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Crowd Charging - An Approach To Shared Services In Charging Electric Vehicles

Ansgar Meroth, Andreas Schneider

Hochschule Heilbronn,
Max-Planck-Str. 39, 74081 Heilbronn,
meroth@hs-heilbronn.de
andreas.schneider@hs-heilbronn.de

Abstract

This paper describes an proposed approach of offering public shared charging services for electric vehicles, based on the idea that persons or institutions that run charging equipment may offer its capacity to the public while car owners easily find the nearest station and make a reservation. Implemented as a social network, the site requires a minimum of central administration. The system is realized on a Meteor platform including a Node.js server, a templating engine, and the MongoDB NoSQL database. A Microservice architecture allows relocating functionality in a cloud environment instead of a dedicated server and opens the potential of nearly unlimited scalability. Furthermore, a model charging station is described that allows the integration into the proposed network. The focus of this paper is to demonstrate the architecture and implementation of a shared service in this framework.

Keywords: Smart charging, V2G, business models, sustainability

1 Introduction

A possibly increasing number of electric vehicles (EV)[1] demands for a narrow grid of charging stations, also called electric vehicle supply equipment (EVSE). Charging needs can be categorized by charging speed (i.e. charging power), total energy, and urgency [2]. For instance, during a working day, a station might be required that offers a rather low charging power and speed, but is available the entire day. During shopping or attending an event for a few hours, it can be sufficient to compensate the energy that was necessary to reach the destination. On a long journey, the vehicle has to be charged as soon as possible to maximum capacity as on a classical fuel stop. Price calculations for providing a charging service can be done on the base of availability and capability of the necessary EVSE within the reach of the vehicle. In any case, a dense network of stations is a main prerequisite for a successful proliferation of electric mobility.

The number of charging stations could be increased if private households and small enterprises were enabled to offer charging capacity as a service, e.g. from their photovoltaic equipment, other sources of renewable energy or taken from the regular grid. The economic objective of this stakeholder group may differ from professional providers in a sense that their service is only occasional and rather not optimized for steady revenues at a limited level of investment. Hence, we see the need of providing a sharing infrastructure for this community. The idea of a shared service includes among others a benefit to the society, creating values and providing an open access for both, users and providers of that service (see e.g. [3]). Hence, our idea supports a simple technical way of connecting private EVSE providers and EV users in real time and on demand. In a non-profit environment, the service infrastructure must be easy to maintain (ideally by the user community) and efficient in terms of computing resources (ideally using computers of the user community). Our approach fulfills both.

1.1. Realization of shared services

As there are many shared services already on the market, e.g. UBER for transportation, eBay for selling goods, or Airbnb for accommodation services, we propose a service model for those public charging stations. Technically, we describe the usage of a framework called Meteor.js in order to realize the necessary communication platform. In contrary to the state of the art as described in the next section, we propose a fully interactive shared service, in which drivers, cars and charging providers share their demands and services dynamically, e.g. the cost per kWh can be adopted in real time based on a local algorithm of the charging station that takes into account the actual supply and demand situation. Furthermore, users can make reservations and payments online, so that the availability of the stations is always up-to-date in real time. As in a social network, the central administration of the website may only be necessary in case of misuse or false content reported by other users.

2 Related work

The fast location based access to charging stations is already realized in several contexts. The fast location based access to charging stations is already realized in several contexts. While companies like TESLA provide their own network of customer restricted charging supplies, publicly accessible charging stations can be found by a lot of services. One example is drehstromnetz.de [4]. The website basically offers a list of private charging stations and instructions how to convert a normal power socket into a charging power socket. It is a non-commercial platform and is based on donations between the user and the charging station provider. This platform doesn’t provide a reservation service, payment handling, or searching mechanisms based on the current location of the user.

Another concept is demonstrated by The New Motion [5]. The website and corresponding app show a map of 25000 charging stations. In contrary to our concept, the provider of a charging station has to apply for an entry, which is centrally administrated, while our concept is rather organized as a social network with an interactive feature rich map. Chargemap.com [6] also offers a web service with over 30000 charging stations within Europe. However, there is no interaction except a phone number between the user and the provider of the charging station as it is proposed in our solution.

Another smart solution for the wide proliferation of charging capabilities is ubitricity.com [7]. The company offers a technical solution for owners of an electrical grid like cities or companies. While the charging stations are simple switchable 20 Ampere plugs, e.g. in a street light post, the computational intelligence, authorization and metering is deployed to a smart cable that communicates with the car and the network provider, allowing charging mode 3 according to IEC 61851-1. The user interface as in case of our solution is deployed to a smart phone or tablet app, however, the system takes advantage of dedicated stations, in contrary to our proposed solution that is open for any provider.

Generally, an important source of developments in electric mobility is the Nationale Plattform Elektromobilität in Germany [8] which provides information about the current state and the future aims regarding the topic electric mobility. It also shows the current technical development and describes tools that are used to achieve the big aim of 1 Million electric vehicles on German streets until the year 2020. Every one or two years there is a report about the current state, the achievement of recent aims, and strategy updates. We show that our solution, in contrary to the already existing services, is independent of a provider, and by technology is able to run in a cloud with a minimum of administrative efforts, enabled by microservice architecture.

2.1 Microservice architectures

Microservices can be considered as a reconsideration of the service oriented architecture (SOA) idea [9,10,11]. They realize small, loosely coupled and independent business cases that form a common functionality.

A comprehensive source about deploying microservice-based apps in the cloud is from the Universidad de los Andes in Colombia. The paper analyses the deployment of "large applications in the cloud as a set of small services that can be developed, tested, deployed, scaled, operated and upgraded independently." The benefits are to "gain agility, reduce complexity and scale applications in the cloud in a more efficient way." [12] In the sequel, we describe the business case of crowd charging and its realization by the Meteor framework and microservice architecture.

3 Meteor

Meteor [13] was founded in 2012 and since then it has been arousing great interest in the web development community.

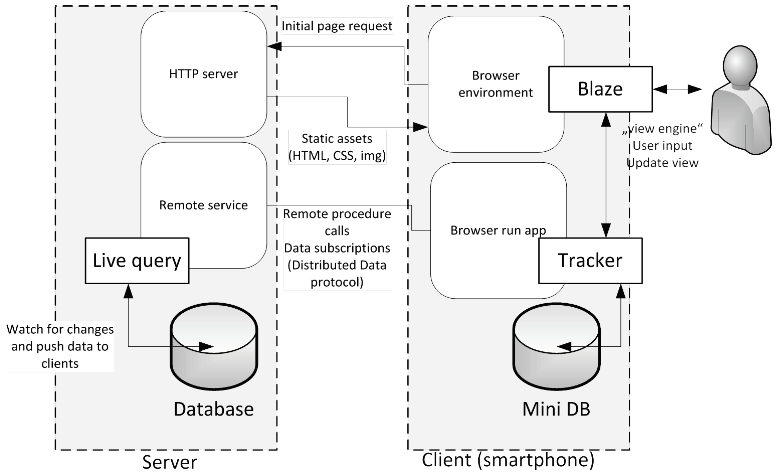

Figure 1. Architecture of the system using Meteor [13]

The Distributed Data Protocol (DDP) is one of the most important components in Meteor. The notion behind it is shown in Fig. 1. As soon as a user connects with a web client, an initial page load is transferred over HTTP and contains all the required HTML, CSS, JavaScript, or assets like pictures, icons etc. Once all resources are transferred, DDP comes into play as it is important to have a lightweight protocol to exchange data without a lot of overhead, because real-time data has to be displayed quickly and shouldn't use a lot of bandwidth. Libraries for this protocol are already available in all major programming languages and is thus appropriate in this crowd charging project as the car and the station themselves need to establish a connection to the Meteor server on an embedded device written in C. [12]

A major concept of our system is Optimistic UI, which enhances the user experience by forecasting the result of a service request and immediately giving feedback to the user without any latency caused by background computation and communication processes. For instance: One user is creating a new charging station on the proposed platform by filling in a web-form. After confirmation, the new station is immediately visible on the screen pretending that all computational processes in the background have been terminated without errors. In the meantime, the request was sent to the back end which checks the user input for validity. If confirmed by the back end, the new station is stored to the database and a confirmation is sent out to the client. If confirmation fails, no change is made to database and the client has to do a rollback. This whole concept is only possible due to a Full-Stack-Database concept (see also Fig. 1).

This concept includes an excerpt of the back end database on the client, called Mini DB, which can be accessed in the same manner as the original database. Thus, all database operations can immediately take effect without latency and thus enable an optimistic UI.

The back end itself is realized with Node.js, which is a JavaScript runtime built on Chrome's V8 JavaScript engine. Node.js uses an event-driven, non-blocking I/O model that makes it lightweight and efficient [14]. It is easy to implement a microservice-based architecture by splitting up features in independent Node.js modules. For massive scalability, those Node.js modules can individually be deployed into the cloud providing an appropriate infrastructure, breaking up the principally monolithic nature of Meteor.

Meteor uses a NoSQL database which has some benefits for modern web applications in comparison to a standard relational database. The most important advantage is the ability of handling large volumes of rapidly changing, structured, semi-structured, and unstructured data [15].

4 Software architecture

The software architecture follows the demands for scalability, maintainability and consequently the complexity of system management. In the last couple of years there is a trend to run applications in a cloud environment instead of just storing data in the cloud. It is possible to invoke functions on the cloud and not on dedicated servers (servlet) or clients (applet). Those functions are scalable in an infinite way, because there is a huge infrastructure behind a cloud provider. In the presentation, we will explain our software architecture approach, including the access to an ISO 15118 [16] compliant EVSE which has been developed in our institute.

Fig. 2 shows the collaboration relations between the instances of our proposed network. The client on the left hand side is triggered by user input and provides information as e.g. required distance, destination, and required start/end time of charging.

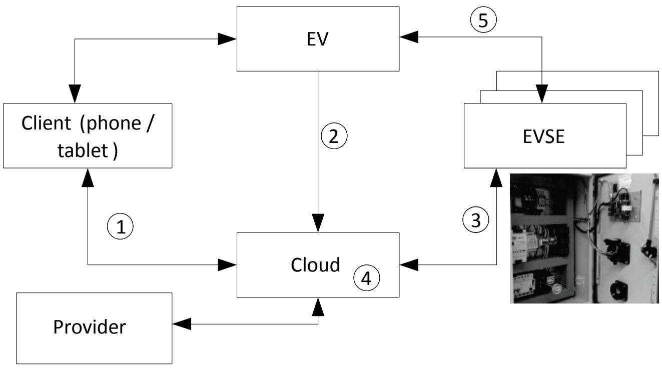

Figure 2. Collaboration diagram

The cloud service is triggered by the client and provides a location based list of available charging stations that match the requirements or a list of different options related to the price calculation. In order to provide this information, the cloud needs to receive data from both the EV and the EVSE. This communication is unidirectional synchronized from all EV, i.e. if data changes (e.g. geo location) the EV connects to the cloud and triggers a function to update the database. Apart from the geo location the most popular data exchanged is going to be SOC (state of charge), SOH (state of health), VIN (vehicle identification number), and maximum required charging power. Cloud service and all EVSE synchronize bidirectional. The Cloud service sends reservation information and a verification code. The EVSE provides information about the occupancy and some static values (e.g. max. charging power) while the EVSE basic data is maintained by the EVSE provider. Is there more than one charging station in the car park supplied by the same connection, the cloud is going to manage the distribution as well.

Once matching between EV, EVSE, and user needs is confirmed, a reservation takes place, providing payment information and the resulting time slot that can start further in the future or immediately. As soon as the EV has connected to the EVSE all necessary parameters are exchanged using the ISO 15118 protocol. This includes a confirmation of the vehicles identity, the payment confirmation, and the charging mode.

After connecting, the EVSE may send information to the cloud that it is now occupied with an EV and starts to deliver energy. The following sequence diagram (Figure 3) shows a typical scenario: The user wants to make a reservation after choosing from a list of available charging stations within a range. It should be noted that all services can be implemented as Microservices that store all effective changes to their local databases which are commonly synchronized in the background, thus, any cloud with the possibility of running remote apps with Node.js can provide the functionality and scale to the appropriate size.

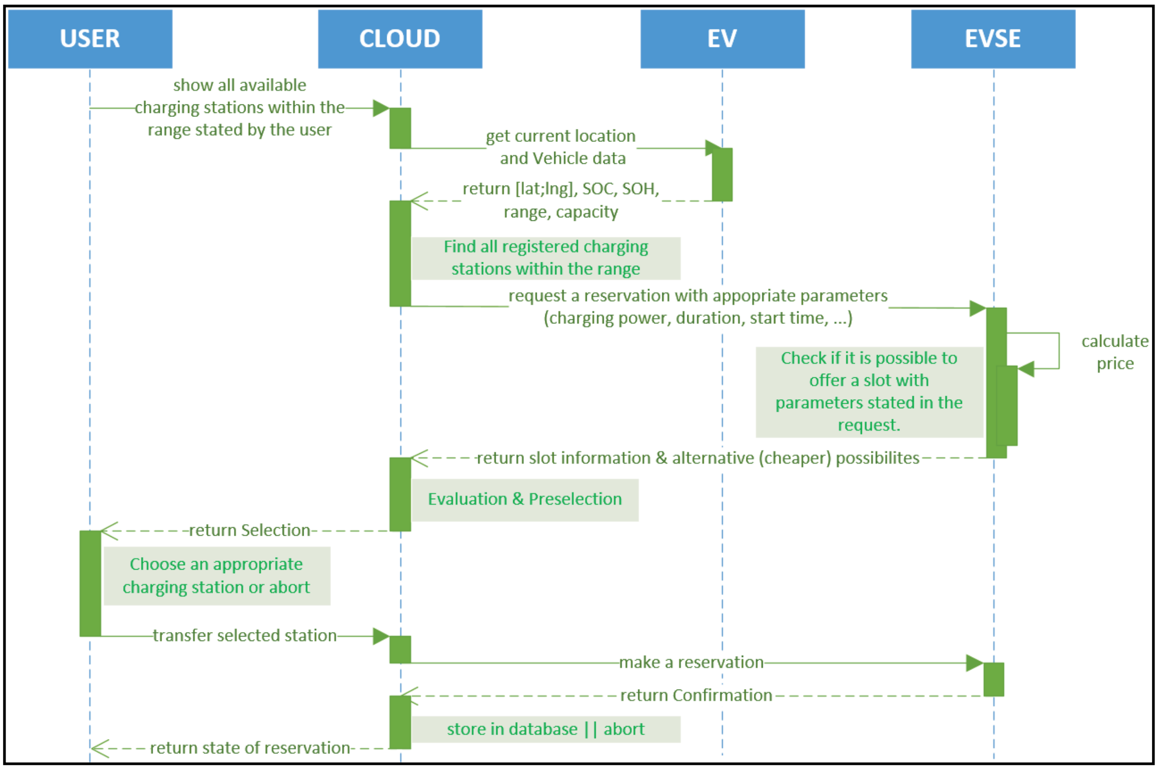

Figure 3. Making a reservation

5 Use cases for drivers

Besides of the ad-hoc search and reservation of an EVSE, there are four main use cases discussed. They are distinguished by the planning period, i.e. the duration from the decision to charge until the start of charging.

The first and probably most frequent use case is the "Charge on short notice". E.g. the user needs to go quickly into the city center for shopping, but the remaining charge in the car is not sufficient to get back home. The problem with public charging stations is that the user doesn't know if there is one available, so the only solution is to reserve a private station via the described platform. It is worth mentioning that users not only book charging energy but also a parking spot at the same time. There are several advantages to present for both the charging station provider and its user. In this scenario the provider can charge a higher price for energy as the demand is at short notice, which means a higher profit margin. The user's benefits are time savings in searching a parking spot and obviously increased security in using an electric vehicle in the first place, because people are still afraid of buying one due to the lack of charging stations.

The second use case is "commuters". The planning period belongs to the category medium-term, because users are going to make multiple reservations for many weeks in advance. A common case is that employees who are working in an industrial area which is adjacent to a residential area want to go to work with an electric vehicle. The car can be charged very slowly, i.e. with less power, during working hours. The benefits in this case for the charging station provider are mainly a good possibility to reach a high utilization so they have a fair bit of planning security in terms of monetarization of the equipment. The advantages of the user are an assured parking spot, a certain charging possibility and probably an option for price reductions since, as mentioned, the user books multiple charging slots for many weeks in advance resulting in a better planning base for the provider.

The next use case “travel” belongs to the long-term category. If an EV owner wants to go e.g. on vacation, there are some obstacles to overcome like the lack of range, the long waiting periods while charging and the uncertainty of being able to find a free EVSE. This platform can help with reservations in advance so the user can be sure to reach his destination. In order to implement this use case, some extra features within the application are needed, e.g. opening up the possibility of a flextime scheme in order to tackle traffic jam issues which can be a problem when the destination is far away. The following example shows the workflow of this particular use case:

- User logs in with smartphone/tablet/PC and chooses long-term planning.
- User selects a car from his car pool.
- User provides the address of the destination & start time of the journey.

App connects to the car database, asks for SOH (state of health) and driving history, then it calculates the range of a fully charged car.

- App calculates the route & determines all sectors of this route where the car needs to be recharged.
- User receives a list with different charging options (i.e. stations and charging modes) sorted by price and charging duration.
- Once the user decides for one charging option, the app reserves all the charging stations with included buffer times (in case of traffic jams).

In addition, the user is able to find and examine more charging stations at the destination.

Once the user arrives at a charging station, he or she enters the verification code, plugs in the cable, waits until charged, and continues the journey. If using an ISO 15118 compliant communication, no verification code is needed through the data exchange between EV and EVSE.

A forth use case is “emergency charging”. This use case is aimed at the user who desperately needs immediate charging to a minimum capacity to reach home or the next mid-term stop. His energy demand is at a short time range with high power. The service for emergency charging offers only close and currently available stations with a charging current corresponding to the fasted charging mode of the car. Due to the short time and high power demand, a higher prize is offered from the supplier.

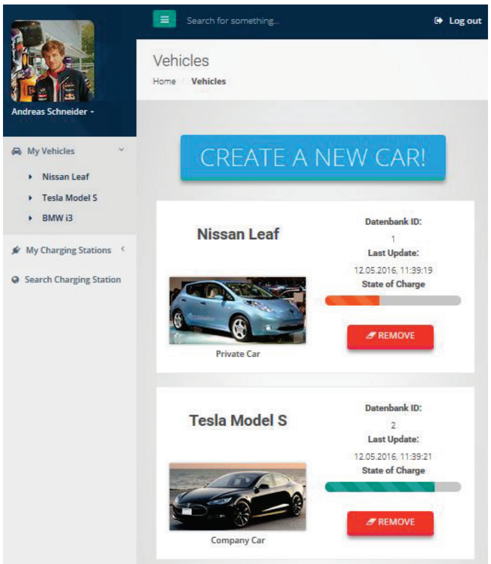

Figure 4. User interface on a mobile device for adding a new EV

We have not yet discussed the question of authentication of the user on first registration. However, this can be done over a trusted credit card verification site.

6 Use Cases for Suppliers

6.1 Business Model

Nowadays there is a trend to self-sufficient energy supply as private households start to refuse the monopoly position of public energy suppliers. In addition, the financial support by the German government for photovoltaic systems has been decreased constantly because of the high popularity of feeding back the energy into the electricity mains. As a result, private energy producers need to find another, more profitable way to use their panels as a good investment source. The presented business model does not only apply to private households but also to mid-sized companies, which either already own the required equipment but with the wish of becoming more lucrative or still need to invest in the required equipment as a future-proof capital investment with good returns. Finally, the presented calculations in the next Section B will be based on the fact that limitations of available solar power are compensated by public electricity to serve the charging station. This option is vital because the whole concept is going to be more effective as it turned out while analyzing the profitability.

6.2 Exemplary Prize Calculation

This section gives a rough estimation of the economic aspects for the region Germany. It is based on the following scenario: A 3 person household runs a solar panel with the size of 80 square meters on their roof, southern orientation, and 30 degrees' tilt in South Germany. This solar panel produces 10.000 kWh a year and is distributed over the year as follows:

Table 1. Solar power yield *[16]*

#	Month	Percentage share [%]	Energy [kWh]
1.	January	2,75	274,95
2.	February	2,95	295,32
3.	March	6,82	682,28
4.	April	13,65	1364,56
5.	May	14,36	1435,85
6.	June	12,42	1242,36
7.	July	13,44	1344,20
8.	August	13,44	1344,20
9.	September	9,88	987,78
10.	October	5,50	549,90
11.	November	2,75	274,95
12.	December	2,04	203,67
Annually		**100**	**10000**

The car Nissan Leaf has a capacity of 24 kWh and considering e.g. the month July, the user is capable of 56 full charges per month. Furthermore, the scenario implies also the possibility to store the energy in a battery in order to be able to provide charging current if there are some cloudy days in between. This will also be interesting in the amortization calculation later on because batteries are still very pricy, but as the technology moves on the prices are dropping. A good example is Tesla Motors since they invest a lot of money in this industrial area and thus they are able to provide a huge 100 kWh energy store called

Powerwall for just 25.000 US Dollar. In this scenario the user would be able to bridge 3-4 days without customers charging.

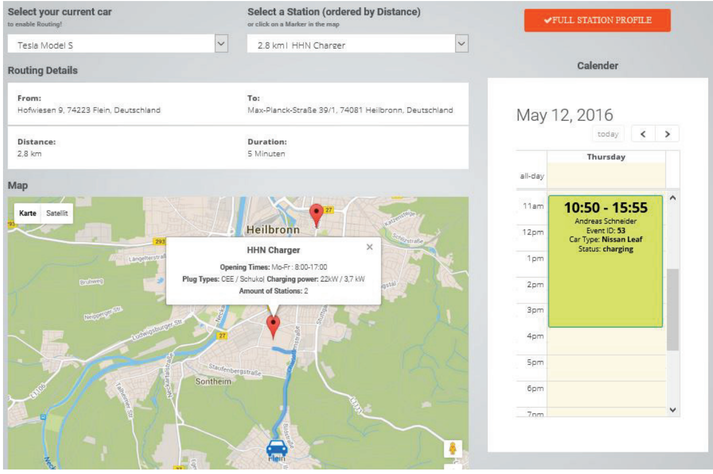

Figure 5. User interface on a computer monitor for finding and reserving a EVSE

Table 2 shows in the first column the personal need for electricity i.e. the estimated consumption of the household. The next column shows the amount of solar energy which is left and free for providing to the public as charging current. The last two columns show the profit for two cases depending on how much charging current is sold (Case A: 50 kWh, Case B: 100 kWh). In Case B there is a profit of 6.443 € each year assuming a combination of selling solar energy for 30 cents and forwarding compensation deliveries from public sources for additional 15 cents to the normal price (which is currently ~28 cents per kWh in Germany).

With an invested amount of 40.000 € for the solar panels of 80 m², a buffer battery, converter units and regulation systems, the commercial break-even point is reached after 8 years and the profit results of 82.000 € after the depreciation time of 20 years. These figures have only an exemplary nature as it is clear that legal restrictions, political promotion, and local prize structures play an important role in the commercialization. However, they show in trend that it is possible to motivate private households and small enterprises to share surplus solar energy without the risk of a supply leak by the lack of sun, and be profitable at reasonable time scale. Our concept supports that notion by creating an easy to configure and use information sharing platform.

Table 2. Analysis of profit

Month	**Personal need**	**Excess energy**	**PROFIT [Case A]**	**PROFIT [Case B]**
	[kWh]	***[kWh]***	***[Euro]***	***[Euro]***
Jan	293,6	-18,65	225	450
Mar	281	401,28	285,19	510,19
May	246,8	1189,05	403,35	628,35
Jul	244,7	1099,5	389,92	614,92
Sep	249,7	738,08	335,71	560,71
Nov	279,9	-4,95	225	450
Total	**3150,7**	**6849,32**	**3743,12**	**6443,12**

7 Discussion

The introduced concept is unique in terms of services provided, and since it is built in form of a social network, it is in line with the spirit of the present time. Starting with the idea of selling self-produced renewable energy (e.g. through solar or wind energy) as charging energy, owners can monetarize their energy equipment. The proposed application helps car users to find an appropriate charging station that matches their needs and prize expectations, provides a reservation service, a routing service which navigates the user to the desired charging station, a payment service, and special searching and reservation functionality with regard to different use cases. In addition, the app is interactive, i.e. every change (e.g. the SOC/location of the car, or a new reservation request) needs to be reflected immediately in the GUI. Interactivity, scalability, and reactivity to graphical resources of the user's client is provided without having a huge infrastructure and special knowledge of web programming as described in this paper. Furthermore, the presented application architecture enables small developer teams to introduce new functionality on a regular basis, because the microservice pattern eases the deployment of new functions as they are mutually independent and thus can be developed without touching sensible parts of the application. Another aim of this project was to create a platform that can be developed and run in a very cost effective manner. Since this application is built in form of a social network, most of the work is done by the users and the providers of charging stations itself. Consequently, this application can help to extend the charging station infrastructure and thus can help to spread out the idea of electro mobility.

On the other hand, it has to be noted that there are open issues prior to a roll-out of the proposed software framework. It is still left to the community to monitor the integrity of the system (as in Wikipedia). As in many shared concepts, user ratings can help to prevent misuse and maintain honest behaviour. However, for security reasons, a constant monitoring is recommended either through voluntary services or by generating revenues by charging a brokerage fee. Due to the decentral character of the software framework, this could be done by non-profit organizations e.g. local sustainability groups.

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Authors

Ansgar Meroth is professor for informatics and vehicle information systems in "Automotive Systems Engineering" at Heilbronn University since 2003. Among other functions he is also program director of the MBA program "International Automotive Management". Before, he was working at Robert Bosch GmbH as a systems and software engineer in car multimedia and later on in the corporate human resources department. He has studied electrical engineering at the Karlsruhe Institute of Technology (KIT), and has received his Dr.-Ing. from the faculty of electrical engineering in high voltage engineering and energy systems.

Andreas Schneider has graduated in Automotive Systems Engineering (B.Eng.) at Heilbronn University. He is currently working as a research assistant at Heilbronn University.