*EVS30 Symposium*
*Stuttgart, Germany, October 9 - 11, 2017*

# How to scale up German Infrastructure

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**Abstract**

The roll-out of the charging infrastructure in Germany is promoted by both, public promotion of investment and commitment of the automotive industry. It runs ahead the market diffusion of electric vehicles (EVs). At the current diffusion level of electrified mobility, effects on the energy supply system are almost negligible. This can be expected to change with the stage goal of one million EVs in 2020 set by the German Government. The paper at hand aims to identify obstacles to a smooth scale up in EV penetration. Based on two scenario the requirements and effects of the development of charging infrastructure on the energy supply system are determined by a quantitative analysis. Therefore, two examples with high impact on the energy supply system are analyzed (i.e., holiday season and a football match). Thereby, energy demand, energy flows and power peaks are estimated and set into relationship with the current demands on the energy suppy system. The paper at hand will provide insights on potential bottlenecks and unresolved challenges at the transition towards an electrified mobility. It concludes with concrete recommendations for further research, technical challenges, business models and legislation need to ensure a smooth upscaling of electrified mobility and its charging infrastructure.
*Keywords: case-study, battery charge, business model, infrastructure, smart charging*

# 1 Motivation

## 1.1 Scale-up of EV-Penetration

The roll-out of the charging infrastructure in Germany is promoted by both, public support of investment [4] and commitment of the automotive industry. Being one of the main drives for the transition to an electrified mobility [10] it runs ahead the market diffusion of electric vehicles. At today's low levels of electrified mobility, current effects on the energy supply system are almost negligible. This will change, as soon as Electric Vehicle (EV) penetration reaches higher levels [13]. The German Bundesregierung has set a stage goal of one million EVs in 2020 [3], which was later postponed by the German chancellor. In Germany, moreover, the transformation to electrified mobility is taking place under the special conditions of the 'Energiewende'; i.e., a more volatile and decentralized energy supply system based in renewable energies. In a system as complex as the energy supply system, such challenges are not always obvious but can rather emerge from the manifold interactions of the systems components. The paper at hand aims to identify these obstacles by a scenario analysis and hereby ensure to a smooth scale up in EV penetration.

### 1.2 Effects of Charging Infrastructure on the Energy Supply System

The rise of volatile renewable energies already challenges the electric grid by causing congestions on distribution and transmission systems. The near to zero marginal costs of renewable energy can foster an all electric society, in which transportation and heating cannot be considered independently from the electric energy supply system. Hence, additional challenges arise with the integration of EVs. Even low penetration levels of EVs, grid congestions are becoming more relevant in Germany. German energy markets assume a the electric grid being a 'copper plate'. When the grid cannot handle the power flows caused by the energy traded, TSOs and DSOs solve the transmission problems by costly re-dispatch and feed-in management, which ends up in the shut-down of renewable energies. Such measures accounted for almost 900 million €in 2015[9]. Today, grid capacity problems arise mainly on the transmission grid but but are expected to rise on the distribution level with the growth of decentralized consumption and injection (as caused by EVs). The expected impacts of EV charging are described by various researchers. [26] use a stochastic modelling approach to simulate the effects of fast charging stations on transformer loading and system bus voltage profiles. They propose local energy storage and voltage conditioning devices as solutions. [16] analyze the effects of high penetration of EV charging stations on the thermal aging of power distribution transformers. They conclude that smart charging and the relocation of charging stations to commercial or industrial ares can enhance transformers life expectancy. [7] research the impacts of EV charging on the residential distribution grid and describe the problem of uncoordinated power consumption. The high demand of simultaneously charging EV can cause power losses and affect power quality (e.g., voltage profile, unbalance, harmonics, etc.). A optimal charging profile based in stochastic programming is proposed to minimize the power loss and maximize the grid load factor.
Research expects a rising number of congestion and issues with power and voltage quality, in distribution systems[9]. In contrary, the scale-up of EVs is not expected to have major negative implications on transmission and generation capacity. EVs can offer additional flexibility to the energy supply system and help to integrate volatile generation of renewable energies [22]. However, in some situations EVs do not offer additional flexibility, but set an additional restriction that challenges the energy supply system on the distribution level. The paper at hand describes two suchlike scenarios and proposes adjustments to handle such situations.

## 2 Method

The requirements and effects of the charging demand on the energy supply system are determined by a quantitative analysis for different market penetration levels. To illustrate the challenges ahead, two examples (i.e., holiday traffic and soccer match) and their impacts on the energy supply system are analyzed. Therefore, the energy demand, energy flows and power peaks at the grid nodes of the events are estimated, based on assumptions of EV penetration, charging power and battery capacity. The resulting demand are set into relationship with the capability of the current and future energy supply system. The main focus is set on the implications on the energy supply system (i.e., generation, transmission and distribution) on the technical and the economical side. First, the challenges on the existing energy supply system are identified. In a second step, interactions with changes in electricity market design and other change processes towards more renewable decentralized generation in the course of the 'Energiewende' are considered. The paper concludes with concrete recommendations for further research, technical challenges, new business models and legislation need to ensure a smooth up-scaling of electrified mobility and its charging infrastructure in Germany.

### 2.1 Case Study 1: Holiday Season

Even today the holiday season causes early adopters of EVs to queue at the charging stations in Southern Germany. The charging demand with holiday and transit traffic can be expected to be much higher, than the average demand underlying many models for the allocation of charging stations. In contrast, both traffic flow and traveling distance are much higher than the values used in most studies. Due to queuing effects the demand of charging stations can be expected to even rise over-proportional to the diffusion of EVs. Besides the questions of the optimal number and positions of charging stations [11] a higher EV penetrations rises more issues: Do traffic currents and charging behaviors change the existing energy flows so far that an adjustment of the energy supply system becomes necessary? Can the rural

transmission and distribution system handle the power peaks of holiday season [7]? Moreover, Germany is a transit country for all kind of visitors to the Alp-Region. In winters holiday season, a substantial number of transiting EVs from the Benelux countries can be expected to higher the demand for charging infrastructure. EV penetration levels of Benelux countries are and are assumed to stay higher than in Germany [5].
Several studies evaluate the demand for charging stations based on traffic flows. [24] classify approaches to determine optimal locations of refueling stations into two broad classes: p-median and flow-refueling models. They find that flow-refueling models are more stable as the number of fueling stations increases. [6] provide a efficient framework to locate a given number of refueling stations on a network, based on the traffic flow among origin-destination pairs considering a given driving range. The framework is base on mixed-binary-integer programming. The work further provides an overview on existing methods for determine optimal locations of charging stations. [25] describes how origin-destination-flows are usually modeled in four steps: First, the Traffic generation estimates the number of trips for each node. Second, the destination is chosen to generate the traffic distribution. Last, the mode of transportation and the routing is determined. [12] propose a method for the construction of charging infrastructure. They acknowledge that the daily maximum charging capacity must be satisfied. The daily maximum charging demand is calculated based on the highways daily average running distance, highway maximum traffic volume, and EV fuel efficiency. [19] provide an estimation for the minimum EV charging infrastructure needs an the optimal deployment for highway corridors. [2] present a spatial and temporal model for fast charging locations based on a fluid dynamic traffic model (arrival rate) and queuing theory. To the knowledge of the authors none of these models was used to calculated the demand of charging stations in traveling seasons. We propose to to further analyze the demand at such peak events an set it into an relationship with the the average demand for charging infrastructure. Due to additional delays while queuing, demand for charging stations to serve all charging demand in an acceptable waiting time can be expected to rise over-proportional with traffic flow. If traffic flow data of holiday traffic can be obtained, future research will focus on the sensitivity of charging station placement for such events. The questions arises whether such over capacities are economically feasible and how the rural distribution grid can handle such days.

## 2.2 Case Study 2: Football Match

Special events like big concerts or sport events attracted a big number of people from a supra-regional radius. The vehicles are usually parked on big parking lots. Charging only a fraction of these cars would turn the parking lot into a huge energy drain for a couple of hours, until it turns back into an energetic no-man's-land for the days to come. This rises a couple of challenging research questions: How can the energy and transmission capacity for such events be quantified. Is it feasible to design such places to carry the peak demand or are other concepts needed? The following section aims to quantify the charging capacity and energy demands for such events, based on the a game day at the Allianz Arena in Munich.

### 2.2.1 Scenario Assumptions and Modeling

Different approaches estimate the charging demand of electric vehicles. [17] model the charging demand of plug-in hybrid EVs in distribution grid. In the plastic scenario of a sports event, however, we only consider one node in the distribution grid and aim to describe the expected demand and effects on game day. Assumptions for the input variables can be found in Table 1. The Allianz Arena in Munich can host over 75,000 spectators and offers 11,000 parking spots. The electricity supply is provided by two 6 MW transformer stations, which provide redundancy [23].
Battery size and charging capacity are expected to rise in the future and are difficult to predicted with acceptable certainty. Therefore the charging capacity is not used as in input variable in the model. However, the charging capacity can be derived as an output variable. This allows to control, whether the models results stay within a realistic range. Nevertheless, assumption for the battery size have to be made to calculate the energy demand for charging. As no other data could be found the battery size was assumed to be uniformly distributed between 100 and 500 km. The energy demand for the traveled distance can be assumed to remain within the same margin, since EVs are already very efficient. Changes in EVs energy consumption are therefore assumed to stay on the same level for all penetration levels. The distance for a car trip in Germany can be estimated with the Weibull distribution (42.6,1.53) based on the German Mobility Panel 2015 [15]. The number of EVs in the arenas car park is given by the

penetration ratio and the total number of cars on the filled car park. The calculations where implemented as an Monte Carlo simulation to allow an easy adjustment of initial assumptions and later sensitivity analysis. For each EV the trip distance, maximal battery capacity, state of charge at arrival and energy consumption is estimated from the underlying distributions. Only cars with a trip distance greater than the state of charge are expected to charge. Charging vehicles are expected to fully charge the batteries, in case they need any charging. The total energy consumption of all EVs is leveled to a constant charging power for the given time frame. The Monte Carlo Simulation as described in algorithm 1 is performed 1000 times.

| Symbol | Description | Value | Source |
|---|---|---|---|
| $n_{carpark}$ | Number of parking sports | 11,000 | Allianz Arena [8] |
| $P_{max}$ | Power rating | 6 [MW] (x2) | Allianz Arena [23] |
| $Dist_{EV,max}$ | EV maximal capacity | U(100,500) [km] | - |
| $Eff_{EV}$ | EV energy consumption | U(7,13) [kWh/100km] | - |
| $Dist_{EV,init}$ | Initial charging state | U(0,$Dist_{EV,max}$) [km] | - |
| $Dist_{EV,Trip}$ | Trip distance | Weibull(1.53, 42.6) [km] | [15] |
| $T$ | Event duration | 3 [h] | - |

Table 1: Scenario Assumptions

**Algorithm 1:** Estimate of energy demand for EV charging

**Input :** Set parameters: $n_{carpark}$ and $T$
**Output:** $P_{total,charging}$, $Q_{total,charging}$
$n_{EVs} = n_{carpark} * P_{EV}$;
$n_{EVs,charging} = 0$;
$P_{total,charging} = 0$;
$Q_{total,charging} = 0$;
**for** *each Car in* $n_{EVs}$ **do**
  draw $Dist_{EV,max}$ from $U(100, 300)[km]$;
  draw $Dist_{EV,init}$ from $U(0, Dist_{EV,max}$;
  draw $Eff_{EV}$ from $U(7, 13)[kWh/100km]$;
  draw $Dist_{EV,Trip}$ from $Weibull(1.53, 42.6)[km]$;
  **if** $Dist_{EV,Trip} = 2xDist_{EV,init}$ **then**
    $Q_{total,charging} = Q_{total,charging} + (Dist_{EV,Trip} - Dist_{EV,init})*$;
    $n_{EVs,charging}$=$n_{EVs,charging} + 1$;
  **end**
**end**
$P_{total,charging} = Q_{total,charging}/T$

### 2.2.2 Results

Results show that the power for charging demand can account for an substantial amount of the arenas power consumption. The total energy demand on game day can grow above 6 MWh for full electrification ( 80% EV Penetration). Figure 1 illustrates the average results of the Monte Carlos simulation with its 5% and 95% quantiles. The uncertainty rises with the number of EVs. Note that the charging demand is assumed to be perfectly leveled over the 3 hours of the event duration. Power peaks would be much higher if the charging of the vehicle fleet is not perfectly coordinated. At full electrification the average charging demand alone surpasses the first transformers capacity and redundancy is not longer given. The calculated average charging capacity for each single EV stays in realistic range for all penetration ratios.

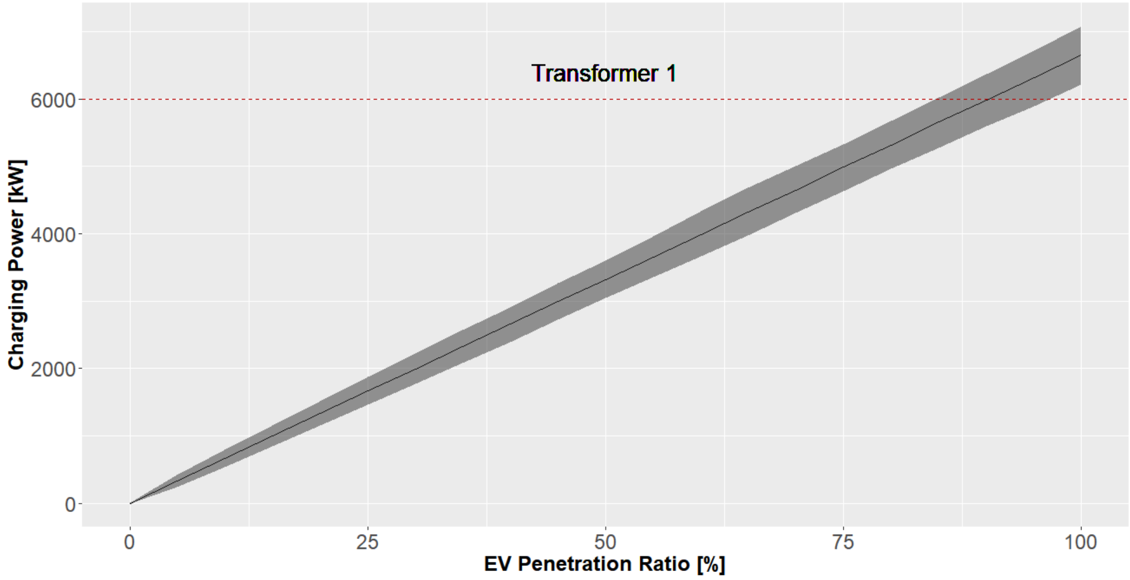

Figure 1: Charging demand for different EV penetration ratios

Further adaptions of the model might include a rise of battery capacity in correlation with higher EV penetration ratios. This would flatten the charging demand for high penetration ratios. In further the model should be validated against real charging demands and be used for sensitivity analysis.

# 3 Discussion

The quantitative analysis of the scenario shows that infrastructure as the Allianz Arenas is well prepared for lower shares on EVs. However, at an penetration ratio of 80 % the first transformer already reaches its maximums capacity for EV charging solely. Considering the total electricity consumption, redundancy will not longer be given at much lower penetration rates. Moreover, the adjacent distribution grid is probably not designed too serve both transformers at full load. At high penetration levels additional investments in distribution infrastructure i.e. lines and transformers will be at need. However, this will not be economically efficient for locations with a small load factor as a football stadium. There is no load factor or load duration curve given for the Allianz Arena. However, the Energy consumption is given with 55,000-63,000 kWh at game days and 20.000 kWh at the remaining days [23]. Figure 2 presents these energy amounts as squares, assuming one game day per week. The squares form a load duration curve under the assumption that the energy consumption is evenly distributed over each day, which is a rather conservative assumption. In addition, the energy consumption on EV charging at 25% EV penetration ratio is added. The blue line gives an conservative estimation for a load duration curve that always full-fills the transformers redundancy and is based on the energy consumption without EV charging. As an example the load duration curve at 25% penetration ratio is given which steepens the load duration curve even further.
It is obvious that a few hours per year (i.e., during the event on game day) account for the biggest part of energy consumption. Building the transmission and distribution infrastructure to serve those hours will most likely not be the cheapest solution for serving these loads. Alternatively, new concepts have to be implemented to find a cost efficient solution. In the remainder of this paper, we discuss implications on future mobility concepts, on the grid and new business models.

## 3.1 Implications on future mobility concepts

The energy demand for EV charging, even at high penetration ratios (as 25%) does not account for the biggest part of the total energy consumption on events as a football match or rock concerts (see figure 2). However, this might change for smaller events and single households. The main challenge is to serve the charging demand through the electricity grid in the limited time frame given. The easiest way to

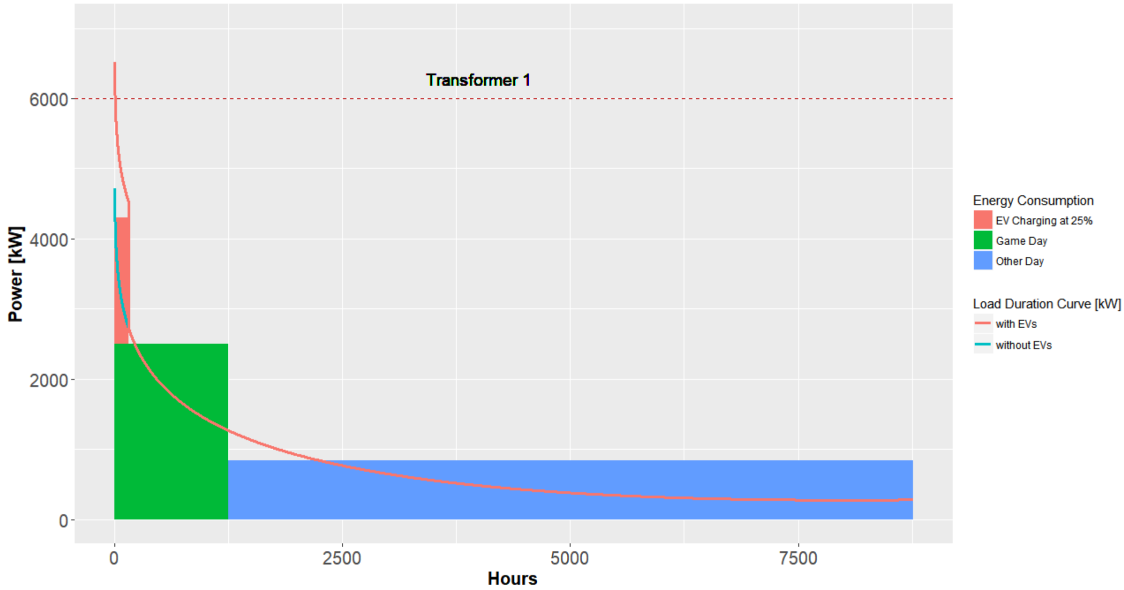


Figure 2: Estimated load duration curve of the Allianz Arena without EV charging and at 25% EV Penetration

reduce charging demands is to reduce the number of EVs. Therefore, an rise of public transportation offers might help to avoid challenges. Park and ride systems allow for a wider spatial distribution of EV's and therefore level the effects of charging over a wider distribution grid area. Autonomous driving and charging during the event is another option to dispense the charging activities over a broader area. The charging demand also lowers with growing battery rage. Once, all EVs battery rage surpasses the trip length, no central charging at the event location will needed. A breakthrough in battery technology would therefore solve the need for massive charging infrastructure. In the meantime other on board storing systems for EVs (e.g., fuel cells) can help to overcome the problems described.

### 3.2 Implications on the Grid

At low EV penetration level, investment in infrastructure will be a cost effective way to provide the energy for charging demands. Grid reinforcements and auxiliary services in die distribution grid, as demand side management, control of EV charging or heat pump, reactive power control and distributed energy storage [5] will provide help to facilitate such events. However, in some situations the scale up of distribution infrastructure will not be the solution (i.e., locations with small load factors). Since the problem can be expected to dwindle with time and rising battery rage, other solutions should the implemented find cost efficient solutions for the transition time.

### 3.3 Implications on Energy Market Design

When the transmission capacity reaches its limits, the system operators have to intervene and manage the energy flows. In this situations the German 'copper plate' market model is not longer feasible. Legislators will have to allow, at least temporarily, new markets with divergent rules. The affected network areas could be allowed so see their own (higher) prices in a temporal nodal or zonal pricing scheme, to reduce energy demand and relieve the distribution system. Long term effects as incentives for investment, however, might not work, since the high prices will only be seen at a few hours a year. Even without investments in generation infrastructure, diverging prices could facilitate new business models as described in the following section.

### 3.4 Implications on Business Models

New business models should prevent the problems of EV charging by offering more cost efficient solutions than the installation of over-capacities in generation and distribution.In both, holiday season and

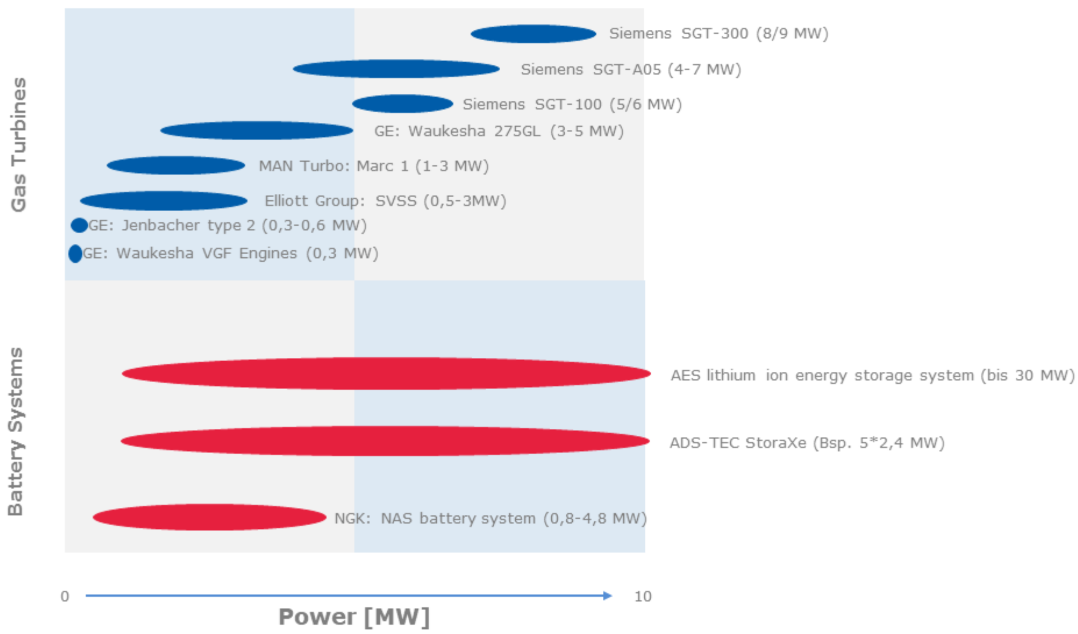


Figure 3: Options for mobile, decentralized generation

big events, the first step could be to influence user behaviour to avoid unnecessary charging and flattening the peaks in charging demand. [18] propose a deadline differentiated pricing scheme for charging in car parks. This allows to schedule the charging demands, based on the time of return of the EV owner. However, this scheme might have limited effect at big events, where visitors all leave at the same time. The scheme might be further developed for fast charging on highways, where the charging could be coordinated by the travelers patience. Such services must consider the users preferences. [14] use an online questionnaire to quantify users' preferences regarding the fast charging infrastructure. Results show that the waiting time, the necessary detour and the charging costs should have be biggest influence on the selection of charging locations. On-site activities to bridge the charging time were less important. The preferences are not influenced by the trip length.
A next step could be investment in local generation to unload the distribution system. [20] present a prototype for an fast charging stations with an energy storage system. Such charging stations, following the smart grid paradigm, can shave of peaks and provide system services. They advocate their system as having zero (negative) on the distribution grid. However, these concepts might not be profitable when operated only a few outs a week. Another concept to reduce the effects on the distribution system is peer-2-peer trading between the EV owners.[1] A service provider could provide a trading infrastructure and platform, where EV owners with more electricity stored then needed could sell it to the owners with charging demand. Instead of peer-2-peer trading, mobile, decentralized generation could be used to serve EV charging demand indecently from the grid. Here, mobile batteries in cargo containers and small gas turbines are possible solutions. Figure 3 presents several market-available solutions in the according power range.
Incentives in investment in charging - especially fast charging stations - still suffer under the chicken-egg-dilemma. [21] conduct a case study in order to estimate the Return of Investment of fast charging infrastructure in Germany. They conclude, that uncertainty about the future diffusion of EV prevents an large scale roll-out at the given time (2011). The low EV-adoption rate is identified as the main risk factor for investing in fast charging infrastructure. A mobile solution that can be set up on demand and rented out for different purposes, could allow a higher utilization and therefore minimize the financial risk.

## 4 Conclusion

To the authors knowledge no systematic evaluation of the fast charging demand in holiday season in its implications has been conducted. We prose this as an important issue for further research. In general, research on electric mobility should focus on the users experience in realistic settings in addition to the existing average-driven models. This can avoid real world problems and ensure a smooth scale-up. The simulation study on big events, as sport events or concerts, shows that energy demand of EV charging is low compared the total energy demand. However, the local power peaks induced by EV charging remain a technical and economical challenge. Since this can be considered a transmission problem, diminishing with rising battery ranges, we propose to focus effort on service solutions and mobile generation, instead of costly investments in distribution and generation infrastructure. The last part of the paper proposed ideas for new business models for such cases during the scale-up of German charging infrastructure.

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- Head of ICT innovation area within the cluster Electric Mobility South-West
- Project management of the parallel research into effectivity within the German federal program "Electro mobility Showcase"
- and author/co-author of various publications plus expert in various special topics:
- Research program "Horizon 2020" of the European Union
- Digital Agenda of the Federal Government – promotion of innovation

Within the scope of innovation and business development Detlef Schumann is engaged with the current trend topic of Digitization – from Big Data, Industry 4.0 and demographic change through to issues of the whole transformation of industries.

**Julian Huber** studied industrial engineering at Technical University of Berlin and Karlsruhe Institute of Technology. During a research scholarship at University of North Carolina at Charlotte he focused on energy economics and analytics. He is currently working at Forschungszentrum Informatik (FZI) in Karlsruhe and engaged in research concerning demand side management, demand response and end-users flexibility in the Smart Grid.