35th International Electric Vehicle Symposium and Exhibition (EVS35)
Oslo, Norway, June 11-15, 2022

An Integrated Approach for the Planning of Public Charging Infrastructure

Matthias Pfriem[1], Laurence Chittock[2], Karen Platt[3], Udo Heidl[4],

[1]*Matthias Pfriem (corresponding author) PTV Planung Transport Verkehr GmbH,*
Haid-und-Neu-Straße 15, 76131 Karlsruhe, Germany, matthias.pfriem@ptvgroup.com

[2]*Laurence Chittock, PTV UK Ltd*

[3]*Karen Platt, EA Technology*

[4]*Udo Heidl, PTV Planung Transport Verkehr GmbH*

Summary

We present a novel integrated approach for the planning of public charging infrastructure. It identifies areas of high charging demand using outputs from a detailed transport model and provides information about grid connection capacity to guide where charging points can be installed for the least cost. Both mobility and grid information are combined in a web tool with an interactive map to choose charging locations in an informed compromise between demand and supply availability. This enables strategic charging infrastructure planning for an area to assist in the acceleration of infrastructure roll-out whilst helping to avoid higher costs and effort of sequential planning processes.

Keywords: charging, demand, deployment, energy network, infrastructure

1 Introduction

The transportation sector is one of the most polluting sectors in our society, contributing 24 % of direct CO2-emissions from fuel combustion [1]. Electrification can significantly reduce transport emissions, especially as electricity generation shifts further to renewable sources. However, as of 2019, electric cars only accounted for 2.6 % of global car sales and approx. 1 % of the overall car stock [2]. The uptake of electric vehicles (EVs) is partly reliant on the development of an appropriate charging infrastructure according to [3]. Hence, administrations around the globe are announcing programs to support the roll-out of public charging infrastructure, such as the USA which has committed an investment of $15 billion for a national network of 500,000 charging stations [4], or Germany which has committed €2 billion for 1,000 fast charging sites in the “Deutschlandnetz” [5]. The global electric vehicle charging infrastructure market is expected to grow up to around $14 billion in 2026 [6]. The U.S. Department of Energy estimates a need of 3.4 DC fast charging plugs per 1,000 EVs in residential areas and another 40 plugs per 1,000 EVs in non-residential areas (work and public parking) [7]. The European Union have set a guiding value of at least one charging point per 10 EVs [8], which has subsequently been replicated in national targets [9]. In the UK the government has set a goal of increasing the number of public chargepoints to 300,000 by 2030 [10]. However, more detailed analysis is needed on a region-by-region basis to understand the requirement for charging infrastructure, to provide a satisfactory return on investment, and to avoid stranded asset investments.

2 Requirements for Charging Infrastructure

The roll out of charging infrastructure has to consider both the vehicle-based charging demand , and the electricity network supply constraints. That leads to two key questions, firstly, what is the requirement of infrastructure based on the vehicle stock and mobility demand patterns? Secondly, where and how can charging points be installed most quickly and efficiently given present constraints of electricity network capacity?

2.1 Mobility Requirements

From a driver's perspective, an efficient charging infrastructure network should provide the means to charge in convenient locations and at a speed that is suitable for their needs, ideally without detour or excessive charging related wait times. Two basic cases can be differentiated: rapid of fast charging and standard charging. Fast charging is intended to deliver energy in a short period of time with high power and should only minimally interrupt a driver's mobility needs. Chargers of this type provide at least 50 kW with some sites offering speeds up to 350 kW. Fast chargers require high investments to install and hence require a high utilization to provide a return on investment. From a commercial point of view therefore, it is desirable to place them in locations where there is a clear need for stop-and-go charging, e.g. along roads with a high proportion of long-distance trips like highways.

Standard charging on the other hand provides comparably lower power rates (typically defined as up to 22 kW). For this type of charging, it is sufficient that adequate charging can be achieved within the dwell time of the parked car, when it would be parked anyway. This happens e.g., at workplaces, at shopping centres, public car parks, or in residential areas where cars are parked for several hours.

2.2 Electricity Network Constraints

Installation costs for public charging infrastructure vary by more than a factor of 20 [11] depending on the location chosen and necessary work conducted to connect and reinforce the electric grid. Such factors include civic costs of excavation and installation, but can also extend to upgrading electrical infrastructure, such as cables or transformers, based on the existing and expected network loads. These costs vary depending on the distance to the grid connection point and local factors such as the ground type. Another effect from the installation of a charging point on the power network can be a drop in the voltage level of the local grid [12]. In those cases of insufficient grid hosting capacity, additional power supplies are needed to serve a new charging site. Depending on the power level of the transformer or substation installed, grid upgrade costs can reach over $ 170,000 for 1000+ kVA installations [13]. Field trials [14], [15] have shown that critical hours for capacity restrictions in residential areas are in the evening, when many EV are plugged in for charging simultaneously and non-EV demand is high as well. To cope with that particular challenge, smart charging connection solution are being developed to provide flexible capacity to new charging connections that reflect the available grid capacity and avoid grid reinforcements [16].

3 Advantage of Integrated Planning

Currently, planning processes usually happen sequentially. Often, the potential location, or several locations, for a charging site is predetermined by the charge point installer (CPO). The CPO will then submit a request for grid connection at each potential location to the Distribution Network Operator (DNO), and the works and costs associated with these connections will be evaluated. If costs are deemed satisfactory by the CPO then the installation will proceed for the selected site(s), balancing the total cost to install against projected income. Often however, due to insufficient network capacity at the chosen location, network reinforcement costs are passed on to the CPO and the proposal might well be dropped. An optimal solution to rolling out charging infrastructure quickly, at low cost, and in high demand areas can therefore only be found with an integrated search approach where energy demand from mobility and possible energy supply from the grid are considered simultaneously.

While agent-based transport models have been used to identify potential charging sites in research for years, e.g. [17] and [18], they have not been adopted as a standard to support planning yet. In some countries, tools based on macroscopic travel models have been made available by the government to support private and public sector in charging infrastructure build up, e.g. [19]. But they all have in common that they only focus on the demand of charging energy. The novelty of this approach lies in the combination of a model for charging demand and a model for available electricity capacity from the grid in one integrated tool for a simultaneous assessment of both dimensions.

With such an approach among all possible sites with the same value to satisfy the energy demand, the one with the least installation effort can be chosen or an informed and explicit balancing can happen to reduce the mobility value of the charger in exchange for a cost reduction. Such balancing can only be done when data from both transport planning and electricity network operation are made accessible at the same time in one integrated tool.

4 Methods

This paper describes the approach to develop an integrated tool to support charging infrastructure decisions considering both public chargepoint demand potential and available electricity network capacity. The chargepoint demand element is estimated through the development of a set of transport models, which contain a detailed representation of mobility and associated electricity demand from electric vehicles. Various trends are forecasted to help estimate the future needs for charging by combining the data from the transport model with scenario-based assumptions. A map of the low voltage (LV, with networks consisting of 400/230 V network assets) and medium/ high voltage (MV/ HV, with networks consisting of 11 kV, 6.6 kV, 6.3 kV, 6.0 kV network assets) electricity grid is developed to present the existing, and regularly updated, capacity potential of network assets allowing informed decisions to be made about the suitability of individual locations to host chargepoint infrastructure.

4.1 Mobility Simulation

Transport models are an established tool in the planning sector and are built to represent mobility patterns and assess infrastructure decisions. In this case these tools are extended to understand the requirement of electric vehicles and help determine where, when, and how often they might need to charge in the future. The transport demand model contains digitised map data of the road and public transport network and spatially distributed socio-demographic data on population. Structural data on jobs, shopping, restaurants and other points of interest are included to provide spatial disaggregation and indicate where people travel to and for what purpose and duration. Travel demand can be modelled with a tour-based model that includes the traditional steps of trip-based demand models such as destination choice, mode choice and route choice, but is extended to include trip chaining, for instance from home to work to the shops and back home. This allows more complex trip patterns to be represented and permits evaluation of energy consumption over multiple trips and days as well as to identify parking times and locations between the trips, which could be used for charging. Through calibration with data from real-world observations – such as mobile phone data and traffic counts, the model can be built to give a realistic representation of the mobility patterns of the population in the area of investigation. Various factors like the availability of private off-street parking, existing car levels, and income are a vital input to allow for the estimation of future EV uptake patterns.

4.2 Scenario Development

With sales of EVs growing, it is important to be able to forecast how uptake might evolve and how this might impact the demand for charging. Since forecasting is inherently uncertain, scenario planning can be used to evaluate a range of plausible futures based on a collective view of the most likely outcomes. Unlike traditional forecasting, which attempts to predict the most likely single future, scenario planning deliberately considers alternative and possibly divergent futures. Thus, when deciding how to react in the future, scenario planning is not about figuring out which scenario will occur and optimising for such a future. Instead, a set of varied futures can be generated that could all be plausible outcomes. If all these futures are deemed to be plausible, albeit with differing likelihoods, the most pragmatic approach is to design a strategy that is robust in the face of multiple possibilities and can react to changing trends.

Scenarios can be developed by canvassing a range of expert opinions to help envisage possible futures and to determine parameter values that cannot be estimated by extrapolation in a model. The development of scenarios can be based on the following principles, similar to those utilised in [20].

- Establishment of key outcomes: What are the outcomes to be represented by the scenarios and what will be assessed by the resultant model?
- Identification of important variables: What factors are likely to affect the above outcome and how much of an influence are they likely to have in the future?
- Selection of critical uncertainties: Which are the most important and uncertain variables that will likely determine which path(s) the future may diverge down?
- Development of scenario narratives: A qualitative construction of core scenarios which draw on possible variations of the critical uncertainties in the future.
- Consideration of scenario pathways: How might the scenarios play out from today through to 2050?

4.3 Grid Modelling

Just as with the transport network, the electricity grid needs to be modelled spatially using the DNO’s data. This data includes their asset records as well as demand characteristics. Simulation tools are then used to calculate and evaluate the network limiting factors, such as currents and voltages, and a traffic light system (red, amber, and green colours) is used to display the capacity of network assets (cables and transformers) based on their design ratings, existing utilisation and voltage drops across the network. The remaining capacity potentially available for EV charging can be calculated from the difference between the modelled capacity already used by existing connections versus the initial design capacity of the network. This approach allows judgements to be made about the suitability of individual network locations to accept new connection and encourages connection size to be tailored to available capacity, making most efficient use of existing network assets. The method described allows infrastructure to be connected expediently and more cost effectively.

5 Results from the Charge project, UK

This novel approach has been applied in the Charge Project [21] in the UK [22], where the sale of new petrol and diesel vehicles will be banned from 2030. As this deadline approaches, the availability of public chargepoints, especially for future EV owners without off road parking is a concern. For their part, electricity network operators want to support the efficient roll out of chargepoints while making best use of existing network assets. To encourage chargepoint rollout and facilitate connections, an online interactive tool, ConnectMore, is being developed that will cover Merseyside, Cheshire, North Shropshire, North and Mid-Wales, the Manweb electricity distribution license area managed by SP Energy Networks [23].

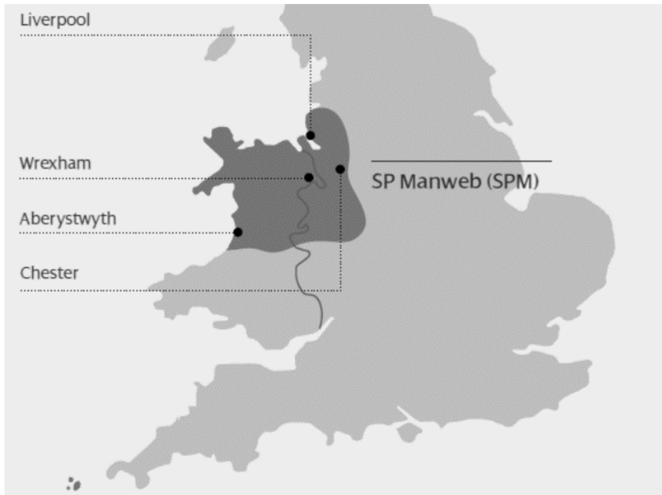

Figure 1: Map of the location of SP Manweb electricity distribution license area within the UK [24]

Four future scenarios have been modelled, with two critical uncertainties providing the main pivot for the scenarios: the level of EV uptake, and the reliance on public charging infrastructure, investigated from low to high. Figure 2 shows the input EV uptake assumptions for the region up to 2050 in each scenario.

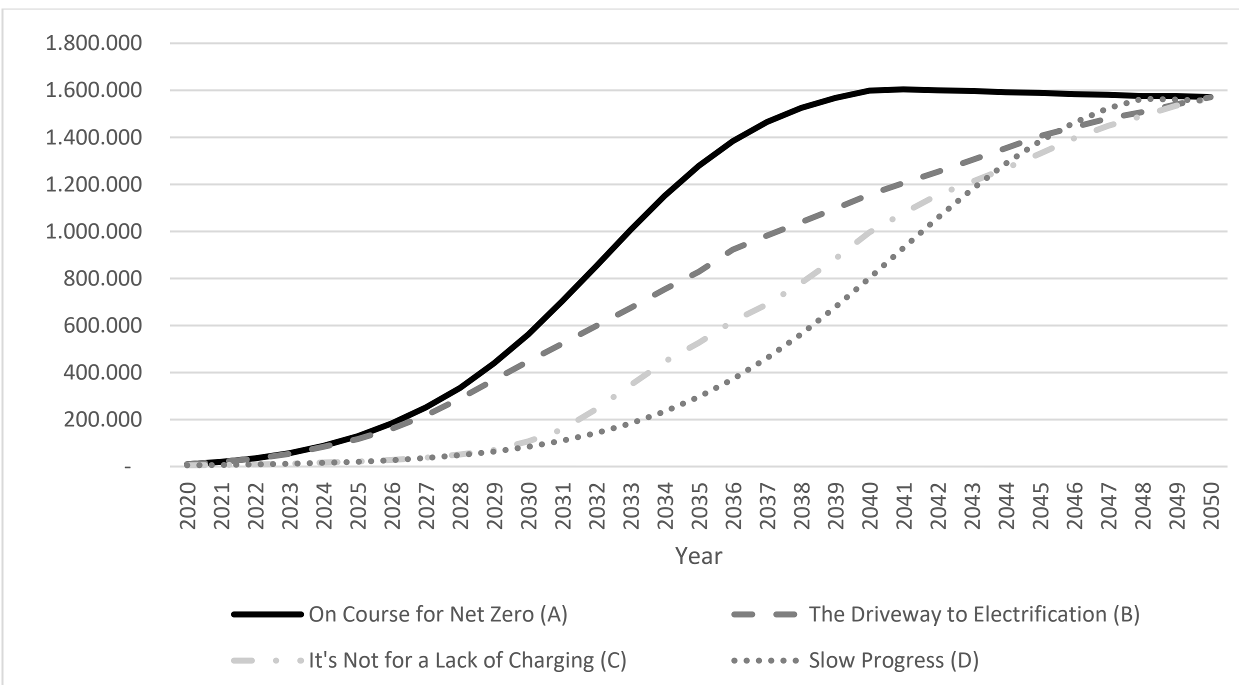

Figure 2: EV Uptake in the project region in four scenarios

The transport model for the project region reflects the mobility patterns of over 6 million people through multiple modes of transport. An EV choice model considering socio-demographic factors and a weekly travel diary for each car is employed to consider feasible EV adoption and use. A subsequent charging model is implemented and calculates the energy demand for potential charging activities based on the decreasing range in the car's battery as a result of the car's trip patterns. Standard charging is equated at a destination (such as home, work, or the shops) and is aggregated to a zonal land parcel. Fast charging is equated along the road network, on the assumption that this activity will be carried out in a dedicated break within a trip. The aggregation of this data for all simulated EVs and across the study region both spatially and temporally can be used to determine locations and numbers (considering simultaneousness) of charging points, and the combination of dwell time and energy demand can be used to derive demand for charging power. This allows for the planning of infrastructure uptake as well as for an evaluation of the business case. Further information about the development of the Charge transport model can be found here [25]. Zones of different charging energy demand are made visible in the demand layer of the interactive map (Figure 3).

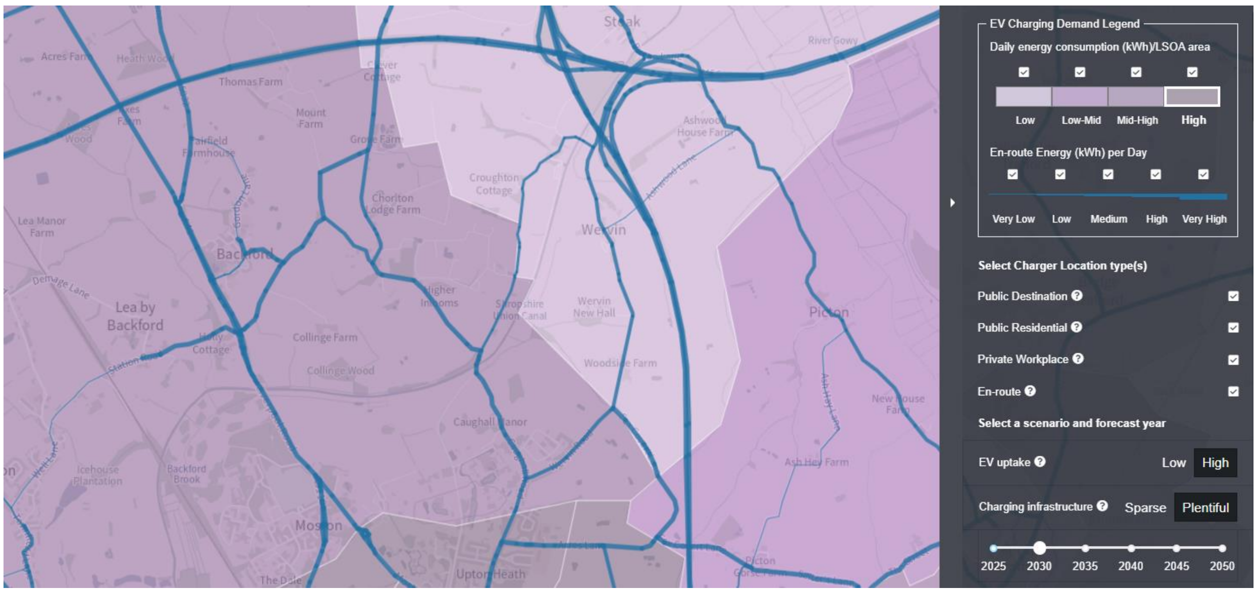

Figure 3: Example from the ConnectMore Interactive Map showing the Charging Demand layer

In parallel, an assessment of the LV and HV electricity network has been undertaken based on its available modelled capacity. The approach is based on the methodology used by connection engineers to make an assessment of available capacity when first presented with a network connection request. Algorithms were developed to calculate available capacity of individual network assets. Available capacity for each asset includes existing modelled customer connections at LV and HV levels. Calculations of the available capacity of the electricity network also included account of the complex interconnected nature of the network in this geographical area (Figure 4). The tool allows users to answer key questions as to where and at what cost connections can be made. As additional functionality added in summer 2022, to understand where the network is more suitable for a new connection, ConnectMore also provides instant and automatic indicative budget quotations for specific user input locations. This will reduce the volume of required firm quotations processed by the DNO and will assist in speeding up the overall connection process.

Figure 4: Example from the ConnectMore Interactive Map showing the LV network capacity layer

The ConnectMore Interactive Map [23] has been developed to overlay the transport demand and estimated requirement for charging infrastructure with the electricity grid capacity. Figure 3 from the transport layer of the web tool gives an example with zones with low (light purple), low to mid (mild purple), mid to high (mid purple) and high (dark purple) estimated daily energy demand for small local areas. En-route demand is represented along road segments with thicker blue lines indicating the degree of estimated demand. For each element, zones and road segments, detailed information is provided, including: estimated energy demand, number of charging sessions, and anticipated dwell and arrival profiles. Figure 4 demonstrates the LV electricity network capacity and the layout of the grid via lines denoting feeders and dots indicating transformers. Good capacity for connection is shown in green as opposed to amber or red, where limited or no spare capacity is available without reinforcement work. In Figure 5 below, the black circle marks an exemplary spot in an area with high estimated EV charging demand where, within few metres of a road with very high en-route demand, good, poor and limited capacity for connection is available. In this example, the transport demand layer provides an estimate for the scale of infrastructure requirement, while the electricity network data gives information about available capacity and installation cost estimation. Thus, by varying the location of installation by only a few metres, connection costs can differ significantly. The provision of this integrated tool therefore allows installers to identify prime locations for demand whilst reducing the cost of installation.

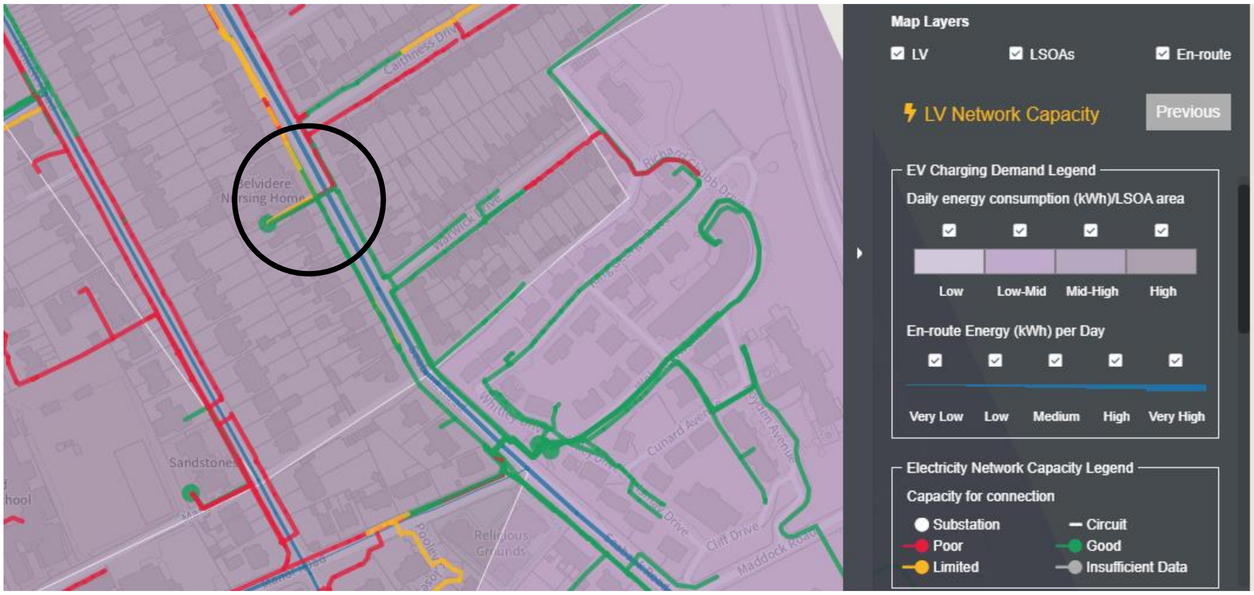

Figure 5: Example from the ConnectMore Interactive Map showing the Charging Demand and Electricity Grid

The input of key stakeholders such as local government transport planners, charge point operators and installers has been integrated to shape the development of the tool's functionality and user experience. Stakeholders have commented about the efficacy and value of the data provided and the method of presentation and the tool is being used actively in the region to assess further rollout.

6 Discussion

The years to come will see heavy investments in EV charging infrastructure to support market uptake and to generate revenue from usage. So that these investments can be targeted with maximum impact and efficiency, charging point locations need to be chosen wisely to meet the requirements of drivers and consider existing electric grid capacity. Combining mobility analysis in an integrated approach with electricity grid data means that within a search area drawn from mobility demand, optimal locations can be chosen to maximise the existing capacity on the network and avoid upgrade costs. This will allow deployment of infrastructure in a more cost-effective manner, benefitting EV drivers, charge point operators, grid operators and the wider community, while reducing the potentially disruptive impact of network reinforcement. As part of a project application of the approach, a free online tool has been developed to support the decisions of infrastructure installers. Although the tool does not provide a fully automated and deterministic location finder, this approach can be used as a planning support system for the integration of chargepoints in an existing grid. It also serves as an information basis for a stakeholder discussion among all the entities needed for infrastructure build up. For larger installations such as an urban fast charging forecourt, the tool can be used to assess demand potential, even if reinforcement to the electricity grid would be required anyway. The cost estimation tool being developed by the project provides accurate data on the cost of connection, or where reinforcement will be necessary with the corresponding effort.

From the perspective of a city administration, this integrated planning tool can be used to strategically control and monitor the process of introducing charging infrastructure in a transparent and understandable way. The authority can therefore understand how much infrastructure might be required and can act as gatekeepers for private industry rollout in the attempt to balance the use of public space among different requirements.

Acknowledgments

We would like to thank our consortium partners from the Charge project, SP Energy Networks and Smarter Grid Solutions, for the successful collaboration in the project and their support of this publication.

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Authors

Matthias Pfriem started his research on electric mobility at Karlsruhe Institute of Technology in 2010. During his time as doctoral researcher he has organised and conducted the scientific analysis of data from several field operational tests with hybrid and full electric vehicles. His doctoral thesis gives an extensive analysis of real-world usage of EV as basis for demand-based dimensioning of future vehicles generations. From 2016 on, he was in charge for build-up and management of a High Performance Center for mobility research working on several aspects of future mobility in a cross-organisational cluster. After joining PTV Planung Transport und Verkehr GmbH in 2021, his main interest in the field of electric mobility lies in optimized planning for public charging infrastructure.

Laurence Chittock became involved in electric mobility in 2009 when he worked as a researcher on the CABLED project, the UK's largest EV demonstration project. He later completed his PhD at Aston University in the UK having developed a location model to help with the optimal siting of charging points in a network. Since 2015 he has worked as a transport modeller, building and developing models to assess planned infrastructure schemes. In 2019 he joined PTV to manage the Charge project, leading on the technical delivery of the transport model, the development of future EV scenarios, and the estimation of future charging demand across the region.

Karen Platt has worked at EA Technology since 2007. Over the last ten years she has been involved in multiple large projects to investigate and mitigate the impact of low carbon loads on the electricity network. These have included Electric Nation which examined whether smart charging and variable pricing could mitigate the impact of domestic EV charging, and OpenLV that investigated if the deployment of distributed intelligence to local substations, combined with making monitored electricity network data more widely available, could help accelerate decarbonisation. More recently she has been part of the team delivering the Charge project which is aiming to accelerate the pace of public chargepoint connections by improved access to transport and electricity data.

Udo Heidl is a transport modelling consultant. Udo has a long-term experience (more than 30 years) in setting up transport models for metropolitan and regional areas with PTV Visum. He is an expert in the calibration and validation of 4 step demand models and he is involved in the several work groups of the German transport research society. Udo is well connected in the German academic transport modelling community; he gives talks and publishes articles related to his modelling work. As a director at PTV AG, Udo was responsible for PTV Vision professional services team for more than 15 years. Recently, he changed his role and became a member of PTV's Mobility Competence Centre, a strategic unit for innovative modelling and simulation solutions and project support worldwide.