 1 the impact of national CO2-Emission reduction targets and the quantities for different sectors is outlined. Up so far the recently observed CO2-emission reduction seems limited.

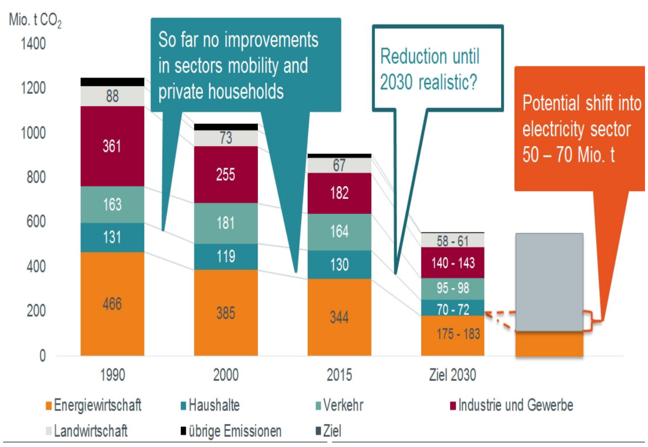

Figure 1. Greenhouse Gas emissions in Germany and targets 2030. (Source: Umweltbundesamt Januar 2016; Klimaschutzplan 2050 der Bundesregierung November 2016

The upcoming development trends of the energy transition remain uncertain (esp. with regard to the policy objective of achieving 80% of electricity usage from renewable energy sources by 2050).

To study some of these impacts on the electric grids a detailed grid study for the time horizon 2035 was performed.

2035 SCENARIOS, METHODOLOGY AND RESULTS

A. Scenaios 2035 and methodologies

In the 50Hertz Energiewende Outlook 2035 five energy transition scenarios were developed, all of which are realistic: the "prosumer-oriented energy transition" scenario depicts a world with a high number of small storage units, often combined with PV installations. The "energy transition in accordance with the EEG model" scenario describes the actual developments where the political targets are achieved through the combination of different technologies. A "competitive energy transition" scenario simulates the impact of technology-neutral tender procedures that would very likely bring stronger support for installations at productive locations. Finally, a "delayed energy transition" scenario, where the political objectives would only be reachable with a delay and an "incomplete energy transition" scenario, where the lack of public acceptance prevents reaching the political targets, are also analyzed. An overview is given in figure 2 [1].

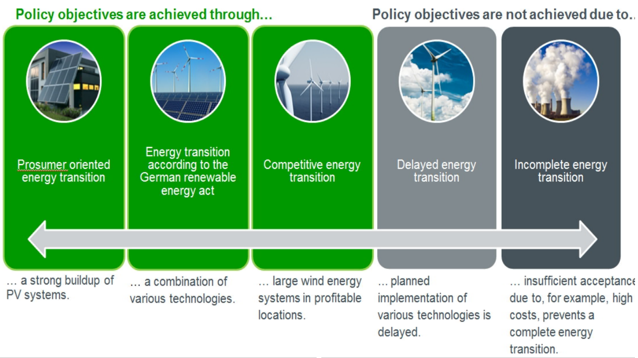

Figure 2. Overview of the 2035 Scenarios in the Energiewende outlook

Looking at the RES scenarios in [1] it is expected, that the German energy mix will change significantly as shown in figure 3.

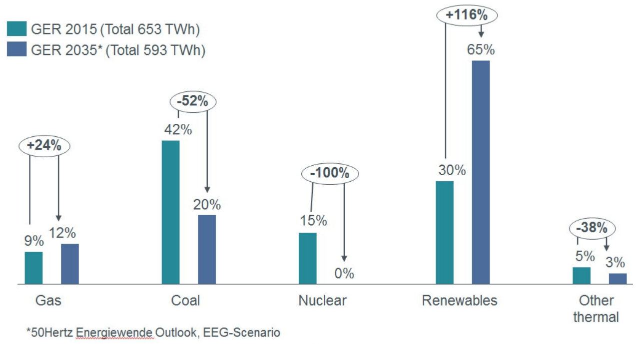

Figure 3. Greenhouse Gas emissions in Germany . (Source: Umweltbundesamt Januar 2016; Klimaschutzplan 2050 der Bundesregierung November 2016

The methodology of the study included prognoses, grid and market calculations as outlined in figure 4 [1].

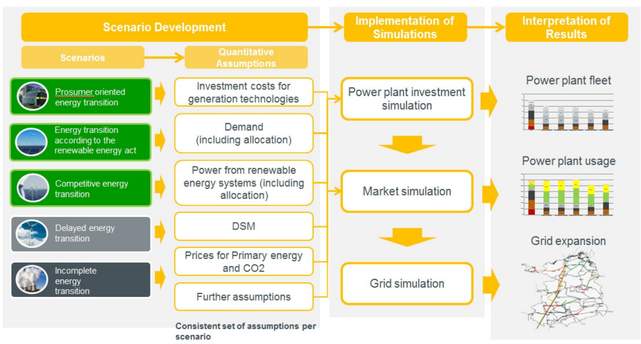

Figure 4. Study methodology

Within the study the effect of a rising number of electric vehicles was modelled according to figure 5. The demand forecast methodology includes the distribution of the demand across Germany and the impact of electric vehicles on demand profiles (in addition to small storages and other flexibilities). To assess the end consumer electricity demand the methodology uses an existing base year and public available statistical data to provide a transparent set of indicators.

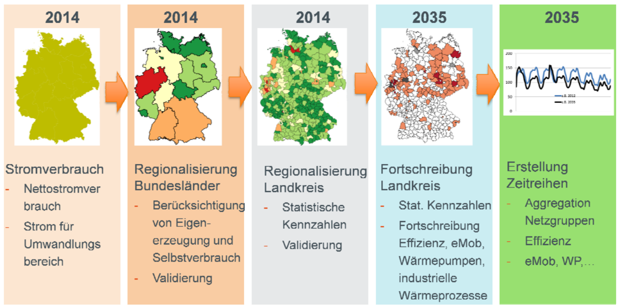

Figure 5. Overview of the methodology.

The indicators for the demand in trade, commerce and small industry, households, industrial heat, heat pumps, transport were derived from statistical data on population, number of households, statistics of buildings, gross value, employees, number of cars etc. which are available on rural district level. The overall electricity demand of Germany can then be distributed on district level and applying a consistent development (e.g. a demographic forecast or sectoral prognoses) a future demand can be formed out of the contribution of the different sectors. To achieve the resulting load profiles of the target year the adjusted and calibrated load curves of the base year were set up using the sectoral curves and specific profiles for single technologies (e.g. e-Mobility, heat pumps). In each profile a certain level of flexibility can be taken into account that influences e.g. the resulting peak load.

B. *Results of the Scenaios 2035*

One of the results for electrical demand in the scenario framework of the 50Hertz Energiewende Outlook 2035 is shown in figure 6. Due to efficiency measures the "classical" demand is expected to be reduced while new consumers like heat pumps and E-Mobility need additional electric energy (figure 6).

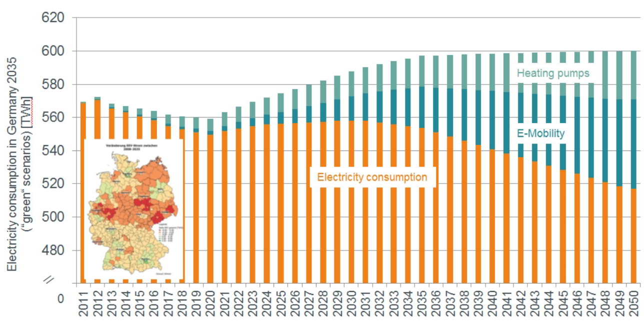

Figure 6. Assumed development of the electric demand in Germany in the scenarios of the Energiewnede Outlook

Results of the market modelling show that in 2035 the total German surplus for export can be considerably reduced and the German surplus for export that can be observed at present will drop substantially. In some scenarios, Germany will even tend to be a net importer of electrical energy. Figure 7 shows the modelling results for Germany:

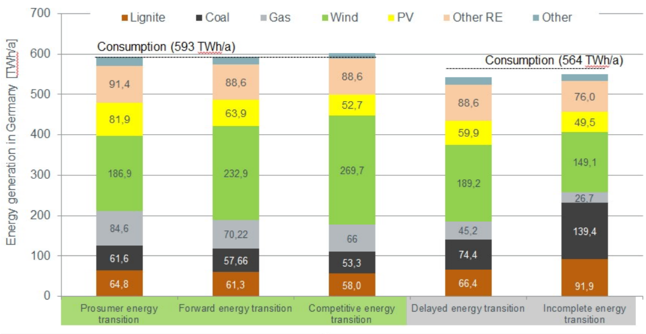

Figure 7. Assumed development of the electric demand in Germany in the scenarios of the Energiewnede Outlook

Questions regarding EVs in Germany

But looking at the future of EVs one may ask the following questions:

- Will the energy system and its current infrastructure in Germany limit a large scale roll-out of e-mobility?
- Can we identify necessary technological requirements resulting from a large scale EV roll-out?
- Do we see opportunities for e-mobility to contribute to cost-efficiency of the future energy system?

Looking at the demand of Electric Vehicles (EVs) it can be seen (in a simplified approach), that – despite of a high uncertainty on amount of EVs in 2035 in Germany – the relevance of EV power consumption on overall electricity demand is expected to stay low even if around 10 million EVs are allowed figure 8.

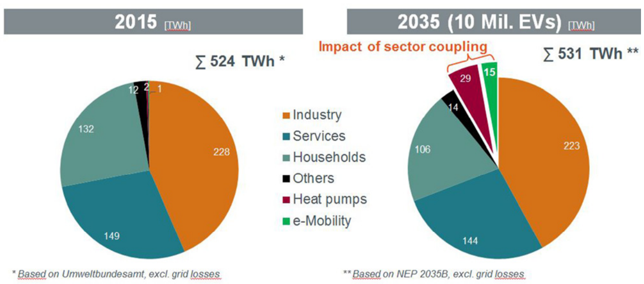

Figure 8. Assumed development of the electric demand in Germany in the scenarios of the Energiewnede Outlook

The planned grid expansion will decrease current constraints in ultra-high and high voltage grid caused by RES feed in, so that in the future no significant constraints are expected e.g. by highway charging in 2035. On distribution system level, new consumers like EVs and heat pumps might lead to congestion in low voltage grid if smart charging strategy is not applied. Amongst the ancillary services in Germany, balancing is by far the most important category (from a financial perspective), but electric vehicles as power storage devices cannot cover long-term storage issues if compared to the infeed of a wind front infeed observed in Germany March to April 2015 (figure 9).

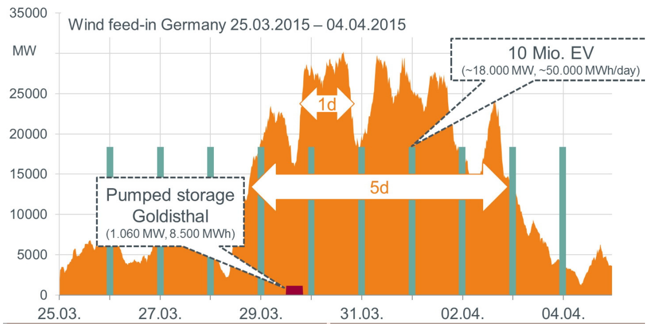

Figure 9. EV as power storage devices in comparison to a 2015 windfront infeed in Germany

There is potential in the electricity market, but it is limited. Regarding flexibility – cheap alternatives to storage do exist therefore sstorage will probably not be a game changer as shown in figure 10 which outlines additional costs/savings of one GW flexibility options in 2023 (43% RES in DE / 22% RES in EU).

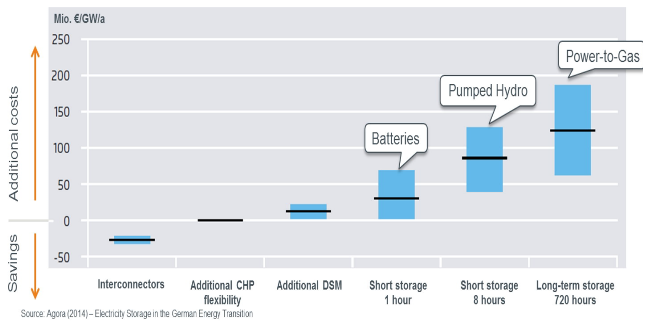

Figure 10. Additional costs/savings of one GW flexibility options in 2023 Source: Agora (2014) – Electricity Storage in the German Energy Transition

Long-term storage is far away from profitability even with significantly reduced storage costs and short-term storage will be driven less by flexibility than other applications. Ancillary services are limited; flexibility is currently not that scarce (in Germany) and is not expected to be. Services around the coordination of EV batteries / optimized charging will be critical up from a certain scale; who are going to be the players that offer these kinds of services?

Developments in other countries

This section describes the approaches adopted in other regions of the world. These regions are subject to different political and market conditions compared to Germany. The insights presented here, were gathered by the authors from utilities and government entities in the corresponding countries. The political motivation and strategies for advancing e-mobility, structure of the electricity grid and the salient consumer behavior in a country can affect the grid operators' approaches to integration. However, the key questions to ask in order to devise the optimal approach can be common.

C. E-mobility sector and integrtaton challenges in Qatar

1) EV penetration targets

In Qatar, there are very limited numbers of electric vehicles (EV) and plug-in hybrids (EHV) at present. In fact, less than some hundreds of vehicles are estimated to be on the roads. However, ambitious targets have been set by the Qatari government in regards to the number of vehicles that shall be replaced by EVs and EHVs in the future. The "Green Car Initiative" is a joint effort of the ministries of transport and energy as well as the state utilities provider Kahramaa. It aims to replace conventional vehicles with EVs and EHVs so that it makes up 4% of the total number of cars on the road by 2022. Furthermore, the target for 2030 is to reach 10%[1].

Qatar's car market is currently dominated by SUVs. However, petrol subsidies are gradually being reduced and several support mechanisms exist to spur on the transition to EVs and EHVs. The country supports the market for electric passenger cars, light commercial vans, buses and trucks (including battery-electric, plug-in hybrid, and fuel cell vehicle types). Industrial stakeholders support/organize different workshops and conferences that promote topics of integrating EVs into the grid which attract many participants from across GCC and the world, including several automakers and utilities. This helps further strengthening the interaction between local various agencies and relevant electric vehicle stakeholders which will help Qatar accelerate its steps to widely adopt electric vehicles. Furthermore the Qatar National Research Fund (QNRF) has funded many research projects on electric vehicles penetration to the grid and on the effect of electric vehicles on the future smart grid. Many different research institutes and universities in Qatar are working on the impact of electric vehicles on Qatar's grid. Qatar works towards the deployment of charging infrastructure to supply sufficient power to the vehicles deployed, increase sales of electric vehicles as well as a decrease in battery costs. In addition, active support of research are observed in this direction. For these reasons Qataris are confident that the targets will be achieved, especially given that the "target is modest and the country is small."

2) Trends and expected distribution of EV infrastructure

Despite the targets and supporting initiatives, Qatar faces difficulties in importing a wide range of EVs and EHVs to offer to the consumers (n.b., it has no manufacturing industry). There appears to be a chicken or an egg situation, with little demand for EVs indicating that there is little market for the products, therefore very few car makers make the effort to import and provide the products. However the lack of demand is also driven by the lack of choice in terms of EVs that are available. For instance, prominent manufacturer Tesla does not even have an agent in Qatar.

Another key to increase the EVs market and support transportation electrification initiatives in the region is increasing the number of Electric Vehicle Charging Stations (EVSE) deployed in public spaces to effectively extend EVs' battery ranges. Range anxiety can be solved by using a slow and fast charging for successful deployment of EVs in the region. However in Qatar, the furthest point from Greater Doha is ~200 km (Wakrah to Al-Ruwais).

Regarding the expected distribution of the vehicles, it must be noted that Qatar is a small country. Correspondingly, most residents live in Greater Doha, so it is expected that there will be a high concentration of EVs in the capital. However, a large percentage of the population in Qatar is expatriates (more than 80%). Furthermore, they tend to rent accommodation instead of buying. This often means that, they are not willing or capable of installing charging stations in their homes. It is not typical for apartment complexes to have charging facilities.

As mentioned, Qatar works towards the deployment of charging infrastructure to supply sufficient power to the vehicles expected to be deployed, mainly through support of research activities. This means that to-date, only a handful of charging stations have been deployed for pilot purposes. Currently the effectiveness of different types of charging infrastructures is being researched in Qatar. These focus on:

- **Residential charging stations:** the EV plugs are installed indoors, and the car recharges overnight. The charging station does not need a separate metering, and does not require a separate, dedicated circuit.
- **Fast charging:** at public charging stations offer a higher power level than 40 kW, delivering for longer distance trips i.e., over 100 km in between 10–30 minutes.
- **Slow charging units:** are typically associated with overnight charging.
- **Wireless power transfer (WPT):** allows power to be transmitted through transmitter unit on vehicles without having any physical contact between utility power supply and electric battery

The expected development in Qatar is for slow charging to be installed as an initial step. Slow charging is expected to be the most used schemes in Qatar, since the distances typically covered by vehicles are not far. Fast charging is seen as being eventually necessary in order to accelerate wider adoption of EVs in the country. Furthermore, due to the level of ambient temperatures in Qatar, implementing fast charging for batteries bears high temperature environments, and to secure this infrastructure for public charging locations could add complexities and cost.

Despite this, concrete targets for the number of different types of charging stations to be built have not been developed yet. Furthermore, there are no specific rules about who is allowed to build charging stations.

3) Potential threats for the electricity system

As a design guideline for installation of charging stations, the state utilities provider considers key criteria to be: size of automobile flow; population density; and possibility to establish charging stations. However they do not themselves consider investing in charging infrastructure. With lack of regulations and standards about the type of charging stations, and the lack of guidance about where they should be installed opens the door to potentially uncoordinated development of charging infrastructure across different parts of the city. This would mean that there will be little control by the grid operator of the locations and

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[1] https://dohanews.co/one-out-of-every-10-cars-in-qatar-could-be-electrichybrids-by-2030/

technical specs of the monitoring and control functionality of the charging stations.

Typically, an electricity system could face the following challenges when integrating additional electricity consumption from EVs:

- Peak on peak: EV charging during hours with high consumption will require generation and grid capacity expansion.
- Voltage control: EV charging will cause large fluctuations in load profile and therefore voltage profile in distribution grid. Present voltage control capabilities may be insufficient to deal with the magnitude and frequency of power swings.
- Low utilization factors for new investments: additional capacity built for EV charging will be utilized very little

In the case of Qatar, the greatest threat expected by achieving the Government's targets is the inadequacy of household connection sizes. Houses in Qatar typically have large AC loads, and consumption of a single house is typically 100 – 120 kW. Even at night, the AC load is still considerable, and adding car charging to that would result in tripping of house connections. This would be far more evident if two adjacent houses on the same feeder have EVs. This means that the main concern is the cost and works that will need to be carried out to upgrade household connections in the distribution grids to cater for the increased peak demands at household level. Most likely the accumulated increase of individual household connections will lead to wider grid capacity and voltage control issues.

For the grid, EVs can be seen essentially as mobile storage devices. Charging stations could therefore be installed in strategic locations and managed in a way that is beneficial for the grid operator. EV charging stations could be installed in locations that have low grid utilization. The charging can be controlled to avoid hours with high consumption. This means that EVs can be an important source of flexibility to help in the total system balance and avoid price spikes, as well as avoid the need to upgrade grid capacity. It could be paired with other technologies like roof-top PVs. The timing of the charging can be coordinated with PV production to avoid reverse power flows and associated voltage control problems. By taking an active approach, grid operators can turn the potential threats of EV and EHV and associated charging infrastructure penetration into opportunities: Threats will be mitigated if the charging of EVs is controlled.

Furthermore, even if the grid operator leaves the market to invest in the installation of charging stations, it would be important to actively steer the process so that the technology is compatible with its plans. For example, technical requirements of slow chargers should be implemented to ensure "smart charging". That means to enable functionality that the hours of charging could be restricted and/or controlled. Incentives can be set on the location and the hours in the day when charging are preferred. Additionally, the grid operator could take over remote control of the charging process. Even if some charging stations are already installed, EV chargers are already high technology devices with remote communication functionalities. Therefore adding controllability should not be a high cost. There are several strategies a grid operator could apply to steer the development of charging stations and charging activities, if he is serious about avoiding potential threats to the system and optimizing its investment and operation activities.

These opportunities and options need to be assessed and during the German Energiewende methodologies needed to provide a stable set of results were developed.

D. E-mobility sector and challenges in Japan

Targets

In Japan, the Ministry of Economy, Trade and Industry (METI) develops a coordinated strategy for Electric Vehicles (EV), Plug-in Hybrid Vehicles (PHV) and charging infrastructure that will enable wide scale adoption of the vehicles. The "Japan Revitalization Strategy", revised in 2015, set forth the goal of reaching a target of 50-70% of "next generation vehicles" penetration among new vehicle sales by 2030. Of this, 20-30% are attributed to EV/PHV. With this target in mind, a roadmap was developed for strategies necessary for the first five years (until 2020), and this roadmap is considered a pillar of the country's future next-generation vehicle strategy.

In this roadmap, an intermediate target was set, to increase the number of EV/PHV (ownership basis) to up to one million by 2020. This is considering that the total sales of EV/PHV as of the end of February 2016 was approximately 140,000, and that Japan will follow an accelerated uptake of these types of vehicles in line with other developed countries.

Trends and expected distribution of EV infrastructure

The roadmap also defines specific actions towards meeting the targets. These are categorized by actions targeting the replacement of existing vehicle fleet with EV/PHV; installation of charging infrastructure; development of vehicle to grid (V2X) capabilities; development of standards; and collaboration initiatives with regional authorities.

1) Vehicles (vehicle price, travel distance, driving performance and product appeal)

Despite price reduction efforts by car manufacturers, the assumption that EV/PHV prices will become equivalent to gasoline vehicles by 2016 has not been realized, and subsidies and tax breaks are still needed for the foreseeable future.

Efforts by manufacturers to make EV/PHV more accessible to a wider base of customers are also needed. This means that vehicles that meet the needs of many users need to be offered at an appropriate price to expand the market. For this, ideas like extending the distance coverage by EVs and the forming a used car market are also important. Although automobile manufacturers are taking actions such as guaranteeing a certain number of years and mileage, in the future it is necessary to establish an evaluation method that is more objective in terms of the life, durability and residual performance of the storage battery. Furthermore prolongation of investment in R&D of storage batteries like those of Lithium-ion batteries and innovative rechargeable batteries would be important.

It must be said also that information about EV/PHV is not sufficiently transmitted to the population. Public-private partnership for information dissemination, such as a test-drive society targeting media outlets, and providing reliable information through websites for potential users, are important. We should also try to enhance neutrality of information on the benefits of EV/PHV.

2) Charging infrastructure (charging environment, charging time)

a) Public charging stations

On-route charging is indispensable for long-distance driving. There appears to be progress when looking at the number of installed on-route charging stations. However, these are insufficient to eliminate range anxiety. For reliable operation, we expect a network structure of on-route chargers and to set up a structure that enables as many users as possible to access the installations. Necessity for maintenance planning is also considered. Provincial level plans for installation of charging stations are reviewed to ensure optimal placing in easy-to-find locations including roadside stations and service areas/parking areas along expressways.

Destination charging is charging stations at common destination of travel, like shopping malls, stadiums and hotels. For potential users to understand the improvement of convenience of EV/PHV, charging stations should be installed with a priority in places with large-scale hosting capacity and high transit, where there are high volumes of customers. Based on the target EV/PHV penetration rate and estimation of parking lot occupancy rate, convenience will improve considerably if about 20,000 (including existing) charging stations are set up for 2020.

b) Basic charging (detached houses, communal housing)

Home charging is standard charging stations at residential housing. This covers EV/PHV owners' houses (detached housing) and apartments (communal housing). There are very limited installations of basic charging facilities in the communal living quarters, in which around 40% of the population live. If the installation of charging infrastructure is made mandatory for parking areas of new buildings and at the time of major renovations of existing buildings, around 300 thousand vehicles could be served. This means up to 2000 charging stations per year are needed to support the target for 2020.

Furthermore, in order to urge the installation of charging stations at the time of construction of a detached house, the content of "Guidebook for setting up charger equipment" should be enhanced and disseminated.

Regarding the existing residential housing, in order to promote the consensus of residents, information on installation costs and necessary procedures, and benefits like strengthening of fire prevention measures should be included in the Guidebook. In addition, the country, automobile manufacturers, developers, management associations and automobile dealers should collaborate; and consider the formation of a coalition group to strengthen efforts. It is also recognized that it could be effective to select regions that will become model cases and to promote successful cases.

c) Basic charging (workplace)

Workplace charging is standard charging stations at places of work. With options for charging at the workplace, it is possible that consumers will choose to buy EV/PHV. Among commuters who travel more than an hour each way to and from work, and have access to basic charging at home, to cover 2 million residents of detached houses that work at large-scale business establishments, 9000 charging stations are required to meet the target of 2020.

Furthermore, some businesses can expect benefits of investment in charging stations, and therefore a return to specific commuters.

d) Improvement of performance and convenience of charger

The need for speed charging grows as the travel distances of EV/PHV increases (i.e., storage battery capacity increases). Eventual migration of basic charging stations to high power output must also be considered. Accordingly, plans are being developed by concerned parties. What is important is to ensure compatibility assuming a market where old and new vehicles are mixed for a long period of time.

e) Utilization of V2X function

If it is possible to use the batteries in EV/PHV for counterbalancing fluctuating outputs from renewables and this benefit can be transferred to the users, it will contribute to the development of EV/PHV penetration. However, to provide balancing power without disturbing the purpose of use of individual vehicles, a large-scale coordination mechanism is necessary. Such technologies are being demonstrated by utilities as Virtual Power Plant projects.

Furthermore, EV/PHV can supply electricity equivalent to several days of consumption in a home. In a disaster situation, power supply, compared to other energy networks is relatively quickly restored. Therefore, if the uptake of these vehicles spreads, it will create social value as a disaster countermeasure. Such information and value should be made clearer and communicated.

3) International standardization

Japan has the world's most progressive charging infrastructure and can contribute to the development of better standards based on experience. Active participation in discussions of international standards including ISO/IEC and contribute to the further spread of EV/PHV is therefore encouraged.

4) Efforts in collaboration with local governments

Through the revision of the Ministry of the Environment's "Global Warming Countermeasures Local Public Organization Planning Manual", it is important to create an environment that makes it easier for local governments to incorporate EV/PHV into measures to combat global warming. In addition case studies of municipalities both inside and outside Japan shall be presented to local governments through the EV/PHV Town Conference Promotion Review Committee, to foster discussion on future efforts.

CONCLUSIONS

We currently make the following observations around the development of electric vehicles: Today we see worldwide subsidy programs for EVs, the global EV sales are predicted to rise while the Li battery pack prices are assumed to drop another 75% by 2030 and strict fuel & emissions regulations try to strengthen the climate protection. Looking at the global EV outlook the predicted maximum and minimum EV stock in 2030 scenarios increased significantly between 2016 and 2017 and a large gap between maximum and minimum scenarios indicates great uncertainty about the further development.

Some of the results for Germany in the shown scenarios assume that the demand of EVs is low compared to total energy consumption (<3%) in 2035. Infrastructure will not limit e-mobility on TSO level; however, limitations at DSO level – especially in residential areas – might arise. A surge of EVs will probably not be limited by energy system, but the energy system will also not offer major business opportunities to e-mobility. Depending on a peak load coordination and control EVs also have limited impact on peak demand (~8%), especially with smart charging in place and when looked at in combination with flexibility of heat pumps or other flexibilities.

However, smart controlled charging is necessary as there is potential for negative influence on peak demand otherwise – this will be even more the case when looking at local low voltage level. Challenges ahead concern the implementation of intelligent charging and the question to what extent are car owners willing to sacrifice availability of EVs for charging optimization?

In this article methodologies to model Electricity consumption of EVs in scenarios were outlined and the results for the target years 2035 in Germany illustrated. Electricity markets will not hold major business opportunities, but probably there will be players coordinating EV charging behavior in the future.

Approaches adopted in other regions of the world were outlined to compare the German situation to different political and market conditions. However, the key questions to ask in order to devise the optimal approach for modelling and analyzing the effects of E-mobility can be common.

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