EVS38
Göteborg, Sweden, June 15-18, 2025

Future Demand and Costs of Megawatt Charging for Battery Electric Trucks

Patrick Plötz[1], Antonio Sgaramella[2], Steffen Link[1], Daniel Speth[1], and Till Gnann[1]
[1]*Fraunhofer Institute for Systems and Innovation Research ISI, Breslauer Str. 48, 76139 Karlsruhe, Germany*
[2] *Department of Astronautical, Electrical and Energy Engineering, Sapienza University of Rome, Rome, Italy*

Executive Summary

Greenhouse gas emissions from heavy duty vehicles (HDVs) must be drastically reduced. Battery electric trucks (BETs) are the main option for low-carbon road freight transport, but they require a recharging infrastructure. However, a thorough cost analysis of public charging is lacking, especially for the Megawatt Charging System (MCS). Here we review existing individual MCS studies and add cost estimates for MCS. Our analysis shows that utilisation is the most important metric for MCS infrastructure costs. Individually, the levelized cost of MCS charging infrastructure in 2050 can be reduced to €0.03-0.07/kWh for MCS. A fleet-wide public and depot infrastructure for Europe would cost about €6.6-10.8 billion (or 2.9-4.7 €cents/km) per year for BETs. Our results quantify the infrastructure costs of HDVs to support policy decisions between competing low carbon road transport technologies.

1 Introduction

1.1 Motivation

Heavy duty vehicles (HDV) are responsible for a large share of greenhouse gas emissions from road transport. In the European Union (EU), heavy-duty trucks and buses (> 3.5 t GVW) are responsible for 7% of greenhouse gas emissions [1]. Battery electric trucks (BET) are currently considered the most promising option for zero-emission HDV [2,3]. However, they require a dedicated fast charging infrastructure. The Megawatt Charging System (MCS) standard, currently under development, would enable BETs to operate over long distances by charging at over 500 kW during regulated breaks. MCS charging would thus complement the expected depot charging [4].

1.2 Existing Literature

The international standard for the technical specification of the megawatt charging system is currently under development and expected to be finalized by 2025. For interim charging for trucks, approximately 400 kWh to be charged in 30 to 45 min, 750 kW average power or up to 1.5 MW peak power are sufficient [4]. The MCS standard is planned to cover up to 3.75 MW peak power (3,000 A, 1,250 V) [5]. However, simulations with different charging strategies show that a maximum power of 2.8 MW per charging point will probably be sufficient for trucks, even in demanding scenarios [6].

Megawatt charging infrastructure will require extensive electricity grid connection, making energy management and potentially buffer batteries necessary. Typically, charging locations will be connected to the medium-voltage grid (10 - 30 kV) with a corresponding transformer. One charging location with several charging points will be a local low voltage grid (0.4 kV). Each charging point will contain an AC/DC converter to supply direct current to the vehicles via an actively cooled cable. As most charging processes are likely not to require megawatt charging [4], megawatt charging could be combined with charging infrastructure for lower charging capacities, e.g. 100 to 350 kW, at one location.

The expected price per kWh to be paid for charging a truck is the sum of various components. These include the cost for electricity (energy price and power price from grid operator), the cost for the initial connection of the charging stations to the grid (CAPEX), the cost for the chargers themselves (CAPEX and OPEX) as well as taxes, levies, and a profit margin for the charge point operator (CPO). In addition, further real-life costs usually not included when building charging stations can include the purchase of land, building of a roof and other costs. In the existing literature, vehicle costs have received considerable attention, e.g. as total cost of ownership (TCO) for vehicles [7], but infrastructure costs have received little interest so far [8]. For BETs, several studies have calculated the required number of public fast chargers and fast charging stations, e.g. Shoman et al. [12] and Speth et al. [13] for Europe, Speth et al. [14] and Hurtado-Betran et al. [15] for the USA. Other studies have focused on optimal locations [16] and station sizing [17]. However, none of them analysed the total costs of refuelling and charging infrastructure for BET.

2 Data and Methods

2.1 Simulating MCS Demand

We analyse all daily trips from 2400 HDV in Germany including starting time, trip purpose, distance and duration as well as stop duration. We simulate each HDV as BET with fixed battery capacity and the minimal required charging power during stops of at least 30 min duration to fulfil all daily driving. The data and method are taken from [4] are described therein.

2.2 Calculating MCS charging station cost

To ascertain the total energy per year, it is necessary to make assumptions regarding the average utilisation of HRS or MCS pools over a period of many years. One complexity arises from different notions of “utilisation” in the literature. For example, fast charging station utilisation may refer to “time utilisation”, i.e., the share of hours per year a vehicle is connected to the chargers, or to “energy utilisation”, i.e. the share of energy delivered compared to the energy that could theoretically be delivered if all chargers were operating at full power all the time.

We include one-time investments, such as CAPEX and annual operational and OPEX. The OPEX values comprise two distinct aspects: a fixed component pertaining to the maintenance of the technologies and a variable component that incorporates the operational costs. To make the technologies comparable we follow standard economical modelling [58] and distribute to costs over the good's lifetime in T years with an interest rate i:

$$Station\ annual\ costs = CAPEX * \frac{(1+i)^T + i}{(1+i)^T - 1} + OPEX \tag{1}$$

We use an interest rate i = 3.5 % throughout with technology specific lifetimes (15 years) for depot and MCS charging points. This assessment aims to consider the MCS network costs along different time horizons. To ascertain the costs associated with the MCS infrastructures, it is necessary to compare the total costs per year with the total energy delivered per year. The resulting values will be expressed in €/kWh electricity. Thus, the levelized cost of stations (LCOX), that can be H_2 (LCO H_2) or electric (LCO kWh), has been defined as:

$$LCOX = \frac{Station\ annual\ costs}{yearly\ X} \tag{2}$$

In Equation (2), X stands for the yearly refuelled H_2 or kWh depending on the respective station.

The key assumptions for the MCS charging stations including several charging points are summarised in the following table.

Table 1: Assumptions for MCS charging stations

Parameter	Unit	2025	2030	2035	2040	2045	2050
Number of Chargers	-	4	8	8	8	8	8
Power	kW	1000	1000	1000	1000	1000	1000
Permanently available power	kW	500	800	900	1000	1000	1000
Hardware Costs - low	k€/MW	336.6	3030	273	245	221	199
Hardware Costs - high	k€/MW	460	437	415	395	375	356
Installation - low	k€/MW	94.5	85.1	76.5	68.9	62.0	55.8
Installation - high	k€/MW	114	108	103	98	93	88
Grid Connection	k€	900	900	900	900	900	900
OPEX share of CAPEX	-	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
Energetic Utilization	-	4%	5%	10%	11%	12%	12%
Demand Utilization	-	16%	20%	40%	44%	48%	48%

Table 1 outlines key cost and utilization assumptions for megawatt charging systems (MCS) from 2025 to 2050, providing insight into both infrastructure development and economic evolution over time. The number of chargers increases initially from 4 in 2025 to 8 by 2030 and remains constant thereafter, each offering 1000 kW of charging power. However, the permanently available power grows progressively from 500 kW in 2025 to a full 1000 kW by 2040, reflecting upgrades in grid capacity and electrical infrastructure.

Hardware and installation costs show a steady decline in both the low and high scenarios. For instance, low-case hardware costs drop from 336.6 k€/MW in 2025 to 199 k€/MW by 2050, while high-case values fall from 460 to 356 k€/MW. Installation costs follow a similar downward trend. The grid connection cost remains fixed at 900 k€ across all years, corresponding to a one-time investment and follows the recommendations of the German Federal Grid Agency [18] to use the typical grid fee power price component for the grid connection fee and we use 150 €/kW as typical value with maximally 60% simultaneity in power demand. Operational expenditures (OPEX) are estimated as a consistent 3% of capital expenditures (CAPEX). Utilization improves markedly over time, with energetic utilization rising from 4% in 2025 to 12% by 2045, and demand utilization increasing from 16% to 48% in the same period. These improvements reflect greater charging demand and better load management as the electric truck fleet grows.

3 Results

3.1 Future MCS demand

Figure 1 shows the simulation results for minimum required charging power. All 2400 truck driving profiles were simulated as BET and the lowest power required to charge during existing breaks (of at least 30 min duration) to fulfil all driving as BET. Please note that about 10 % of trucks were not electrifiable with the assumed range of 400 km and left out of the picture.

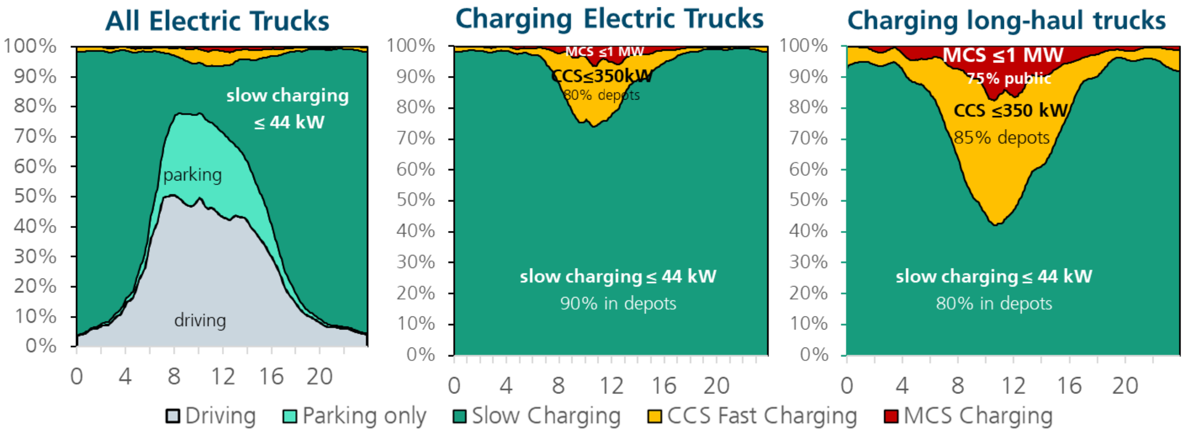

Figure 1: Simulation results for minimum required charging power

The diagram illustrates the daily activity and charging behaviour of electric trucks across three categories: all electric trucks, those actively charging, and long-haul electric trucks. For the overall electric truck population, most activity is concentrated in the daytime, with most trucks driving between 6:00 and 16:00. Outside of these hours, trucks are typically parked, but only a small portion of this idle time is used for charging, primarily via slow charging (≤44 kW). This suggests a significant currently unused potential for controlled flexible charging during long overnight parking periods.

When focusing on electric trucks that are charging (central panel), it becomes evident that slow charging dominates, accounting for over 90% of charging events, with approximately 80% of this occurring in depots. Fast charging using CCS (≤350 kW) and megawatt charging (MCS, ≤1 MW) plays a minor role and mainly occurs during midday. This indicates that current operational patterns and depot infrastructure are largely sufficient to support most electric truck use cases without high dependency on fast public charging, at least for short- and medium-haul operations.

In contrast, long-haul electric trucks show a markedly different charging profile. In Figure 1, “long-haul” is defined das vehicles with more than 500 km per day. While slow depot charging remains significant, fast charging with CCS is more common, and megawatt charging becomes substantially more relevant. Around 75% of MCS charging for long-haul trucks occurs at public stations, highlighting the critical need for a widely distributed high-power public charging network to support continuous, long-range operations. This segment of trucking, therefore, requires targeted infrastructure deployment to ensure operational reliability and efficiency. Overall, the chart underscores the diversity of charging needs in the electric truck sector and the importance of segment-specific planning for infrastructure and grid integration.

In summary, depot charging with less than 100 kW can be expected to be the dominating charging option, but that MCS will be needed for long-haul BET.

3.2 MCS station costs

Figure 2 shows the results for the expected long-term per kWh cost for MCS charging based on the assumptions shown above.

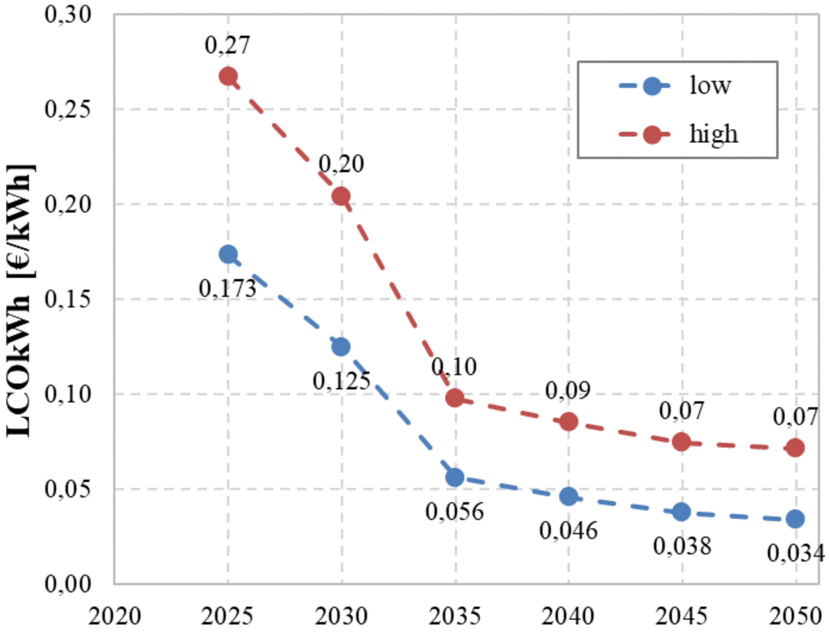

Figure 2: MCS annual station cost in M€ for high- and low-cost assumptions (left) and MCS station costs in €/kWh for 2025 to 2050 (right).

The line chart illustrates the projected development of the levelized cost of charging (LCOC) via Megawatt Charging Systems (MCS) from 2025 to 2050 under two scenarios: one with low utilization and one with high utilization of the charging infrastructure. The LCOC, measured in euros per kilowatt-hour, represents the average cost of providing electricity via MCS over the system's lifetime, incorporating both investment and operating costs.

In 2025, costs are significantly higher in the high-utilization scenario (€0.27/kWh) than in the low-utilization case (€0.173/kWh), reflecting the higher upfront investment and relatively limited usage in the early deployment phase. However, as utilization improves over time and infrastructure costs are amortized over a growing user base, both scenarios show a strong decline in LCOC. By 2035, costs converge, with the high-utilization scenario reaching €0.10/kWh and the low-utilization scenario dropping further to €0.056/kWh. This downward trend continues at a slower pace toward 2050, when LCOC levels off at around €0.07/kWh for the high-utilization scenario and €0.034/kWh for the low-utilization scenario.

The chart highlights two key conclusions. First, early deployment phases are cost-intensive, especially under high infrastructure rollout scenarios. Second, higher infrastructure utilization over time is critical to achieving lower charging costs. The sharp cost decline suggests significant economies of scale and technological improvements, underlining the importance of coordinated deployment and increasing vehicle adoption to ensure the economic viability of high-power charging networks for electric trucks.

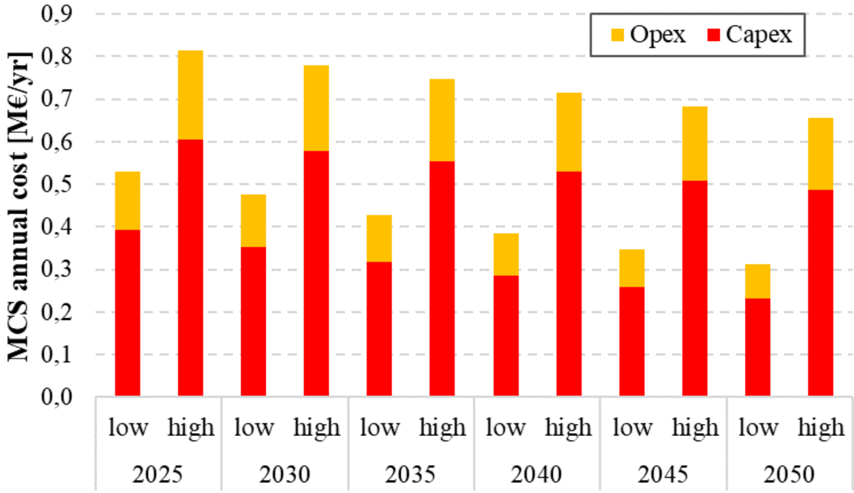

Figure 3: MCS annual station cost in M€ for high- and low-cost assumptions (left) and MCS station costs in €/kWh for 2025 to 2050 (right).

Figure 3 shows the results for the annual MCS station costs in two scenarios from 2025 to 2050, distinguishing between capital expenditures (Capex) and operational expenditures (Opex). For each five-year interval, the costs are shown under two scenarios: low and high-cost assumptions for MCS. In all years and scenarios, capital costs constitute the dominant share of total annual costs, indicating that upfront investments in infrastructure and equipment are the most significant financial component of deploying MCS charging networks.

In the short term (2025–2035), high-cost scenarios lead to higher annual costs, with total values approaching or exceeding €0.7 million per year, while low-cost scenarios are closer to €0.5 million. However, after 2035, a notable trend emerges: in several years, such as 2040 and 2045, the low-cost scenarios show relatively constant or even decreasing total costs, while high-cost scenarios show more variability but also a relative plateau or slight decline in Capex. By 2050, the difference between low and high scenarios becomes less pronounced, and overall costs slightly decrease compared to earlier years.

This suggests that while early-stage deployment requires large investments, economies of scale, technological improvements, or more efficient deployment strategies might reduce per-unit infrastructure costs over time. Additionally, as infrastructure matures, the relative share of Opex becomes slightly more important in later years, emphasizing the need for operational efficiency and maintenance strategies to manage long-term cost sustainability. Overall, Figure 3 highlights that MCS infrastructure deployment will be capital-intensive in the coming decades but may stabilize or become more manageable as the market matures.

4 Summary and Conclusion

This paper assesses the cost dynamics of megawatt charging systems (MCS) for electric trucks in Europe through two key indicators: annual system costs and levelized cost of charging (LCOC). The analysis considers both low and high-cost scenarios from 2025 to 2050. Results show that annual MCS costs are initially 0.5 – 0.8 M€ per year and decrease over time. The LCOC declines substantially in both scenarios, dropping from €0.27/kWh to €0.07/kWh in the high case and from €0.173/kWh to €0.034/kWh in the low case. These trends underline the long-term cost competitiveness of high-power charging infrastructure as electric truck adoption increases.

The findings suggest that early investment in megawatt charging infrastructure is economically justified, if utilization increases over time. Achieving low charging costs by 2035 and beyond depends on a coordinated rollout strategy and sufficient demand aggregation. Therefore, policy support and targeted infrastructure planning are essential to unlock the cost-saving potential of MCS in heavy-duty transport.

Acknowledgments

PP, TG, DS and SL acknowledge funding from the German Federal Ministry of Education and Research

(Ariadne project FKZ 03SFK5D0-2) as well as the German Ministry of Digital and Transport (HoLa project, FKZ 03EMF0404A).

References

[1] Eurostat. Greenhouse gas emissions by source sector. 2024.
[2] Plötz P. Hydrogen technology is unlikely to play a major role in sustainable road transport. Nat Electron 2022;5:8–10. https://doi.org/10.1038/s41928-021-00706-6.
[3] Liu H, Ampah JD, Afrane S, Adun H, Jin C, Yao M. Deployment of hydrogen in hard-to-abate transport sectors under limited carbon dioxide removal (CDR): Implications on global energy-land-water system. Renewable and Sustainable Energy Reviews 2023;184:113578. https://doi.org/10.1016/j.rser.2023.113578.
[4] Speth D, Plötz P. Depot slow charging is sufficient for most electric trucks in Germany. Transp Res D Transp Environ 2024;128:104078. https://doi.org/10.1016/j.trd.2024.104078.
[5] CharIN. Megawatt Charging System (MCS). Https://WwwCharinGlobal/Technology/Mcs/ n.d.
[6] Schneider J, Teichert O, Zähringer M, Balke G, Lienkamp M. The novel Megawatt Charging System standard: Impact on battery size and cell requirements for battery-electric long-haul trucks. ETransportation 2023;17:100253. https://doi.org/10.1016/j.etran.2023.100253.
[7] Noll B, del Val S, Schmidt TS, Steffen B. Analyzing the competitiveness of low-carbon drive-technologies in road-freight: A total cost of ownership analysis in Europe. Appl Energy 2022;306:118079. https://doi.org/10.1016/j.apenergy.2021.118079.
[8] Barman P, Dutta L. Charging infrastructure planning for transportation electrification in India: A review. Renewable and Sustainable Energy Reviews 2024;192:114265. https://doi.org/10.1016/j.rser.2023.114265.
[9] Shoman W, Yeh S, Sprei F, Plötz P, Speth D. Battery electric long-haul trucks in Europe: Public charging, energy, and power requirements. Transp Res D Transp Environ 2023;121:103825. https://doi.org/10.1016/j.trd.2023.103825.
[10] Speth D, Sauter V, Plötz P. Where to Charge Electric Trucks in Europe—Modelling a Charging Infrastructure Network. World Electric Vehicle Journal 2022;13:162. https://doi.org/10.3390/wevj13090162.
[11] Speth D, Plötz P, Funke S, Vallarella E. Public fast charging infrastructure for battery electric trucks—a model-based network for Germany. Environmental Research: Infrastructure and Sustainability 2022;2:025004. https://doi.org/10.1088/2634-4505/ac6442.
[12] Hurtado-Beltran A, Rilett LR, Nam Y. Driving Coverage of Charging Stations for Battery Electric Trucks Located at Truck Stop Facilities. Transportation Research Record: Journal of the Transportation Research Board 2021;2675:850–66. https://doi.org/10.1177/03611981211031542.
[13] Gönül Ö, Duman AC, Güler Ö. A comprehensive framework for electric vehicle charging station siting along highways using weighted sum method. Renewable and Sustainable Energy Reviews 2024;199:114455. https://doi.org/10.1016/j.rser.2024.114455.
[14] Nareshkumar K, Das D. Optimal location and sizing of electric vehicles charging stations and renewable sources in a coupled transportation-power distribution network. Renewable and Sustainable Energy Reviews 2024;203:114767. https://doi.org/10.1016/j.rser.2024.114767.
[15] Mohamed AAS, Jun M, Mahmud R, Mishra P, Patel SN, Tolbert I, et al. Hierarchical Control of Megawatt-Scale Charging Stations for Electric Trucks With Distributed Energy Resources. IEEE Transactions on Transportation Electrification 2023;9:4951–63. https://doi.org/10.1109/TTE.2022.3167647.
[16] Stefan Kippelt efRuhr D-I. GRID-RELATED CHALLENGES OF HIGH-POWER AND MEGAWATT CHARGING STATIONS FOR BATTERY-ELECTRIC LONG-HAUL TRUCKS. n.d.
[17] Schroeder A, Traber T. The economics of fast charging infrastructure for electric vehicles. Energy Policy 2012;43:136–44. https://doi.org/10.1016/j.enpol.2011.12.041.
[18] Beschlusskammer 6 Positionspapier zur Erhebung von Baukostenzuschüssen (BKZ) für Netzan-schlüsse im Bereich von Netzebenen oberhalb der Niederspannung. n.d.

Authors

Prof. Dr. Patrick Plötz studied Physics in Greifswald, St. Petersburg and Göttingen. Doctorate degree in Theoretical Physics from the University of Heidelberg. Since 2011 researcher in the Department Energy Technology and Energy Systems at the Fraunhofer Institute for Systems and Innovation Research ISI and since March 2020 he is coordinator of Business Unit Energy Economy. Since 2020 private lecturer at the Karlsruhe Institute of Technology (KIT) and adjunct professor for Sustainable Energy and Transport at Chalmers University of Technology.

Antonio Sgaramella studied Engineering at Sapienza University in Rome and Budapest University of Technology and Economics. He currently is a PhD student at Sapienza University in Rome and obtained a master's degree in engineering for energy-economic simulations around hydrogen use in transport and other applications. He currently works on Hydrogen Refuelling Stations for Urban Areas

Steffen Link studied Industrial Engineering and Management at the Karlsruhe Institute of Technology (KIT). His master thesis dealt with European CO_2-legislation for passenger cars and its implications on market diffusion of alternative fuel vehicles. Since 2019, he is a researcher at the Fraunhofer Institute for Systems and Innovation Research ISI in Karlsruhe, Germany. Areas of work are the modelling of market diffusion for electric vehicles with a special focus on heavy-duty vehicles and its implications on the energy system.

Dr. Daniel Speth studied Industrial Engineering and Management at the Karlsruhe Institute of Technology (KIT). His master thesis dealt with European CO_2-legislation for passenger cars and its implications on market diffusion of alternative fuel vehicles. Since 2019, he is a researcher at the Fraunhofer Institute for Systems and Innovation Research ISI in Karlsruhe, Germany. Areas of work are the modelling of market diffusion for electric vehicles with a special focus on heavy-duty vehicles and its implications on the energy system.

Dr. Till Gnann studied industrial engineering at the Karlsruhe Institute of Technology (KIT) and at the Politecnico di Milano (Italy). He gained overseas experience in Santa Clara, CA (USA). Since April 2011 he has been working in the Department Energy Technology and Energy Systems at the Fraunhofer Institute for Systems and Innovation Research ISI. He received his PhD from the Karlsruhe Institute of Technology (KIT) in 2015 on „Market diffusion of plug-in electric vehicles and their charging infrastructure". In 2016, he stayed for a research visit at Argonne National Lab (Chicago), Oak Ridge National Lab (Knoxville) and the US Dept. for Transportation (Washington, DC). Since 2020, he coordinates the cross-cutting topic electric mobility at Fraunhofer ISI.