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On the Collaborative Use of EV Charging Infrastructures in the Context of Commercial Real Estate

Joela Gauss[1], Sascha Gohlke[2], Zoltán Nochta[3]
[1]*Karlsruhe University of Applied Sciences, Germany, Joela.Gauss@gmx.de*
[2]*Karlsruhe University of Applied Sciences, Germany, sascha.gohlke@h-ka.de*
[3]*SAP SE, Germany, zoltan.nochta@sap.com*

Executive Summary

Resource sharing in general is a means of solving the problem of infrequent and, thus, inefficient utilization of expensive or scarce resources. In this paper, we present an approach to run shared EV-charging infrastructures in the context of commercial real-estate facilities. Collaborating EV-charger owners thereby create a pool of chargers for shared use. With the help of pooled chargers, the overall utilization of the entire charging infrastructure improves. To operate the system, the corresponding management software must fulfil specific requirements and fit the processes of involved entities. The prototype implementation demonstrates the technical feasibility of our concept, and it was also used to evaluate its attractiveness to potential end-users.

Keywords: business model, charging, ICT, infrastructure, pooling, sharing

1 Introduction

Thanks to huge investments made by the automotive industry as well as the political and financial support given by government incentives worldwide, the number of electric vehicles (EV) will continue to rise in the coming years. Therefore, the rapid creation of sufficient EV charging capacity for diverse mobility scenarios is required. For instance, in Germany, by the end of 2021 there were ca. 52,000 publicly accessible charging points (CP) registered [1] serving estimated one million EVs (PHEV and BEV) in the country [2]. The German government's goal is to reach up to 15 million EVs by 2030 [3]. Currently, the installation and operation of *public* EV charging stations - especially in urban areas - appears to be economically unattractive, with the result that the required upscaling effects have so far failed to materialize. It is similarly problematic to scale the number of *private* charging points (”wall boxes”), which are mostly installed in single-family homes in the suburbs: If large numbers of EVs were to be charged at the homes on the same street simultaneously, e.g., during the after-work hours, the local power supply could reach its limits. As a countermeasure, local grid operators can increase grid connection capacity by installing additional cabling, transformers, or by implementing means of remote control, to actively manage EV charging. Both options are highly cost intensive as well as having low profit margins. Due to these limitations, in the near future, *semi-public* parking areas and charging stations, i.e., located at office buildings, factories, industrial areas, shopping centers, hotels, etc., might play an increasingly significant role in ”fuelling” the growing EV population. Such charging facilities primarily power EVs that are used for business purposes of a company, including service cars, delivery vans, and shuttles. At the same time, the charging stations can also cover the electricity demand of privately used vehicles to a huge extent, e.g., EVs of employees, customers, visitors, or even neighbours if they are authorized to enter the respective parking area. Thus, companies' semi-public charging infrastructures can help relieve the entire (public) power system [4] and reduce investments that would be required otherwise.

Commercial real-estate facilities and corresponding in- or outdoor parking areas are often used by several tenants simultaneously. For example, the first floor of an office building might house a medical practice and a restaurant, while the upper floors contain offices rented by different corporations. Usually, each tenant has dedicated, reserved car parking lots for its employees, customers, business partners, and visitors. As EVs become increasingly attractive, tenants may want to establish exclusively used EV chargers on their own parking spots. In real-world scenarios, however, the exclusive assignment of EV-charging equipment to single tenants can be challenging due to both economic (high TCO per charging station, low utilization outside of business hours) and technical (insufficient electrical infrastructure in the building, power limitations) reasons [5, 6, 7, 8, 9]. The collaborative use of charging stations, that are shared among multiple independent tenants of a building, might help overcome these problems.
In our approach, collaborating CP owners make their own installed equipment basically available and accessible to each other.
The resulting *pool of charging points* helps cover peak demand time intervals of all participating contributors, especially when intervals do not overlap significantly, and, it also helps increase the overall utilization of the entire charging infrastructure.

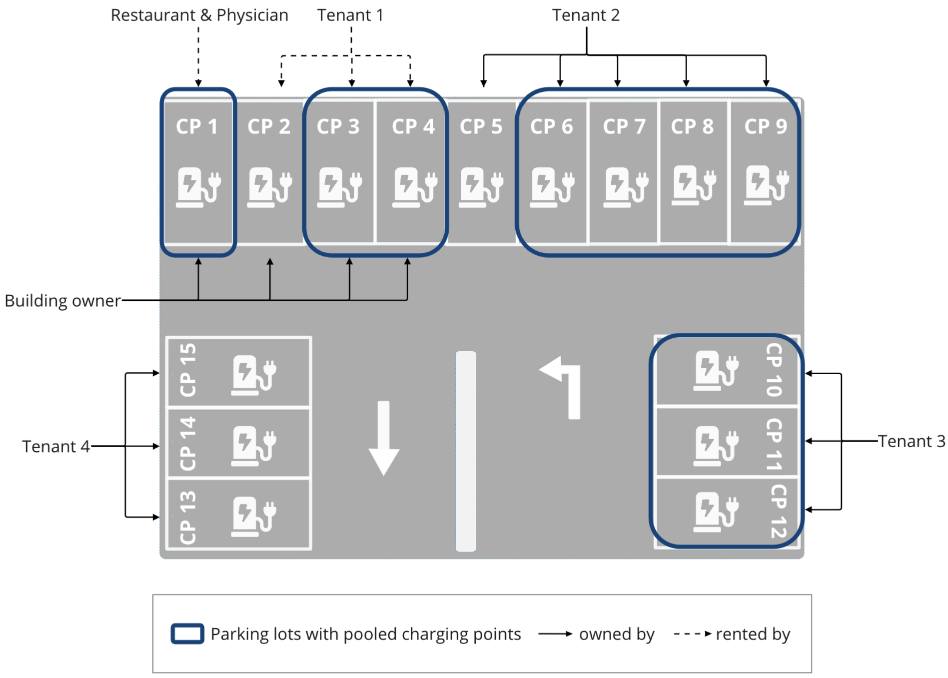

Figure 1: Example CP pooling scenario in an office building's parking area

For a better understanding, Fig. 1 shows an example scenario for the proposed pooling of CPs in the context of a building with an integrated parking space in the basement. Due to technical limitations, the building can host a maximum of 15 charging points: With e-mobility in mind, the building owner has initially foreseen 15 cable trays for future EV charger installations and installed four charging points before opening the building. Since then, CP 1 has been jointly used by a physician (on weekdays during the daytime) and by a restaurant (in the evening hours and on weekends), while CPs 2, 3 and 4 are rented by a company termed as "Tenant 1". Over time, Tenants 2, 3, and 4 had been equipping their parking slots with own EV chargers as well, because the building owner himself did not want to invest in additional EV-charging equipment. Meanwhile, the available charging points of single tenants are not sufficient anymore to cover their respective demand. They are faced with availability problems especially at peak times specific to their businesses. Employees, customers, guests, and visitors often cannot find an available charging point at the given company's dedicated parking lots, while at the same time chargers of other tenants are unused. To improve the frustrating situation, some tenants joined forces and created a shared CP pool. The pool consists of 10 (out of 15 installed) charging points, because Tenant 1 and Tenant 2 only partially share their CPs, and Tenant 4 does not participate in the pooling initiative at all.
The CP pool and related processes are managed with the help of a software system that enables independent participants to individually configure their specific settings and preferences.
This paper is structured as follows: In Section 2 we discuss the advantages of the CP pooling approach, describe the most important requirements for a software system to manage pooled CPs of multiple owners, and introduce main processes as well as our current prototype implementation. Section 3 covers the evaluation results, based on a case study and interviews with small and midsize companies in Germany. In Section 4 we revisit publications that deal with related aspects and problems of EV charging. Finally, Section 5 outlines directions of future work.

2 Concept and System to Manage Pooled Charging Points

The proposed pooling is an approach to bundle charging points that are owned and operated by multiple independent entities (typically businesses). Generally, a pool of charging points is not limited to a specific geographic location or context, such as the parking area of a single office building. Rather, a pool may include charging points that are installed at multiple locations of the pooling participants, such as larger companies that usually have offices in different cities or even countries. Establishing a pool increases the basic availability of charging points to individual EV-drivers, e.g., employees, guests and customers of pooling participants, as they gain access to all pooled charging points at their respective location.
From a driver's perspective the creation of a pool of CPs leads to a higher likelihood to find an available charging point at the given location basically at any point of time.
In addition to the benefits for EV drivers, the pooling of charging points can also increase the utilization of the overall charging infrastructure. If a particular charging point is exclusively used by only one business, it could remain completely unused outside of that company's regular business hours, i.e., up to 120 hours per week. There is also no guarantee that such a bound charging point will be used continuously during the owner's business hours, for example, when the EV-driving employees are on vacation.
The increased utilization of pooled charging points compared to exclusively used equipment can be formally proven as follows.
Let $M(|M| \in \mathbb{N})$ the set of installed charging points within a charging infrastructure and $I(|I| \in \mathbb{N})$ the set of participating CP owners. M_i denotes the set of charging points of a given owner, whereas $M = \cup_{i \in I} M_i$ $(M_i \cap M_j = \emptyset, i \neq j)$ holds for the entire infrastructure at the facility.
Let N_i the set of EV drivers who are assigned to the charging points of a given owner. It is assumed that $N = \cup_{i \in I} N_i$ $(N_i \cap N_j = \emptyset, i \neq j)$ holds, because normally an EV driver is an employee (business partner, customer, visitor) of only one company at the same time.
$N_i(t) \subseteq N_i$ is the set of EV drivers that are assigned to a given CP owner and require a charging point at time $t \in \mathbb{R}$. Thus, $N(t) = \cup_{i \in I} N_i(t)$ is the set of all EV drivers that look for an available charging point at t. $M_i(t) \subseteq M_i$ denotes the set of charge points of a given owner that are used at time t and $M(t) = \cup_{i \in I} M_i(t)$ is the set of all used CPs at t.
The function $l(t) : \mathbb{R} \rightarrow \mathbb{N}$, $l(t) = |M(t)|$ shows the level of utilization, i.e., the total number of charging points that are used at time $t \in \mathbb{R}$.

Thus, $L = \int\limits_{-\infty}^{\infty} l(t)\,\mathrm{d}t$ stands for the total utilization of the charging infrastructure over time.

$\widetilde{L}$ stands for the utilization of the charging infrastructure in which all CPs are pooled, while $\underset{\sim}{L}$ represents the same CPs' utilization in case each of them is used exclusively by just one CP owner, i.e., without being added to a pool. Accordingly, $\widetilde{M}(t)$ is the number of actually used CPs over time, which are part of the pool, while $\underset{\sim}{M}(t)$ stands for the "non-pooled" case.

Claim. $\widetilde{L} \geq \underset{\sim}{L}$

Proof.

$$\widetilde{L} = \int\limits_{-\infty}^{\infty} \widetilde{l}(t)\,\mathrm{d}t = \int\limits_{-\infty}^{\infty} |\widetilde{M}(t)|\,\mathrm{d}t = \int\limits_{-\infty}^{\infty} min\{|M|, |N(t)|\}\,\mathrm{d}t = \int\limits_{-\infty}^{\infty} min\{\sum_{i \in I} |M_i|, \sum_{i \in I} |N_i(t)|\}\,\mathrm{d}t$$

$$\geq \int\limits_{-\infty}^{\infty} \sum_{i \in I} min\{|M_i|, |N_i(t)|\}\,\mathrm{d}t = \int\limits_{-\infty}^{\infty} \sum_{i \in I} |\underset{\sim}{M}_i(t)|\,\mathrm{d}t = \int\limits_{-\infty}^{\infty} |\underset{\sim}{M}(t)|\,\mathrm{d}t = \int\limits_{-\infty}^{\infty} \underset{\sim}{l}(t)\,\mathrm{d}t = \underset{\sim}{L}$$

□

Note that in the above proof the following equations were applied:
$|\widetilde{M}(t)| = min\{|M|, |N(t)|\}$, i.e, when using a CP pool, the number of usable charging points at a given time is basically limited by the total number of pooled charging points of all CP owners.
$|M| = \sum_{i \in I} |M_i|$, because $M = \cup_{i \in I} M_i$ (with disjoint charging points) holds.
$|N(t)| = \sum_{i \in I} |N_i(t)|$, because $N(t) = \cup_{i \in I} N_i(t)$ (with disjoint driver population) holds.
$\sum_{i \in I} min\{a_i, b_i\} \leq min\{\sum_{i \in I} a_i, \sum_{i \in I} b_i\}$, is a consequence of $\sum_{i \in I} min\{a_i, b_i\} \leq \sum_{i \in I} a_i$
$|\underset{\sim}{M}_i(t)| = min\{|M_i|, |N_i(t)|\}$, i.e., if charging points are not shared, an EV driver can only occupy an available CP of exactly one CP owner that she is assigned to.
$|\underset{\sim}{M}(t)| = \sum_{i \in I} |\underset{\sim}{M}_i(t)|$, because $M(t) = \cup_{i \in I} M_i(t)$ (with disjoint charging points) holds.

2.1 Main Processes in Overview

Despite the above discussed potential for higher utilization, it can be assumed that the tenants/users of a real estate facility would first try to use their own, self-installed charging points exclusively. The charging points within an existing infrastructure would only be shared when a noticeable shortage on the part of the EV drivers and thus the advantages of a shared use of charging points become perceptible.
In context of an office building that hosts multiple businesses, such as in the scenario in Fig. 1, the building owner may provide the tenants with access to an integrated building management system. With the help of the system, a tenant can, for example, control access to its offices, book meeting rooms or additional desks in a co-working space when required, report problems, and, it can also self-manage its own locally installed charging points. Establishing such an overarching system is also meaningful to centrally monitor and control energy flows (mainly consumption, but also production and storage) in the building, including the entire EV-charging infrastructure installed by the different tenants.
The introduction of pooling in an already existing EV-charging environment requires specific tasks that have to be carried out by each contributor as shown in Fig. 2.

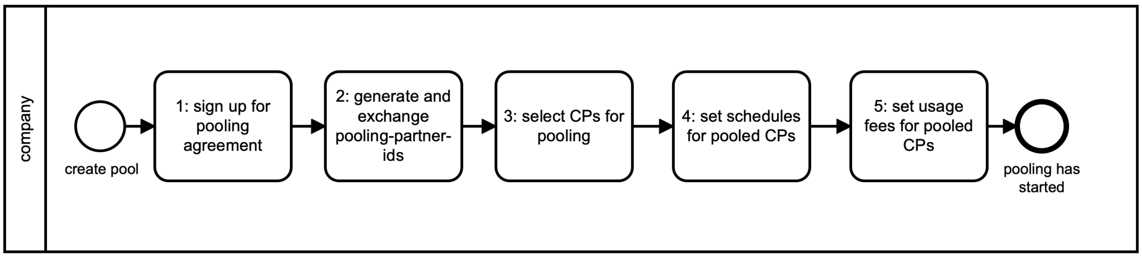

Figure 2: Main steps to initiate a pool of charging points

In the context of an office building, as a first step (1), participating tenants -as the owners of charging points- can jointly negotiate and sign up for an agreement, e.g., a formal contract. The agreement can state how many or which of the respective charging points shall be added to the pool by which owner, and under which conditions they can be co-used. Example parameters that can be agreed on are time-related aspects (validity period of the agreement, time intervals in which charging points are excluded from pooling), fees for using a pooled CP and the corresponding parking lot by another participant including payment modalities, as well as specific countermeasures in case of technical problems. In addition, the agreement can also regulate operational aspects of the pool, such as the removal of charging points from the pool must be confirmed by each participant or temporary access restrictions due to repair or maintenance work must be announced in advance by the given CP owner.
In accordance with the agreement, the pooling-specific tasks can be implemented and carried out in a centralized or decentralized way. In a centralized setting, a dedicated entity, for example, the owner of the building, a contracted facility manager or an elected tenant can take over responsibility for managing the pool. In this role, the manager fulfils all partner-specific technical (change) requests concerning the pool, including adding or removing CP owners from the group.
In a rather decentralized approach, pooling-partners act more autonomously, retain administrative control and self-manage their own charging points. Consequently, they implement and run the pool of CPs in collaboration. Centralized pooling can reduce management effort for individual CP owners by bundling all related tasks at one entity. Participating businesses must, of course, cover related costs and make sure that the managing party gets access to all necessary information and related systems. In multi-site environments (of larger companies), it is assumable that the CP pool at each site would be under control of a different (local) entity specific for that site, which can increase the overall complexity.
The main advantages of a decentralized management are increased flexibility and lower operating costs for the pooling participants. It enables each partner to control and monitor its own charging points without further interaction or negotiations with some central party. A continued self-management of processes and related data might also ease the handling of multi-site scenarios. This approach also fits better with the assumption that CP pooling is more of an evolutionary step for companies, namely after it has become apparent that their own installed capacities are no longer sufficient to meet their respective demand. To initially create the pool in the above mentioned decentralized way, each participant can generate a unique secret and share it with the pooling partners over a proper trusted channel (see step 2 in Fig. 2). There are many possible ways to implement this step. As an example, a CP owner can generate a random number and store it in form of a QR code, which can be scanned by one or more respective pooling partners during face-to-face meetings via smart phone. The secret code received from a CP owner empowers the receiving pooling partners to co-use the pooled charging points (and only those) of that particular CP owner. For instance, the code can be used as an API key to get access to relevant data in the IT system in a controlled way. In the next step, each pooling partner selects and configures the (subset of its) charging points that shall be part of the CP pool (3), determines associated schedules and time restrictions (4), in case these were agreed on. For example, a particular charging point might not be co-used on weekdays between 8 AM and 7 PM.

Afterwards, the monetary aspects of sharing, i.e. usage fees for each pooled charging point, can be configured (5). The fee for the co-usage could contain a fix component to cover the costs of general operations (maintenance and repair), and a variable part to compensate actual expenses related to the particular charging process including cost of electricity, parking fee, taxes, etc.

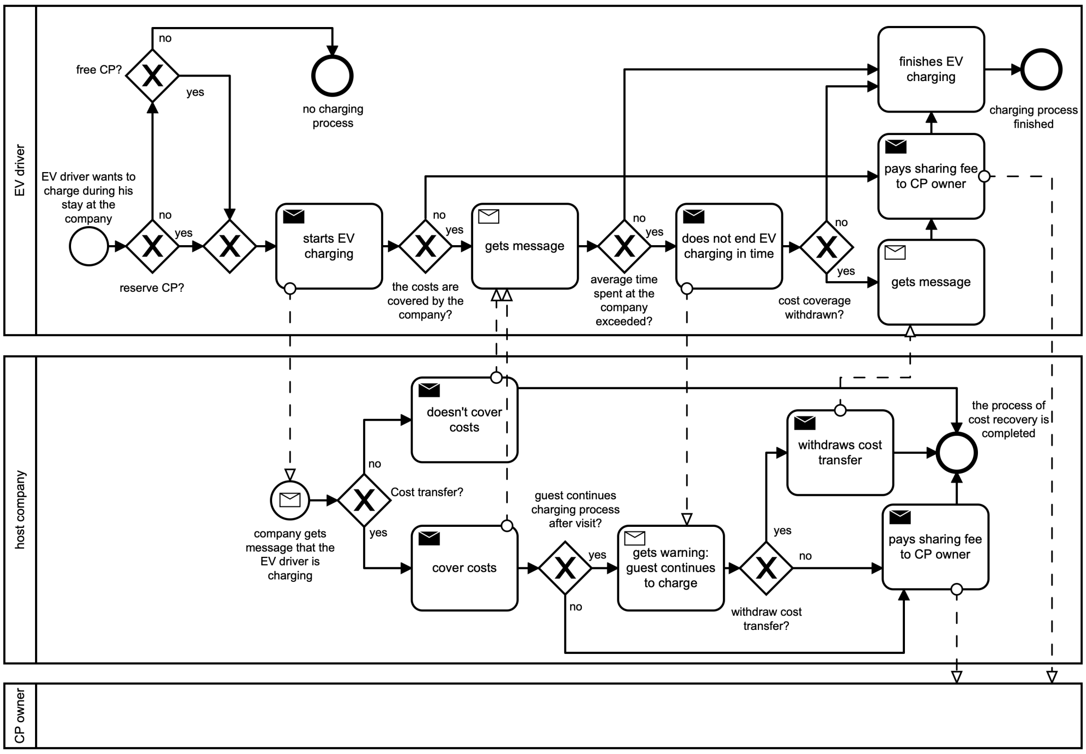

Figure 3: Example process: An external guest EV driver uses a pooled charging point

Following the Business Process Model and Notation (BPMN) standard, the diagram in Fig. 3 shows how an EV driver can use a pooled charging point within a semi-public infrastructure. An EV driver, say a restaurant guest, who has never visited the restaurant before, wants to use a charging point close to the restaurant entry. As the restaurant participates in the pooling initiative (refer to Fig. 1), the guest can reserve not only the restaurant's charging point on the website, but also any of the pooled CPs (incl. parking slot). The reservation can be implemented as part of the usual table reservation procedure, in which the guest's credit card number is also captured. Note, that the guest does not need to know whom the selected charging point actually belongs to. Upon arrival, the guest parks her EV and identifies herself by presenting her credit card at the reserved charging point. In accordance with the available capacity, the local system triggers power scheduling for the particular CP and the charging starts. As the guest actually uses another tenant's charging point, the restaurant gets a notification. After the dinner, the guest accepts the restaurant's friendly offer to take over the costs for using the parking slot and charging her car's battery, so that she only has to pay for the expensive dinner. As a consequence, the restaurant will have to pay the calculated pooling fee to the CP owner as it was stated in the sharing agreement and also configured in the system. Note, that in case the guest would have used the restaurant's own charging point, these costs could be significantly lower (mainly electricity). Thereafter, notifications can be sent to all three involved entities about the related expense claims. Normally, the EV driver would drive away, i.e., free up the parking slot and the charging point, within a few minutes. As a result of the cost transfer, there will be no additional fees charged on her credit card, the CP owner will pay the actual electricity costs for the charging (as part of his usual monthly or yearly bill), and the restaurant's owner would pay the calculated sharing fee to the CP owner as compensation. The latter transaction can take place immediately after the charging process ended or the underlying system may also collect such costs and conduct a periodic clearing between pooling participants. Should the host not agree to take over the costs for its guest's EV charging, the guest would have to pay the respective sharing fee to the CP owner, in the example case via a credit card payment transaction. The basic possibility for rejecting the transfer of costs can be helpful to prevent misuse of the charging infrastructure. If the guest has not finished EV charging or still blocks the parking lot after a certain period of time, the restaurant, as host, may receive a warning about the (meanwhile potentially much higher) sharing fee, so that it can refuse its generous offer. In this case, the EV driver can get a notification message and must pay the bill for the prolonged battery charging. In order to implement such measures against "unfriendly" drivers, additional proximity sensors at the charging points or a camera-based observation of the parking lots may be required.

The above described process and the respective BPMN model can be significantly simpler, in case the EV driver is a known (permanent) user and assigned to one of the CP owners, for example, to her employer. The EV driver can possess an ID card from the company, which can be used for authentication at the company's own and at every other pooled charging points as well. The routing of related costs for "charge at work" to the employer's account can occur without any further interactions and notifications in a fully automated manner.

2.2 System Requirements

In order to operate pooled charging points in semi-public EV charging infrastructures in the context of commercial real estate facilities, the corresponding software system must fulfil specific requirements, which we outline here (without claiming completeness):

- **Multi-tenancy:** Provide means of maintaining the data of multiple independent CP owners in one system allowing them to effectively monitor and control their part of the physical infrastructure at a given location (building, campus, industry area) in a safe and isolated way.
- **Autonomous administration:** Support the self-management of data about both shared and exclusively used charging points in the context of a given location. Enable CP owners to add/remove charging points to/from the pool, maintain potential time-based restrictions, pricing related information and other optional parameters concerning the shared usage of charging points.
- **Secure access control:** Manage the authentication and authorization of different end-users in case they try to use pooled or non-pooled charging points, or when they access the system via an app or web-based user interface. Each CP owner has basically under its control whether and whom he or she might provide access to the charging points, since the overall infrastructure is considered to be "semi-public". An administrator representing a CP owner in the system shall be able to maintain data that is needed to securely authenticate the internally known, registered end-users, such as related EV-drivers and maintenance staff. The system should allow the assignment of these users to the charging points of the given organization/tenant and manage related permanent credentials, such as personalized RFID badges. In addition, support the CP owner to grant external, previously unknown "guest" users (visitors, customers) with temporary access and respective credentials to use the charging points for a limited duration or limited number of charging processes. The CP owner can send some secret (e.g., one-time password) upfront or hand out physical tokens (e.g, RFID cards) to its guests once they arrive. If the charging point supports the technology, previously unknown users can also be identified by using well-established systems, such as credit cards (via the NFC interface). In case an EV driver wants to use a pooled CP that does not belong to his organization/tenant, the system must check the user's presented credential against the authentication data of all tenants that participate in the CP pooling before rejecting the request. Should the user possess a valid credential issued by one of the pooling partners (whether permanent or temporary), the access must be allowed.
- **Reservation:** Offer charging point reservation capability for known, i.e. frequent or permanent users and also for previously unknown (guest) users. EV drivers shall be able to select and reserve each available charging point within the pool in addition to the visited host's own CPs. Various ideas and options of implementing a reservation system can be found in [10, 11, 12]. In case of yet unknown users, reservation must be coupled with an initial registration procedure in conjunction with the above mentioned authentication mechanisms.
- **Cost and payment management:** Enable CP owners to maintain fix or variable fees for the co-usage of charging points. At the end of a charging process, ensure that all data items that are needed to calculate relevant expenses are captured correctly, such as consumed power (to calculate electricity costs), duration of charging (to calculate parking fees), etc. Ensure the correct routing of resulting pre-calculated expenses towards the right entities that are involved in the charging process (EV driver, host, actual CP owner) based on predefined rules and configuration. Implement interfaces to respective (external) rating, billing, invoicing, payment and clearing systems to further process actual payments and deliver related information in a secure way.
- **Exception handling:** Implement measures to detect and handle exceptions in case of technical problems (e.g. when a pooled CP is out of order). Implement proper workflows and notifications to deal with the intentional misuse of pooled chargers, such as "long term parking".
- **Power management:** Support the optimal utilization of available power capacities within the entire infrastructure [13, 14], for example, in conjunction with a local energy management system. The overall system must fulfil the charging demands of EVs, while considering local power limits, total capacity and current state of charge of EV batteries, intended departure times and other relevant parameters. The pooled usage of CPs at a given location should not negatively impact the (previously established) load management system. Once a charging process has started, the power supply for the given charging point has to be managed independently from its membership in the pool.

2.3 Prototype Implementation

To implement our CP-pooling concept and demonstrate its technical feasibility, the open-source system "Open E-Mobility" has been chosen as technical foundation [15]. "Open E-Mobility" supports the management of EV charging equipment at multiple sites of organizations that operate EV fleets. It has been already deployed in several productive and trial environments. The system can connect to and work with charging stations of multiple vendors and provide the operator with real-time status information about ongoing charging processes. Thanks to an integrated smart charging capability, the system can monitor and adapt the use of charging points to optimize energy consumption, while protecting the local grid against overloading.
The software system is designed to be deployed as a scalable cloud application. The high-level architecture is shown on Fig. 4. The internal business logic and processes are implemented by the backend server built in NodeJs. The data, that is created and managed in the backend, is persisted in form of document collections in MongoDB. The datasets of multiple CP owners, who are also termed as "tenants" of the system (as this term is commonly used in cloud applications), are maintained in isolated collections. With the help of the front-end server and respective views of the web-based graphical user interface (GUI), each tenant/CP owner can model its EV-charging infrastructure at multiple sites by assigning charging points accordingly. User access to the system and the underlying data of single tenants is controlled by means of roles (e.g., "Admin" or "Basic") that can be assigned to users. Furthermore, a "SuperAdmin" can conduct overarching tasks, including the creation and removal of tenants within the system. The system enables the management of charging points (both AC and DC) of multiple vendors in heterogeneous environments. The communication between connected charging stations and the backend server is based on the Open Charge Point Protocol (OCPP) using both HTTPS and secure WebSocket as transport options. Each CP owner can maintain information about its users helping to authenticate them at the charging points (e.g., via RFID badges issued by the CP owner) as well as in the web application (via password). In addition, a CP owner can monitor the status of ongoing charging sessions and collect comprehensive logging information about relevant events. End-users can also access the system via a mobile application, for example, to view available charging points at a site, to trigger charging, or to get notifications (in form of emails).

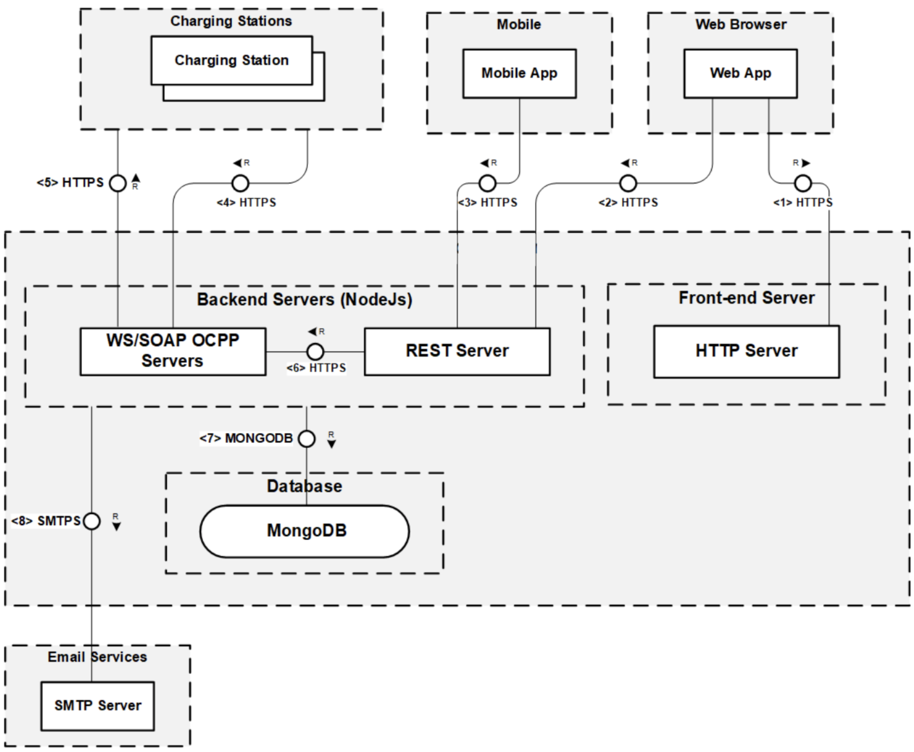

Figure 4: High-level system architecture of "Open E-Mobility" [16]

In the course of the prototype implementation, the publicly available source code of "Open E-Mobility" (see the current version on GitHub [16]) was extended, mainly by adding relevant functionalities to the server, creating new and altering existing database objects as well as by slightly modifying user interfaces. The resulting prototype has been so far only used to present the CP-pooling idea to potential end-users as part of a survey described in Section 3.

In order to maintain a pool of charging points, each CP owner manipulates its own local data within the boundaries of its own isolated tenant environment. With other words, the pool is not explicitly created as a system-wide entity that some super-user could maintain. Instead, all information about the pool is stored in the participating tenant's datasets. For that purpose, the previously existing user role ”Admin” has been extended by additional activities related to CP pooling that a given CP owner has to perform. Accordingly, a user assigned to this role is allowed to generate a pooling ID (specific per cloud tenant) which is encoded in the form of a QR code. The user can also add pooling partners by scanning QR codes that he received from another CP owners/tenants. In addition, the user can mark charging points as ”pooled” and also remove them from the pool. The user is also capable to manually approve (or deny) a requested transfer of costs, if a guest used a pooled charging point.
The user role ”Basic” has not been enhanced by new software capability related to CP pooling. However, a user in this role (typically an EV driver) will see in her app all charging points of the default-assigned CP owner (employer, business partner, host). In addition, she can also see all other pooled CPs as basically usable charging points. This is achieved by checking the database to see which tenants have actually joined the pool and which of their charging points are flagged as shared. To achieve these steps efficiently, a new document collection is created in each tenant's database in which data about the pooling partners of the respective cloud tenant is stored. With the help of this information, the server can quickly determine which tenants' datasets it should inspect. In case the tenant has no pooling partners the collection would be empty. In the collection, that stores data about the charging stations of the given tenant, the Boolean property ”pooled” is added to the documents, which serves a flag.
In order to start the charging process at a particular charging point, the authentication request sent by the CP is first checked against the user data of the respective CP owner. In case the user/credential is unknown or not valid, the authentication would normally fail and the charging point would reject to start charging the EV. Following our pooling concept, if the user/credential is unknown to the directly targeted CP owner, the server would check against (potentially all) other tenants' respective data collections whether the presented credential is known and valid and notify the requesting charging point about the result finally. During this procedure the server uses the above mentioned mechanism to select and inspect candidate tenant's data. In the current prototype version, all users of the cloud tenant get access to all pooled charging stations of each pooling partner equally. The enforcement of potential restrictions, such as exclusion time intervals, are not yet supported. For that purpose, further properties could be added to the pooling partner collection scheme.
Concerning the graphical user interface, a new view for the administration of pooling partners was added and assigned to the user role ”Admin”. The view contains options for adding and removing pooling partners and the generation of a QR code to be exchanged with potential pooling partners.
In addition, the already existing detail view of charging points is enhanced by a check-box to add (or remove) the given charging point to (or from) the pool, as shown in Fig. 5).

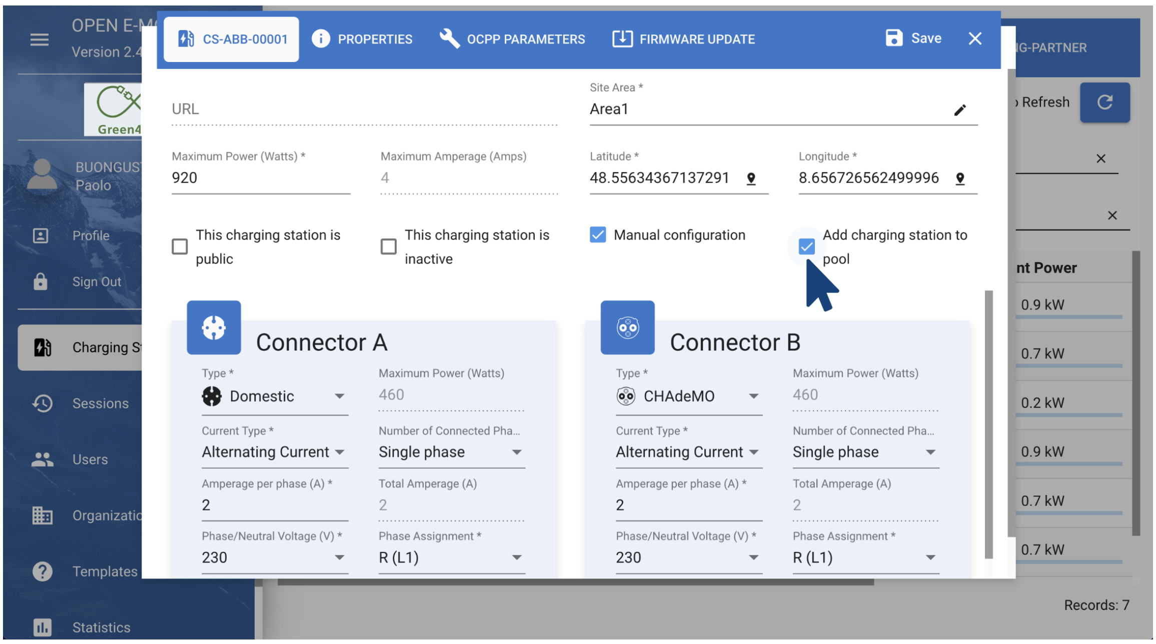

Figure 5: Example screenshot for adding charging points to an existing pool

To explicitly allow or deny the cost coverage for unregistered guests and to carry out related monetary transactions after the charging ended, a switch button shown in Fig. 6 was added to the detail view about ongoing charging sessions. When switched on, the backend server replaces the CP owner's account by the paying tenant's account to which the cost transfer should to be invoiced.

Note that the current implementation is not yet capable to prepare and launch actual monetary transactions with payment systems that are otherwise supported by ”Open E-Mobility”.

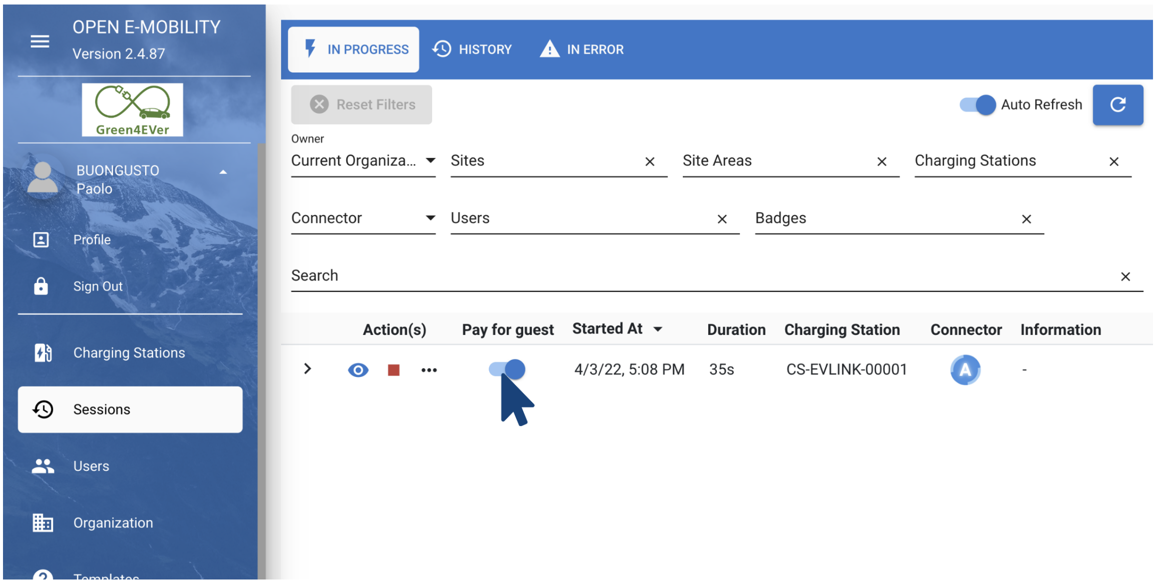

Figure 6: Example screenshot to initiate the transfer of costs of charging in the system

3 Evaluation

To verify the concept of pooling charging points with other companies and to evaluate the idea of related cost coverage, two different surveys were conducted in a small town in Germany. Firstly, we conducted qualitative interviews with five business owners. The problem was thereby explained based on a simplified version of the scenario shown in Fig. 1 with only two tenants (a restaurant and a physician) that create a pool of CPs by using the prototype system. Secondly, we used a questionnaire with 46 responding companies for evaluation of monetary aspects of cost coverage.
The feedback given by interview partners regarding the pooling concept was mainly positive. While some of the respondents also see the possibility of using such a solution by themselves, all business owners consider the concept of pooling useful under certain conditions. For instance, the owner of a restaurant stated the importance of the company's location: His restaurant is located outside of the town and there are no other companies within walking distance to apply a reasonable pooling. This feedback underpins the assumption that pooling is more beneficial in urban areas where potential pooling partners are in close proximity to each other and the number of charging points is rather limited. However, we consider pooling also potentially relevant in smaller towns, villages and sparsely populated areas, because people use their vehicles more often and in general drive much longer distances. Although there are fewer multi-family homes in those areas, making charging at home more likely, the greater number of vehicles per household might lead to shortages of available chargers.
Because there are currently only few charging points in the town, another business owner would install own charging points as prestige objects for its business and make those exclusively available for its own customers, employees and business partners. We see this as a common strategy, especially at the beginning of the considerations on e-mobility. However, we assume that this argument will become obsolete as the number of EVs increases and more and more companies invest in charging infrastructure. In addition, we assume that companies will heavily demand for pooled charging points, e.g. at peak hours, if they cannot expand their own infrastructure due to limiting local factors (transformer, cable, parking, etc.). This is especially feasible for businesses with different opening hours, as it was stated by a business owner from the retail business, who already shares parking spots (currently without charging points) with a restaurant nearby. While it is obvious, we consider pooling also useful for businesses having similar opening hours but usually less overlapping peak demand time intervals, in order to cover increased demand caused by irregular or exceptional events, such as a wedding party. As another business owner mentioned, some companies, such as bakeries or post offices, may not have a need for pooling at all, due to very short customer visit times. Nevertheless, the pooling of CPs to charge own delivery trucks or the privately used EVs of employees or business partners (instead of customers) can still be beneficial for those companies as well.

One business owner believes that adding public charging points to the car park in the city center would be more practical than adding them to the short-term parking spots at the companies themselves. Looking at Germany, we experience a lack of charging points in public areas by now. This could change in the future and be different in other countries, but by now, semi-public charging infrastructure can help Germany overcome this shortcoming from the faltering expansion of public charging infrastructure. Pooling is particularly interesting for the business owners, when they know each other well and have common customers. However, they see open questions regarding the initial communication with the customers: How could spontaneous customers know, which charging point is already reserved? How could a first-time customer know, whether or not the cost of charging can be covered by the respective business? This problem of communication is difficult to address in a practical implementation, as some users could refuse the usage of a provided mobile app, for example. Via an app, it is possible to view current reservations and to see which charging point is already occupied. If no app can be used, the EV-driver can only receive this information, e.g., via signs or user instructions placed at the charging points. Most business owners consider the need of such a dedicated app for their customers with their words ”annoying”. Only one respondent assumes that EV-drivers would be willing to install such an app for this purpose. As a possibility to achieve this without providing an additional app for each company, one business owner suggests to cooperate with an e-roaming provider that already enables its registered EV drivers to search for and reserve available charging points.

For the prototype implementation of the administration interface, it is important to the business owners that its design is user-friendly and, if possible, can be used on mobile devices by the employees. For example, one business owner misses the option of multiple selection so that he does not have to select every single charging point when the CP pool is first created.

To ensure the validity of the description and interpretation of the interviews, as well as to reduce bias, a presentation was used. Nevertheless, deviating wording of the questions may have influenced the answers given by the respondents. In the system demonstration that was used during the interviews, the example companies were chosen in such a way that their different opening hours would particularly illustrate the advantages of pooling. To support the validity of the theory, it was asked whether pooling was also conceivable for other companies. In addition, two participants commented that it is not easy for them to imagine such a scenario, because they do not own e-cars and therefore find it difficult to empathize with the challenges of charging. Moreover, since the interviewer and respondents already knew each other, it is possible that responses to the concept were influenced by the relationship.

Besides the interviews, we also used a questionnaire with 46 responding companies to identify if they consider cost coverage of employees, customers or business partners an interesting application. Most of the responses came from retailers (30 %), along with service providers, restaurants and manufacturers. While one-third of the companies refuse to cover costs, two-third consider to use cost coverage under the right circumstances. At least one of them was interested in covering costs for customers and business partners without further restrictions. This corresponds to the answers to the question of whom the companies want to cover costs, in which almost all participants stated employees and customers. Furthermore, a few also considers suppliers and business partners interesting for cost coverage. Cost coverage is also an interesting topic for the business owners who participated in the above described interviews. The owner of the restaurant considers cost coverage of interest for his business and is already looking for a solution to install charging points that use electricity from nearby waterworks. In addition, another business owner considers cost transfer to be a ”real bonus” for his customers.

The question regarding which methods of guest user authentication and which means of cost coverage are preferred has revealed no distinct result. The answers were equally spread between the use of credit cards, RFID tags, QR-Codes and vouchers. This result indicates that different companies have different opinions and diverse requirements regarding a potential cost transfer process. A technical solution should therefore be built as much flexible as possible, in order to meet individual needs.

As mentioned above, both questionnaire and the surveys were conducted with only a few participants in a relatively small town, where currently only few EVs and charging stations are in operation. Therefore, the answers and opinions of the participants can be biased in regard to e-mobility and the results cannot be generalized.

4 Related Work

In conjunction with the shared use of (material) goods and (immaterial) services, the terms *sharing economy* and *collaborative consumption* are widely used in academic literature. According to Luri Minami et al., “Sharing economy consists of the practice of use and share of products and services with two or more individuals, with or without the transfer of ownership, with no material compensation (neither non-monetary compensation) and mediated through social mechanisms” [17]. Our CP pooling approach partly fits this definition, because pooled charging points are made accessible to other pooling partners without transferring ownership. There is a difference with regard to the pooling agreement, which is negotiated between the participants to regulate the co-usage under fair conditions upfront, including usage fees as means of compensation. The introduction of usage fees is seen as a property of collaborative consumption, i.e., “transactions where people coordinate the exchange of goods and services for a fee or other compensation (monetary or non-monetary), where a triadic is existing among a platform provider, peer service provider and a customer, there is no ownership transfer and it is mediated through market mechanisms” [17]. However, the jointly negotiated pooling agreement eliminates the need for a platform provider acting as mediator. Due to the predetermined fees for using pooled CPs, a mediation through market mechanisms is excluded as well. The term ”sharing” is also frequently used in context of ad-hoc and short-term rental services, such as car sharing. In [18] Belk unmasks and criticizes those rather commercial activities as ”pseudo-sharing”. In this spirit, we consider our pooling approach as ”real” sharing, because all involved participants can both provision and consume shared resources under previously accepted (and therefore fair) conditions. The shared usage of expensive and less frequently required machinery is common practice in the agricultural domain [19]. A simple manifestation of it is ”mutual aid” between neighboring farmers to help out each other with equipment. So called ”machinery rings” are established to coordinate the demand-driven cross usage of machinery, for example to temporarily replace a broken machine. Lastly, members of ”machinery partnerships” jointly purchase equipment and define operational policies as well.

Our approach can be seen as a mixture of these variants, as neighbouring CP owners help out each other especially to cover EV-charging demand at peak visiting hours, while they buy and manage own equipment without involving a coordinating party. Ideas to increase the utilization of charging points by making them available to others can be found in existing products and also in academic literature. As an example, the Webasto ChargeConnect App [20] allows the owner of a private charging point to grant a time-limited access to guest users. The guest must register in the provided App and be added by the owner to start the charging process. The use of a third-party platform to coordinate the sharing of private charging points is also discussed in [21, 22]. With the help of the demonstrator ”CrowdStrom”, CP owners could provide access to other EV drivers in return for a financial compensation. The prices for charging point usage could be set on an hourly basis, and authorized EV drivers could reserve the advertised charging points prior to their arrival. This approach can also be characterized as short-time rental service rather than ”real” sharing among equal peers. A broad application of pooling and the resulting increased utilization of charging points could enable basically more drivers to charge their EVs at work, which can in turn help lower the peak energy demand when people return home, as advised by Alatise et al. [4].

As another measure, the shifting of charging demand at home is suggested by Gaikwad, who simulated and analyzed daily charging profiles and predicted substantial distribution transformer overloading when most cars are charged at the same time [23]. Enabling EV drivers to charge at work and thereby reduce the power demand at the after-work hours differs from the approach of Ghosh et al.: In [7] peak electricity demand is reduced by means of dynamic pricing, which makes charging at peak times increasingly unattractive for newly arriving EV drivers. While such dynamic pricing schemes and associated services can help avoid critical electricity demand spikes, they are not helpful in ensuring the fundamental availability of a sufficient number of charging points at a given location. The same applies for smart charging concepts, which mainly focus on the proper distribution of a limited available power capacity between multiple EV chargers. Related solutions often combine different EV charging strategies with demand-response management to optimize also the energy cost of company fleets [24, 25, 26, 27, 28].

Another problem that negatively impacts the availability of charging points is the malicious blocking of parking spaces, for example, by gasoline cars or by EVs that are not charging. To provide an incentive to drive away after the charging is complete, the authors of [29] calculate a time-based fee for using a charging station at the end of charging. However, this solution cannot detect unplugged vehicles and therefore be used to punish drivers that block free parking spaces without the intention to charge at all. To automatically detect this type of misuse, the authors of [30] suggest the use of sensors that are mounted at parking lots. Based on this sensor data, a charging station on a platform can be classified as occupied if the corresponding parking space itself is blocked. This is important for pooling as a problematic customer no longer only blocks the company’s own charging station, but other companies are also affected as a result of pooling. At the same time, the exclusion of a customer by one CP owner results in the customer no longer being able to charge at pooled charging points of the other participants neither. For the automatic detection of blocked parking spots that are occupied by unplugged EVs (e.g. with the help of sensors), each pooling partner must invest in proper equipment.

5 Outlook and Future Work

The proposed approach to pool charging points can help improve the overall utilization of charging infrastructures in context of commercial real-estate facilities that are used by multiple tenants. A positive effect can occur in particular if the peaks of utilization of the participating entities overlap less.
Our survey of companies showed that the basic idea is of interest to them. Nevertheless, further efforts must be made to test the economic viability and profitability of CP pooling. It can be yet assumed that in a corporate context, the purely economic interest in sharing charging points with other companies would be a less important motivating factor. However, the improvement of customer satisfaction (through the high availability of charging points) can lead to a measurable positive financial impact in specific business areas, such as gastronomy, retail and hotels.
National and international regulations, laws and taxation rules can heavily influence, whether real-estate investment and management corporations -as building and facility owners- would invest into e-mobility equipment in future. Our current findings show that, at least in Germany, they mostly install no or only a few charging points in new buildings and related parking areas, but allow users/tenants to build and operate own equipment if needed. As of today, it is therefore less likely, that a building owner would provide its tenants with access to a specific (separate) software system to manage their own charging points. Without such a commonly used system, however, the creation and operation of a shared pool of CPs can be a challenging task. To gain a broader overview, we will study relevant regulations outside of Germany as well.
The first prototype implementation of the concept is based on the open source system ”Open E-Mobility”. The required modifications and extensions, especially regarding elements of the existing user interface, led to affordable development efforts. The prototype was so far only used to demonstrate the concept and gather early feedback of potential users for evaluation purposes. In parallel, we have been also running first simulations of fictive charging processes on the system, which will be analyzed in detail in the near future. As of today, the approach to share charging points between entities has not yet been tested in neither a productive nor in a sand-boxed trial environment.
For the purpose of practical evaluation, the current software prototype must be significantly improved and tested before the actual deployment can occur. We are looking forward to conducting field tests under realistic conditions, which will help validate not only the system but also the underlying idea and assumptions.

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Presenter Biography

Prof. Dr.-Ing. Zoltán Nochta studied computer science at the TU Budapest/Hungary and received his PhD from KIT/Germany in 2004. He is Chief Development Expert at SAP SE and has been a part-time professor at Karlsruhe University of Applied Sciences since 2014. At SAP he has initiated and managed the execution of several R&D projects on e-mobility, incl. Future Fleet, MeregioMobil, OpenEcosphere, iZeus, Green eMotion. Currently, he coordinates the project Green4EVer, which aims the integration of e-mobility into future real estate and location management processes.