Parking and Charging: New Concepts for the Use of Intelligent Charging Infrastructure in Car Parks

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Abstract

A reliable charging infrastructure for electric vehicles used in individual transport including availability and accessibility is necessary because it contributes highly to the decision of purchasing a BEV (battery electric vehicle). In Germany, charging is mainly done at home; however, parking spots in car parks have the potential to densify charging infrastructure in semi-public spaces. Intelligent car parks represent further developments which add a variety of technologies, energy management tools and value-added services to parking in general. The article addresses the question of technical maturity of charging infrastructures used in intelligent car parks and their marketability. Examples are charging methods such as conductive and inductive charging or various payment options. Pilot projects are described, and possible concepts of charging in intelligent car parks are explained, thereby addressing a growing interest in the subject.

Keywords

e-Mobility · Charging infrastructure · Intelligent car parks · Big data · Artificial intelligence (AI)

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11.1 Introduction

In this article, a literature overview on the state of the art in e-mobility, charging infrastructure and various charging technologies is conducted. Use cases and pilot projects related to car parks are presented. An expert survey has been pursued, and its results are published for the first time. Finally, an outlay of future technologies that can be used in intelligent car parks is given.

Climate Change and Mobility

Although greenhouse gas emissions have risen continuously since the beginning of industrialization, the recent acceleration of climate change currently poses one of the most pressing global challenges. Addressing this issue, 197 countries signed the Paris Agreement in 2015 to limit global warming to a maximum of 1.5 °C by 2050. To achieve this agreement, the reduction of greenhouse gas emissions had to be readjusted. Therefore, the EU agreed to reduce carbon emissions by 55% until 2030 compared to 1990 (DW 2020). By 2050, greenhouse gas neutrality is targeted. Road transport contributed 21% of the total EU CO₂ emissions in 2017. To achieve climate neutrality by 2050, rapid changes and measures for limitation are necessary (BMU 2019: 8–9). E-Mobility has the potential to contribute highly to the reduction of greenhouse gas emissions. Based on latest knowledge, the mandatory targets can only be reached by using battery electric vehicles (BEVs). From an environmental policy point of view, the end of combustion engines by 2050 is unavoidable (Clausen 2018: 14–15).

State of the Art of BEV

In Germany, the BEV market is still relatively small. Nonetheless, it is highly dynamic and presumably will grow exponentially. Out of the approximately 140 models offered in Germany in 2020, 70 models are produced by German car manufacturers. Government incentives are supporting the market and the transition to e-mobility (VDE 2020).

Major drivers for the BEV market in Germany are the expansion of charging infrastructure, an improved range of the vehicles, affordable pricing of charging and subsidies by the government (Mehta et al. 2019: 3). Significant barriers of e-mobility are the high purchase price, the limited range and the lack of a nationwide battery charging infrastructure (Clausen 2018: 13; Mehta et al. 2019: 3). From 2016 to 2019, the buying interest in BEV in Germany has doubled to 55% (Aral AG 2019). Experts predict an expansion of the charging infrastructure from 2025 until 2040. Furthermore, the vehicle’s range will be optimized, and the number of BEV owners will increase (Mehta et al.: 6–9). In order to achieve the EU targets for 2030, the demand of six million electric vehicles must be met in 2019 (Cornet et al. 2019: 35).

The number of charging stations in Germany grows linearly and has reached more than 21,000 units in Q4/2020 (Chargemap SAS 2020). On average, users of electric vehicles in Germany charge 65–70% at home, 15% at public charging stations and 7% at charging stations at the workplace (BDEW 2019: 6–8). Charging stations are often located in urban...
areas. One-quarter of all charging stations listed in Chargemap is located at parking spaces. In German cities, there is one charging station available for three electric vehicles on average (Chargemap SAS 2020; Oberst 2018: 1–3).

Deficiencies of charging stations include the varying payment system, the insufficient transparency of charging costs and the need for a special registration to operate the charging process (Clausen 2018: 13; Oberst 2018: 1–3). A nationwide charging infrastructure is an essential prerequisite. However, its expansion faces a problem as sales in charging do not cover investment costs and refinancing takes several years. Thus, there is an interdependency between the market development of BEVs and the charging infrastructure (Oberst 2018: 1–3) (Fig. 11.1).

The Role of Parking in Mobility
Parking is an essential component of mobility since it marks the beginning and the end of each driving process and covers as much as 23 h per day on average. In large cities, space for car parking can cover up to 40% of the total traffic area. Most parking spaces are located in the city centre, mainly close to shopping centres. The demand for parking depends on the number of cars and further on the number of retail shops and commuter traffics (Quantum Immobilien 2018).
11.2 State of the Art

Charging Technologies
Currently, there are four different charging systems in use: cable-bound (also called cable-bound charging or the so-called plug and charge) is a conductive charging system, whereas wireless charging is an inductive charging system. Furthermore, there is battery swap and finally the so-called redox flow principle. In Germany, only cable-bound charging technology is in use. There are two kinds of conductive charging methods: alternating current charge (AC) and direct current charge (DC). Cable-free charging is currently being tested in pilot projects as another technology, for example, for cabs (Universität Duisburg-Essen 2019). Battery replacement has not been standardized and is rarely used (VDE FNN et al. 2020: 8).

For cable-bound charging, there are different charging modes, which are defined in the standard DIN EN 61851-1 (VDE 0122-1): charging processes with an output of max. 22 kw are considered “normal charging” and represent the modes 1–3 of AC charging. Higher powers (e.g., 50 kw) are called “fast charging” and are considered DC charging mode 4. This is stated in the EU Directive 2014/94/EU. For both conductive charging technologies, communication between infrastructure and BEV operates via cable. For AC charging, communication in accordance with ISO 15118 is optional; for DC charging, communication is mandatory and operates via charging cable that is permanently integrated in the charging station. Information on energy requirements, planned duration of the charging process and information on pricing and billing are exchanged during communication (VDE FNN et al. 2020: 9–11). The DC fast-charging infrastructure is expanded to ensure a wide coverage along the motorways and main traffic axes and to supply a new generation of BEVs with higher ranges. The Combined Charging System (CCS) is used to ensure the compatibility of different generations of charging infrastructures (NPE 2020).

Charging Infrastructure and Legal Requirements of Maintenance and Handling
When selecting charging infrastructures for parking garages with a floor space of 100 m² or more, the garage regulation of the respective federal state must be considered, and identification and safety obligations must be fulfilled. VDE 100-722 must be followed, and the infrastructure is supposed to be designed for mode 3 or 4 (NPE 2020; VDE FNN et al. 2020: 19–20). It is necessary to analyse the type and number of BEVs expected at the location. Furthermore, data of considered charging capacities, duration of parking and charging behaviour of the vehicle owners need to be estimated. Since charging infrastructure demands much electrical power for several hours, supply lines and distributors must be designed generously, also considering the fast-growing market of BEV leading to increasing requirements. There is an obligation to notify the network operator if power levels exceed between 3.7 and 12 kVA to avoid unnoticed network overload. Above 12 kVA, the network operator has to be asked for approval (VDE FNN et al. 2020: 14–17).
Measures for monitoring, evaluating and billing of charging processes need to be considered in the planning process of the public charging infrastructure. The facilities for these measures are called back-end system. Suitable interfaces between charging stations and back-end are required. Relevant standards for the development of charging infrastructures are currently progressing. For example, it is important to position the charging station in the immediate proximity of the parking space and without affecting the other users of the parking space. Operators of charging stations must ensure that fire and data protection criteria are confirmed. The intuitive operation of the charging station in a well-lighted environment must be ensured. According to the charging station ordinance, charging stations in public spaces must be usable for charging without prior conclusion of a contract. DIN IEC 63119-1:2018-04 stipulates that the operators of different charging infrastructures must conclude contracts with each other for shared use, i.e., “roaming” by customers (VDE FNN et al. 2020: 23–25). The charging stations are exposed to environmental factors such as weather, temperature fluctuations and vandalism.

For easy handling across manufacturers, the plug and charge system is being pursued. This system enables immediate charging once the cable is plugged in. The payment process is initiated automatically. This requires a standardized and secure communication between BEV and charging station, guaranteed by ISO 15118. In a strategic collaboration between Hubject and Electrify America, the introduction of the system in North America has started at the end of 2020 (Werwitzke 2020).

An argument against the plug and charge system is that the situational electricity costs, network load and battery charge level are not considered. The charging method per kWh may be more expensive than other charging systems (Torres-Sanz et al. 2018: 22875–22888). The utilization and amortization period of public charging points can be seen critically. Although customers are willing to pay for DC charging, subsidies are required to convince charging point manufacturers to provide the overly scaled number demanded by policy makers (Wirges 2016: 131–133).

Further, the expansion of public fast-charging stations is planned. Until 2023, 1000 locations are identified for DC fast-charging networks. These charging stations will supply electric power of more than 150 kW. In addition, it is planned to expand the number of normal and fast-charging stations to 72,000 (BMVI 2020).

This article mainly focuses on charging infrastructure in public car parks. However, one should consider the public funds of private charging stations since charging at home is still preferred by around 65% in 2019 (BDEW 2019: 8). The purchase of private charging points is funded with 900 € by the Federal Ministry of Transport and Digital Infrastructure. It includes private homes, residential buildings and any other non-public construction of charging points. This, for example, could lead to increasing sales of wall boxes (BMVI 2020).

**Grid Integration**

A conflict of objectives arises between the permanent supply of energy and the three attributes cheap, efficient and environmentally friendly (Gemsjäger, Monscheidt 2020). If
electric vehicles demand electricity in an uncontrolled and uncoordinated manner, high loads occur at peak times, which endangers the stability of the electricity grid. Due to the expansion of renewable energies and the use of small generators, the electricity supply is more volatile anyway (Linnhoff-Popien et al. 2015: 52). Energy producers, storage facilities and consumers organize their operations efficiently in smart grids, considering the demand and supply situation (VDE FNN et al. 2020: 33). Parking and charging time is decoupled in this intelligent charging management. Factors such as the current grid load, battery capacity and BEV demand are considered. The charging quantity is also calculated under these paradigms (Gemsjäger, Monscheidt 2020).

Grid stability is supported by bidirectional charging which is defined as charging at times of low demand and feeding into the grid at peak times. For stakeholder satisfaction, the collection and evaluation of Big Data using artificial intelligence (AI) is useful. Thus, an energy management system can be operated in real time, which allocates the available resources using AI (BDI e.V 2018). As the expansion of e-mobility continues, parking lot operators are invoked to provide more charging points.

11.3 Pilot Projects

Daily business of parking lot operators may be expanded to real-time charging load management in the future. The integration of charging as an added service during parking could possibly be profitable for car park operators. Since demand in charging stations increases, their availability at parking spots might become important (Wirges 2016: 236). Charging is already possible in selected car parks of the operator APCOA—the biggest European parking-space provider—in German cities but is limited to a few charging points (APCOA PARKING n.d.).

The project AUTOPTES (automated parking and charging of electric vehicle systems) was performed from January 2013 to June 2015, and it was funded by the German Federal Ministry of Education and Research, BMBF. The goal was the development of a parking and charging system in the car park Hofdienergarage in Stuttgart. The research focused on an intelligent charging infrastructure. The concept seeks to be technically feasible, economical and marketable. It is possible to gradually expand the 16 charging points, which are integrated in the car park infrastructure. The parking spots need to be booked and reserved in advance via app. Since several vehicles can be charged simultaneously, the planning of energy demand is important. The reservation system contributes to a better demand forecast. The conductive charging process could be further automated when using a robot which finds the charging socket independently without human intervention. The user can monitor the charging status via app during the parking process (FZI 2015).

The V-Charge project of Volkswagen AG in cooperation with Robert Bosch GmbH, the Swiss Federal Institute of Technology Zurich, the Technical University of Braunschweig, the University of Parma and the University of Oxford was funded by the European Commission within the “Europe 2020” programme. Reservation and booking of a parking
spot are operated via app. A status check is carried out, whereby the demand of the vehicles’ energy and the parking time are queried (Furgale et al. 2013: 809, 811). The charging is operated inductively (Pudenz 2015). Big Data regarding the expected parking time, the current battery level and the planned travel distance are required to distribute the energy capacities according to the demand of all charging vehicles (Furgale et al. 2013: 811).

A different approach was taken by the project of Volkswagen AG’s “CarLa” loading robot in 2018 (Volkswagen AG 2018). Mobile robots equipped with a battery pack approach the vehicle and charge it independently without human intervention. The robot’s gripper arm detects the position of the charging socket and identifies the plug type. Smartphone, robot and vehicle communicate with each other exchanging information and data. Relevant data includes the type of vehicle, type of plug, position of the plug and energy demand. These robots act intelligently and decide in which order they approach and charge the vehicles based on communicated data (Walzel et al. 2016: 110–111).

It can be deducted that the technical maturity and marketability of intelligent car parks varies and that a wide range of technical feasibility studies of intelligent car parks has been conducted. In the following section, several technologies will be evaluated and discussed based on the literature review and the expert’s opinions.

### 11.4 Technologies in Intelligent Car Parks

During the research of this paper, the authors have interviewed eight experts on the topic of intelligent car parks. The results serve as a basis for further discussions of the technology maturity state and the expected marketability of intelligent car parks. In summer 2020, a questionnaire was handed out to stakeholders such as parking spot operators, energy suppliers, companies operating in charging infrastructure, associations and state agencies. The time to marketability is given in years (Fig. 11.2). The technology maturity state is depicted by a scale from 0 (low) to 10 (high).

According to the experts, the expansion of the DC fast-charging infrastructure will benefit the use of DC technology to a high degree. However, there are different opinions about the time until its implementation. Although DC is already a standard for BEV, its penetration for plug-in hybrids (PHEV) will still take time. One expert sees DC charging stations as a niche solution in car parks. Fast charging is predicted to be possible as an additional service with a higher price. Fast inductive charging will complement conductive charging in 5–10 years.

In general, there is a high interest in research about autonomous driving. Due to this, it is included in the survey. In six of seven answers, autonomous driving is categorized in terms of the technology maturity state with a low to medium degree, and the time horizon to marketability is seen in the range of 5–10 years.

Payment via app is a valid solution. According to the eight experts, this payment option has a high level of technology maturity and is already marketable, no later than within...
Fig. 11.2  Survey results of technologies in car parks
5 years. Opinions regarding pay and charge payments differ. Nearly half of the answers are in matrix quadrant four, indicating a medium to high technology maturity. Two answers suggest a timely deployment within the next 5 years and a low to medium maturity level. The marketability of plug and charge depends on the ISO 15118 standard, which is essential for charging and the payment process. Currently, so far only few electric vehicles support the ISO 15118 standard. This leads to a lower market attractiveness of this payment possibility. Starting from 2025, a nationwide implementation seems realistic, although the technology’s maturity is considered to be on a medium to high level.

The usage of Big Data and AI in the category of technical infrastructure is an essential component of intelligent car parks. Big Data and AI is already used in internal route planning of vehicles, although its expansion to other potential use cases takes more time. The current technology maturity level is estimated to be low by three-quarters of the experts. Further, the marketability is expected within the next 6–10 years. Smart grid technologies are already applied in individual applications. However, their legal integration is not established yet. The grid operation and energy supply contracts still need to be revised for a practical application, and the relevant markets need to grow. The marketability of smart grid technologies is expected in 5–6 years, while the technology maturity is perceived on a medium level. As long as a smart grid is not implemented, the missing load balancing needs to be compensated by higher standby energy generators or energy storage.

According to the experts, technical conditions for the use of photovoltaic systems in car parks and their integration in the charging infrastructure are on a high level. There is disagreement about the time required for the implementation of renewable energy management like photovoltaic systems. Car park operators cast doubt on the willingness to invest in an own photovoltaic system. However, several car park operators already use it. Controlled charging defines a controlled and coordinated electricity supply for electric vehicles within the charging environment. This is technically already possible, and the experts assess an implementation within the next 5 years. Estimations regarding the technology maturity level of bidirectional loading differ; however, three-quarters of the experts assume that a technical solution is implemented in the next 5 years. The lack of a policy framework/legislation and high investment costs endanger the large-scale implementation and influence the time for marketability. According to one expert, energy storage devices (e.g., batteries) will be used in public parking spots during peaks of energy demand. Further, an integration in the energy management is easier and less complex. According to the experts’ assessment, the use of intelligent controlled charging will be implemented in the next few years. Bidirectional charging is a further development towards an integrated energy management. Due to the lack of a legislation framework, it probably will take longer.

As described in the pilot projects, reservation via app as a value-added service is already possible; however, it is not used frequently so far. The marketability of this service is expected within the next 5 years, and the technology maturity level is rated high by three-quarters of the experts. Vehicle cleaning during parking is expected to be implemented until 2025. However, due to the expected high price, the involvement of a third-party
company and the legal complexity, a general low demand for this service is presumed. The service of luggage loading in a vehicle operated by a third party has a medium technology maturity level, while the marketability of the service is considered in 5–10 years. However, there are obstacles regarding the customer acceptance since a high level of trust is required for this.

11.5 Conclusion and Outlook

Due to the increasing demand for electric vehicles, the expansion of charging infrastructure meets high interest. It is estimated that parking spots in car parks have a high potential to increase the number of charging stations. In this article, the state of the art of e-mobility in relation to the charging infrastructure is presented. It can be deducted that the technical implementation of charging infrastructure in car parks is not an issue. Rather, the establishment of legal standards is a far greater challenge. However, standardization of charging points is urgently required to support the growth of e-mobility.

In August 2020, the national central office for charging infrastructure in Germany published a position paper on the “User Journey” of charging electric vehicles. It is explained that charging electric vehicles differs from refuelling a conventional car and, therefore, is a new experience for users. Results show that high user-friendliness and an integration of the charging process in daily routine are essential for a good experience (Nationale Leitstelle Ladeinfrastruktur 2020: 4–5).

Therefore, these issues need to be solved fast in order to meet customer demands. In Germany, the automotive industry will play an important role in establishing harmonized or competing charging infrastructures. Standardization helps to reduce investment risks for the stakeholders. The number of electric vehicles increases continuously, and therefore, the demand for charging infrastructure in public places will rise. To increase the number of BEVs in Germany and to support the car manufacturing industry, the German government decided to extend the subsidies to buy or lease BEVs from 2021 to 2025. Since the implementation of charging infrastructure is a competitive advantage, car operators should already prepare for this. e-Mobility is currently subsidized, which supports investments of car park operators. However, sustainable business models are needed in the future.

Further, in the position paper of the national central office for charging infrastructure, it is discussed that there will not be one universally valid concept for charging. Still, until 2025, the plug and charge technology will mainly be more important since the ISO standard 15,118 will be developed (Nationale Leitstelle Ladeinfrastruktur 2020: 26).

In a long-term perspective, more international cooperation and standardization would be beneficial but is hindered by competition. In an alliance with the Chinese Electricity Council, the Japanese CHAdeMO Consortium develops its own fast-charging standard by the end of 2020, which is implemented in Japan and China. It is supported by Asian car
manufacturers. Technically, it is ahead of the in Europe prioritized CCS standard. Charging capacities exceed 500 kW, and the charging time can be reduced to a few minutes. Thus, the introduction of this new fast-charging system could lead to a gain in German and possibly worldwide market leadership for Japan and China (Holzer, Kirchbeck 2018).

References


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