D4.5 EV mobility integration and its impacts in Leipzig

31/03/2023

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 864242
Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

Deliverable administration

No & name	**D4.5 EV mobility integration and its impacts in Leipzig**
Status	Released · **Due** M42 · **Date** 2023-03-31
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Description of the related task and the deliverable. Extract from DoA	**T4.4 E-mobility integration (FHG) M1 – M42** A component to enable positive energy buildings and districts is the integration of public and semi-public e-mobility. This refers to the use of privately-owned electric vehicles using public chargers, as well as fleet vehicles owned by companies, which provide mobility-as-a-service to their customers or to their own employees for work purposes. This platform supports the new and innovative use-cases of SPARCs and leverage previous project results. It provides a general functional basis for management, booking, monitoring and controlling shared company electric vehicle fleets and charging stations, as well as optimization of charging profiles and is finally based upon open and extendable interfaces. **D4.5 EV mobility integration and its impacts in Leipzig** • Report presenting developed and demonstrated E-mobility • Integration actions in detail, evaluating the impacts on the grid and urban planning requirements, and the • replicability potential of demonstrated solutions. The deliverable is the final report of task T4.4
Participants	FHG LPZ LSW CEN
Comments	

V	Date	Authors	Description
0	06/03/2023	WP leader	Deliverable checked by WP leader and released to the Coordinator and the Quality Manager for quality check and subsequent submission to the EC.
1	31/03/2023	VTT	Coordinator submits the deliverable to the EC

Dissemination level

PU	Public	X
CO	Confidential, only for members of the consortium (including the Commission Services)	

About SPARCS

Sustainable energy Positive & zero cARbon CommunitieS demonstrates and validates technically and socioeconomically viable and replicable, innovative solutions for rolling out smart, integrated positive energy systems for the transition to a citizen centred zero carbon & resource efficient economy. SPARCS facilitates the participation of buildings to the energy market enabling new services and a virtual power plant concept, creating VirtualPositiveEnergy communities as energy democratic playground (positive energy districts can exchange energy with energy entities located outside the district). Seven cities will demonstrate 100+ actions turning buildings, blocks, and districts into energy prosumers. Impacts span economic growth, improved quality of life, and environmental benefits towards the EC policy framework for climate and energy, the SET plan and UN Sustainable Development goals. SPARCS co-creation brings together citizens, companies, research organizations, city planning and decision making entities, transforming cities to carbon-free inclusive communities. Lighthouse cities Espoo (FI) and Leipzig (DE) implement large demonstrations. Fellow cities Reykjavik (IS), Maia (PT), Lviv (UA), Kifissia (EL) and Kladno (CZ) prepare replication with hands-on feasibility studies. SPARCS identifies bankable actions to accelerate market uptake, pioneers innovative, exploitable governance and business models boosting the transformation processes, joint procurement procedures and citizen engaging mechanisms in an overarching city planning instrument toward the bold City Vision 2050. SPARCS engages 30 partners from 8 EU Member States (FI, DE, PT, CY, EL, BE, CZ, IT) and 2 non-EU countries (UA, IS), representing key stakeholders within the value chain of urban challenges and smart, sustainable cities bringing together three distinct but also overlapping knowledge areas: (i) City Energy Systems, (ii) ICT and Interoperability, (iii) Business Innovation and Market Knowledge.

Partners

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EXECUTIVE SUMMARY (FHG, LSW, CEN)

This report describes the results of SPARCS work package 4.4 "E-mobility integration," which was implemented in the project's Lighthouse City Leipzig. This report reflects the solutions developed and deployed in the SPARCS project to use electric vehicle and bus charging in an electricity system with high shares of renewable electricity sources in a system stabilising manner. Developments in Leipzig as a lighthouse location are taken into account. The implementations of the three subtasks in WP 4.4 are presented, as well as the main results of the investigations and the replication potential.

First, the approach of the implementation of load-balanced fleet management is described. The aim of the SPARCS fleet management tasks was to help improve Leipzig's charging infrastructure by upgrading it to intelligent charging and enabling future use cases through it. The developments enable grid-resilient charging, allowing for the implementation of new business models for electric mobility.

Subsequently, the developments regarding *E-bus integration* are presented. By the year 2021 three bus routes of Leipziger Verkehrsbetriebe (LVB) were electrified, with a fleet total of 21 electric buses. One of the electrified lines serves as the subject of investigation. The analyses made during the investigations are described and the results are presented. In addition, a concept for the implementation of an integrated charging and load management system for intelligent charging of electric buses is described.

Finally, the implementation at the Baumwollspinnerei site is presented. On site a bidirectional charging system was installed and has been integrated into the energy management system of the property. Considering local conditions such as PV feed-in into account, the energy management system was able to achieve an optimal strategy for operating the local facilities.

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1 INTRODUCTION (FHG, LSW, CEN)

1.1 Purpose and target group (FHG, LSW, CEN)

This report reflects the solutions developed and deployed in the SPARCS project to use electric vehicle and bus charging in an electricity system with high shares of renewable electricity sources in a system stabilising manner. Developments in Leipzig as a lighthouse location are taken into account.

It presents the deployed solutions, the process of implementation, the results, and the remaining challenges for each task. In the following paragraphs, it reflects the interaction of the deployed solutions and what needs to be done to make the whole system even more useful. Furthermore, it describes possible impacts on the grid and the replicability potential of the demonstrated solutions.

The report is targeted to interested but non-expert readers from other cities, both in Germany and abroad.

1.2 Contributions of partners (FHG, LSW, CEN)

The general sections in this report were written jointly by all partners involved in the work package. This mainly includes Section 1 (Introduction) and Section 5 (Conclusions).

LSW vehicles and charging stations were used to implement load-balanced fleet management. The corresponding software for the implementation of the task and the demo case were also developed by LSW. Therefore, the results in Sections 2.1 to 2.4 therefore mainly come from LSW. Within work package 4 a *Study on tariffs, business models and additional services* was conducted by Fraunhofer. The main results of the study are presented by Fraunhofer in Section 2.5.

For the evaluations of the E-Bus integration, data from LSW and LVB was used. These were made available to the Fraunhofer via interfaces, and the corresponding work was carried out by Fraunhofer. Hence, the essential content of section 3 comes from Fraunhofer, LVB and LSW.

The solution to implement bidirectional charging was implemented on the Baumwollspinnerei site in Leipzig. The site and the energy facilities on the Baumwollspinnerei are operated by CENERO. The construction of the bidirectional charging station and the integration into a measurement and control system was also implemented by CENERO. Therefore, the main contents of Section 4 come from CENERO.

1.3 Relations with other activities (FHG, LSW, CEN)

The activities in the context of e-mobility are linked to other work packages within the project, as well as activities outside of the project.

The work for *Load-balanced fleet management* is connected to other activities of the Leipziger Stadtwerke. Leipziger Stadtwerke operates a charging station backend system and many charging stations in Leipzig. In addition, Leipziger Stadtwerke provides charging cards for electric vehicle users and an app for the convenient charging of electric vehicles. The work within this project is a complement here. There are also similarities with other work packages, such as subtask 3.4.2 New E-mobility hub in Leppävaara centre.

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The works regarding *E-bus charging integration*, whose results are described in Section 3, are integrated into other activities of Leipziger Verkehrsbetriebe. In recent years, Leipziger Verkehrsbetriebe has driven the electrification of the bus fleet and increased the proportion of electric buses. In addition, an intelligent charging and load management system has been rolled out at the bus depot, which manages the charging processes at the depot charging stations. Relations to other actions of the SPARCS project exist particularly in terms of the connection to the urban data platform, the provision of the corresponding data, and the integration into the virtual energy community.

The *Baumwollspinnerei* demo district is representative of the urban transformation in the German real estate industry. Originally, during the late 19th century, it was used as a large-scale industrial processing site for cotton. Later, from the 1990s onwards, the site was increasingly made available for other uses. Thus, a large site that previously served a fixed purpose gradually became a place of different tenants with different requirements and demands. This change brought about unique challenges for the historically developed energy infrastructure. As a contractor working on site, CENERO is designing a sustainable energy system for the Baumwollspinnerei in harmony with the preservation of the historical monument and the needs of the tenants. To achieve this, CENERO is successively implementing digitalisation of the energy resources on the site. To be more specific, remotely readable energy meters are installed that communicate generation and consumption information to a software solution that consists of energy management and load management. The cenero.one energy management system records and visualises these data, while the load management system makes it possible to control the energy flows in a targeted manner. Digital load management is essential for real-time management of an energy system with different sources of generation and consumption. CENERO's activities in the field of bidirectional e-mobility overlap with other project components. For the targeted control of the bidirectional charging flows (e.g. for the use of the EV as storage or the implementation of peak shaving), core functions of digital load management are essential. The load management, in turn, is also required to implement the diversification of the energy system at Baumwollspinnerei. Thus, information on the generation of the PV system, the electricity storage system and the grid transfer point to the upstream distribution grid is also recorded and processed by the software. The implementation of load management is an essential prerequisite for the implementation of Action L2. For this purpose, the infrastructure of remotely readable energy meters and a LoRaWAN-based radio network is required, which were also installed as part of Action L2.

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2 LOAD-BALANCED FLEET MANAGEMENT (LSW, FHG)

Electric mobility is becoming increasingly relevant in today's world as people become more aware of the environmental impact of traditional vehicles. Electric vehicles offer several advantages over conventional vehicles, including reduced greenhouse gas emissions, lower operating costs, and low noise pollution. This has led to a rise in demand for electric vehicles, which is expected to continue to grow in the coming years. To meet these requirements, LVB has installed many charging stations in recent years. The charging stations in Arno-Nitzsche-Straße are shown in Figure 1.

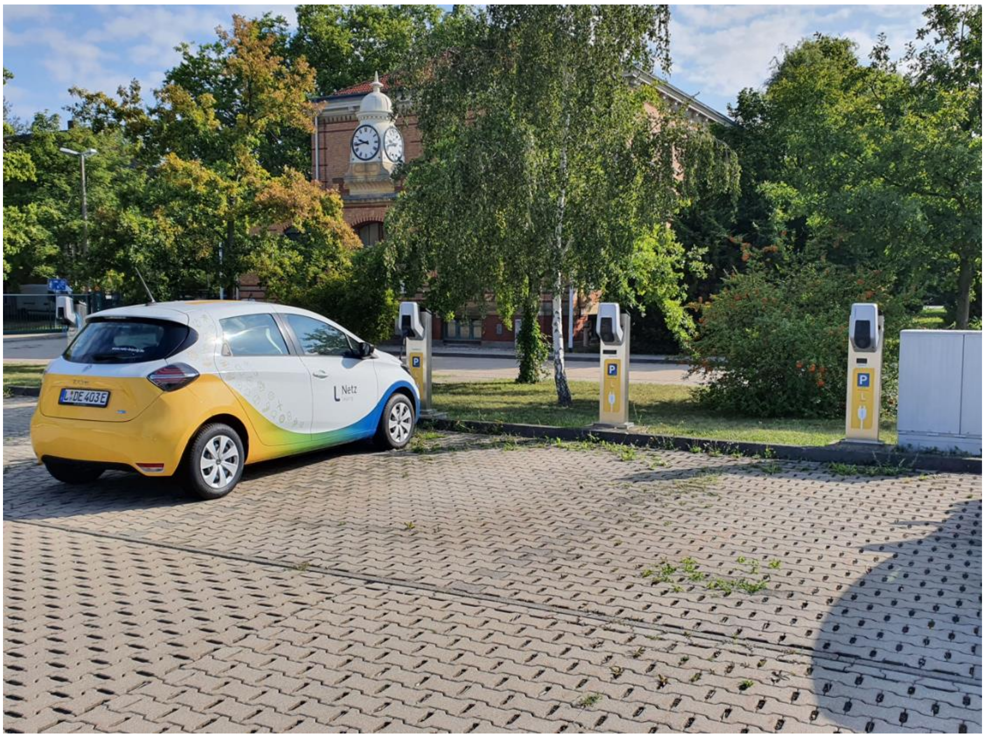

Figure 1: Charging points in Arno-Nitzsche-Straße (Source: LSW)

2.1 Task description (LSW)

The aim of the SPARCS fleet management tasks was to help improve the Leipzig charging infrastructure by upgrading it to intelligent charging and enabling future use cases through it. At the start of the project, LSW operated about 200 public charging points at more than 80 locations and aimed to enhance the existing network of public charging infrastructure with intelligent charging. This will allow LSW to meet the increasing demand for electric mobility and further promote the adoption of sustainable transportation. The task involved developing the process for the intelligent design of the stations and integration into the existing technical framework for publicly available charging. This allowed LSW to optimise the charging infrastructure utilization, e.g., by enabling fleet management and a reservation function for charging stations. Additionally, it enables grid-resilient charging, allowing for the implementation of new business models for electric mobility.

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2.2 Implementation and demonstration (LSW)

To implement intelligent charging, LSW first developed possible use cases in coordination with the IT, operations and market department and analysed the available information from the charging infrastructure. LSW designed the specifications for the charging stations and worked with the charging station manufacturer and E-mobility IT service providers. LSW then started developing its own backend based on the Open Charge Point Protocol (OCPP), a communication protocol that enables remote management and monitoring of charging stations and to balance the load on the power grid by remotely starting and stopping charging sessions.

LSW procured charging stations that are compatible with OCPP 1.6. The charging stations were installed in strategic locations in Leipzig to increase the utilization of the charging infrastructure. LSW then integrated the charging stations with its own OCPP backend /Central Management System (CMS) to manage and monitor the stations. The CMS enables remote management and monitoring of charging stations from a central location where charging processes are started and stopped.

The CMS is used to dynamically manage the demand for electricity from the charging infrastructure. The CMS receives real-time information about the load on the power grid and uses this information to balance the load. During periods of high demand, the CMS can signal to EV owners to adjust their charging behaviour via an app. By reducing charging times or pausing charging sessions during these critical times, the risk of blackouts and brownouts can be reduced.

LSW has further developed a mobile application (Leipziger App, see Figure 2) that directly connects the end-user and the Central Management System (CMS). The app sets the foundation for easy access to the intelligent charging functions of the OCPP-based CMS in a user-friendly way, especially for future business cases. The mobile app provides a convenient way for end users to remotely monitor and manage their EV charging sessions. Users can view their charging history, check the status of their charging session, and receive notifications when their vehicle is fully charged. Additionally, the app allows users to schedule charging sessions and receive alerts if the charging station is out of service or not available. This approach eases the use of E-mobility in Leipzig, as it enables easy access to the charging infrastructure and provides a seamless experience for users.

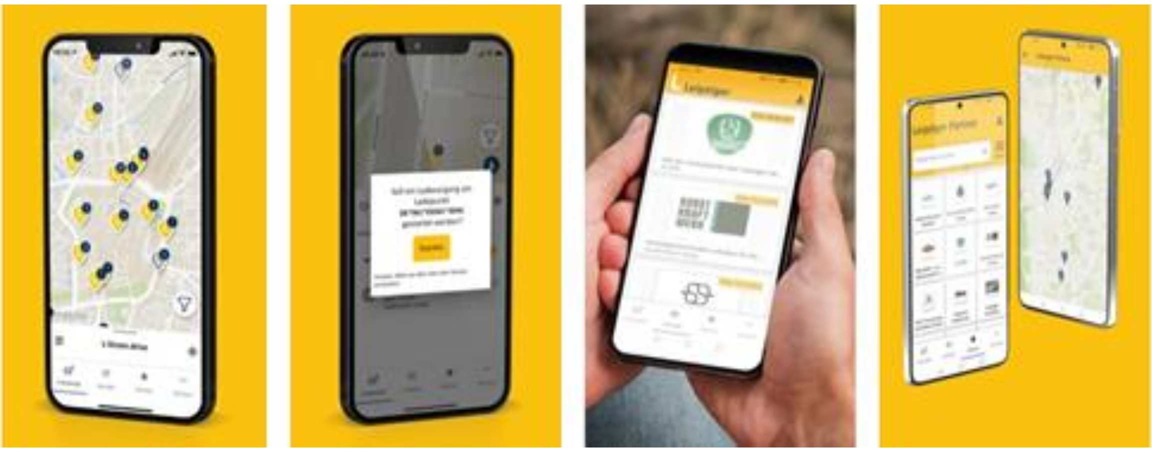

Figure 2: Leipziger App view according to current status (Source: LSW)

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The mobile app is designed to be user-friendly and accessible to a wide range of users, regardless of their technical expertise. The conceptualization of the mobile app involved defining the app's requirements, functionality, and design together with product/market and operations department and IT, as well as external app developers. The app was tested to ensure that it met the defined requirements and functionality. The testing process involved different stages, including functional testing, performance testing, and security testing. It was tested on different devices and both iOS and Android. The implementation involved designing the final user interface and integrating the app with the OCPP-based CMS.

The CMS has been used to develop a demo for intelligent fleet management. A dashboard has been created to integrate all charging functions into the fleet management context, allowing us to control the OCPP functions of all charging IDs connected to LSW-owned charging stations or wallboxes managed by LSW. In the demo showcase, a number of vehicles are selected and their current online status is checked. Based on the status of the distribution grid and the potential threat to its resilience, the charging processes are stopped. Currently, this test case is only carried out with vehicles owned by LSW, but this function can be carried out for every customer. Some of LSW fleets' vehicles are shown in Figure 3.

Figure 3: LSW fleet (Source: LSW)

2.3 Impact (LSW)

The impact of these tasks is twofold: Regarding the Leipziger App and charging infrastructure, LSW has experienced a substantial increase in charging station utilisation and positive feedback on the app. The fleet management app is shown in Figure 4. LSW was able to build value added services on top of the intelligent charging infrastructure. For example, the new CMS allows LSW to handle charging protocols and remuneration of public charging points and LSW-managed wallboxes in private homes in the same way. This allows for a wide-spread integration of e-mobility users in the city's mobility ecosystem. Customers can charge their vehicle at home and later at work using the same app. This substantially simplifies their overview of vehicle billing and utilisation. Furthermore, LSW provides a service that creates tax reports for the charging company's fleet vehicles. This is relevant in countries like Germany, where private use and charging of company vehicles has impact on personal taxation. Therefore, by using the

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newly developed charging CMS, the entire process of use of e-mobility is therefore streamlined for the user.

Regarding the aims to foster grid resilience, we have just developed the foundation for future utilization. At the present time, the impact of stopping the loads of vehicles currently in the charging processes is not significant for the operation of the distribution grid. The reason for that is the still relatively low number of electric vehicles compared to fossil-fuel-based vehicles, the adequately designed grid structure and the currently well predictable load pattern of charging processes. However, as the relevance of electric vehicles increases in the future, these variables will change. For this likely scenario, SPARCS has provided the foundation for business models that provide the necessary flexibility to address these challenges.

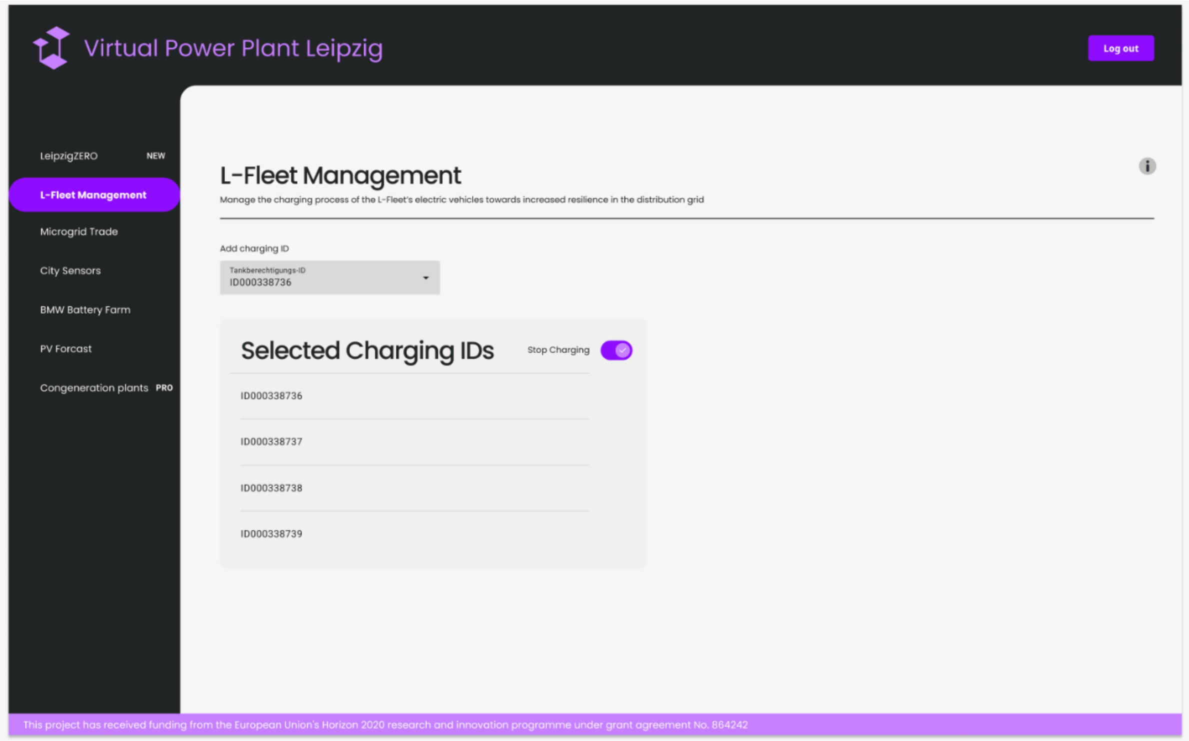

Figure 4: Leipzig fleet management app (Source: LSW)

2.4 Replication potential of demonstrated solutions (LSW)

The product, operations and IT department are working on business models to ensure remuneration for this function. The backend and the fleet management dashboard provide an innovative solution for ensuring the resilience of the power distribution grid while also enabling the intelligent management of company vehicles. In this process, we have discovered notable implications for replication:

Regarding one of the early proposals to use bi-directional instead of intelligent charging: The overall aim was the realization of demand side management for urban e-mobility, i.e. enable digital platform to adjust the charging process of EV in reaction to signals from the power grid. The most pressing issue was that the car manufacturing industry has so far not provided sufficient electric vehicles supporting bi-directional charging. Since the number of supported vehicles in the distribution grid is crucial to the utility of this measure, other demand response mechanisms are more suitable at this point for the dynamic control of the grid. Therefore, the following changes were undertaken: in order to implement the most effective tools for demand

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side management, Stadtwerke Leipzig focuses on the installation of its back-end architecture that provides intelligent charging of the EV. This includes remote starting and stopping, shifting and deferring of loads in response to signal from the grid or the market. For replication of intelligent charging use cases, it is notable, that the circumstances in the car manufacturing industry have not changed. Right now, bi-directional charging is only a prototype level topic and not applicable to current business cases.

The development of a product based on the intelligent charging project has both advantages and disadvantages. The OCPP-based CMS and the fleet management dashboard demonstrate innovative solutions to ensure the resilience of the power distribution grid and efficient management of charging infrastructure. However, at the current state, these solutions are not widely deployed yet. At present, there are not enough electric vehicles on the road to pose a significant threat to grid resilience and the charging behaviour of existing electric vehicles does not present a major problem for the grid. Therefore, as of now, it is unlikely that products based on intelligent charging and vehicle-based demand response would be financially stable. However, from the perspective of a utility that also meets public requirements, we believe that on a city-level it is important to prepare for future circumstances that may require a more robust approach to grid resilience and charging infrastructure management. As the adoption of electric vehicles grows, it is crucial that other cities start replicating this approach of developing information systems as a foundation for smart charging business models. By doing so, they can better position themselves for future growth and ensure that they are ready to take advantage of emerging opportunities in the electric vehicle market. We will continue to monitor the market and work closely with stakeholders to evaluate the feasibility of the business models focused on intelligent fleet management.

2.5 Study on tariffs, business models and additional services (FHG)

Within the task *load-balanced fleet management* business models and services for residents regarding reservation of charging spaces, selection of charging tariffs and priority setting were developed. A summary of the main results of the study is given below.

First the e-mobility ecosystem was analysed and the relevant roles, actors and systems that exist in the context of e-mobility were examined. The two essential roles in the ecosystem of electric mobility are the Charge Point Operator (CPO) and the E-Mobility Provider (EMP).

- **Charge Point Operator (CPO):** A CPO is a company that operates various charging stations. CPOs are often also responsible for the installation and maintenance of charging stations and own the operating charging infrastructure. Mostly the CPO operates a charging station backend system, its charging stations are connected to.
- **E-Mobility Provider (EMP):** An e-mobility provider (EMP) is a company that offers charging services to its customers and enables electric vehicle users (EV users) access to charging points. In general, EMPs provide a visual map of their supported charging stations and enable charging via app or authentication token. Local energy utilities, vehicle manufacturers or other companies often operate as an EMP and operate the corresponding systems and processes.

To enable innovative business models, the complexity of the ecosystem has been reduced and the CPO and EMP roles were combined into one actor. In practice, this could be implemented by LSW for example, because LSW offers CPO and EMP functionalities. This is shown in Figure 5.

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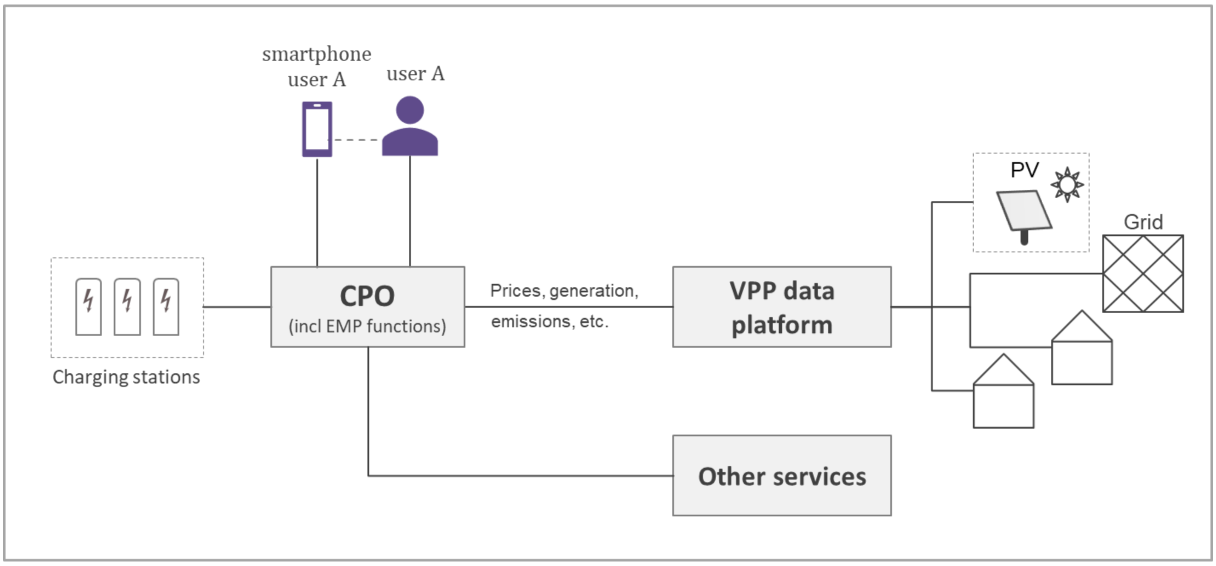

Figure 5: Architecture and systems for various tariffs and business models (Source: FHG)

In Figure 5, the CPO and EMP functions are aggregated to one system considering CPO and EMP functions. In that case the CPO (e.g. LSW) can define a price/tariff the end consumer has to pay. Since the CPO backend includes EMP functionalities, the CPO can determine the end customer price and then offer new tariffs. This provides flexibility in billing charging processes and enables the CPO to offer a specific price/tariff to the customers (e.g. via an app). The CPO's price to the customer can be based on external signals. In Figure 5 the VPP (Virtual Power Plant) data platform backend of LSW provides such signals. The VPP data platform aggregates the data that energy producers, consumers and grid elements provide and provides predictions. In Figure 5 two buildings, one PV module and the power grid are connected to the VPP data platform. As seen in the figure, the VPP data platform transmits predictions (e.g. price or emission) to the CPO backend. These serve as input for price and tariff determination.

Based on that architecture business models and services for residents regarding reservation of charging spaces, selection of charging tariffs and priority setting can be shown. The main models for this are the following.

Reservation of charging points

Currently, only a few systems allow the reservation of charging stations, but the reservation function can increase the user's comfort for charging. An exemplary reservation process and an app mock for reservations are displayed in Figure 6 and are described below. Before being able to issue a reservation the respective charging station (Figure 6 view 1 and 2) and a date for the reservation (Figure 6 view 3) must be selected. For the depicted example the 23.05.2021 is used. On the last view the user can then see available and already booked time slots. Finally, the user can book his preferred reservation time slot.

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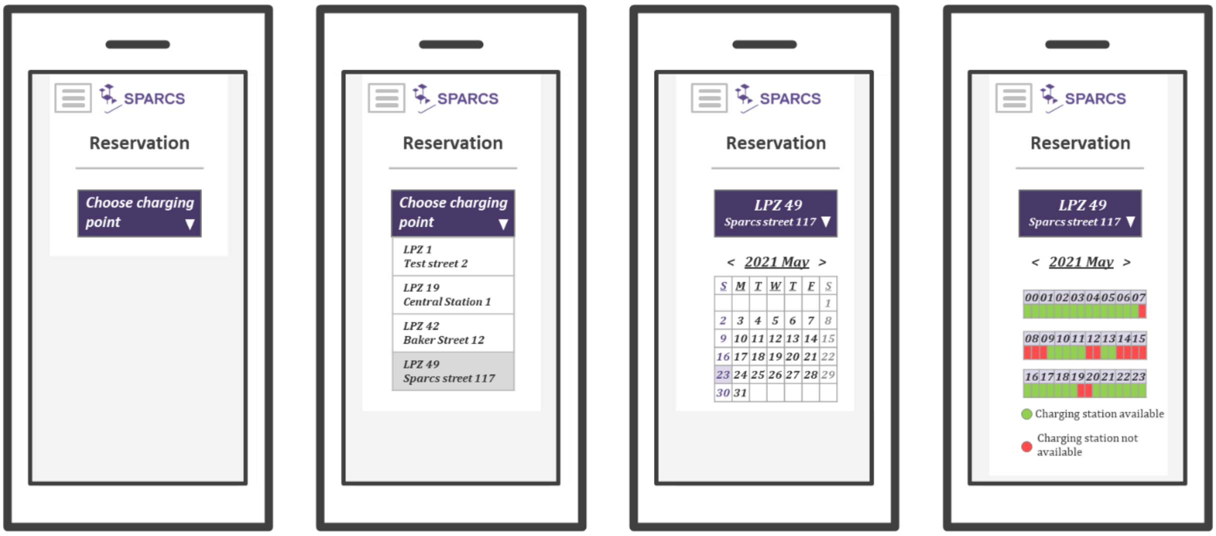

Figure 6: Reservation of a charging point - mock-up (Source: FHG)

For a reservation a fee could be issued with which the CPO can generate revenue for blocking the charging station. On the one hand, a fixed fee for the reservation could be defined. For the fee calculation the location or the utilization of the charging station could be considered. Another possibility of a reservation fee is price based on the duration of the reservation.

Selection of charging tariffs

To define various tariff structures different tariff types were defined according to the OCPI interface (Open Charge Point Interface). The Open Charge Point Interface (OCPI) is a protocol that supports communication in the ecosystem of e-mobility and defines four different tariff options: regular, cheap, fast and green. These four tariffs could be offered to the user through the app using different configuration options.

- **Cheap:** In case of the *cheap* tariff, the driver wants the cheapest tariff for the charging process. Therefore, the functionality of the VPP data platform could be used. The VPP data platform provides future price signals for various players. If the current SOC, the charging power and the desired departure time of the driver are known, the vehicle can be charged at those times when the VPP data platform predicts the lowest prices, e.g. when there is a low demand for energy in the grid at the time.
- **Fast:** In case of the *fast* tariff, the electric vehicle user wants to charge his vehicle as fast as possible. In this case, the CPO backend and the VPP data platform provide the maximum charging power of the vehicle/charging station. The costs, greenhouse gas emissions or other parameters are not considered for optimization.
- **Green:** For the *green* tariff, the driver prefers the most ecological tariff to charge his vehicle. Therefor the functionality of the VPP data platform can be used. The VPP data platform provides forecasts of the greenhouse gas emissions of the electricity mix for various actors. If the current SOC, the charging power and the desired departure time of the electric vehicle driver are known, the vehicle can be charged at times when the VPP data platform predicts the lowest greenhouse emissions of the electricity mix - e.g. at times with high feed-in from renewables.

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- **Regular:** The regular tariff is used if the driver's preferences are not specified and the charging periods are not specified. Control of the charging process based on the needs of the users is therefore not possible as they are not explicitly defined

Flexibility through bidirectional charging

Bidirectional charging enables the use of electric vehicles (EV) as accessible battery storages that can be used to feed power back to the grid. Therefore, more flexibility is available to compensate for load peaks within the energy grid. At times with high PV generation the EV batteries can be charged and discharged when immediate energy is required and the renewable energy sources do not provide enough power.

To compensate for the additional usage of the battery, incentives are necessary to convince users to participate in the flexible market. Therefore, different kinds of reimbursements could be made:

- Compensation based on the provided power (€/kW)
- Compensation based on the accessed power (€/kW)
- Compensation based on the retrieved effect work (€/kWh)
- Compensation based on time (€/h)
- Combination of previous aspects

Residents can gain profits by providing flexibility to the energy market. The desired scenario for bidirectional charging would be that EV drivers can define their own boundaries. Therefore, a driver could communicate his desired minimal SOC which shall not be undercut. Another use case could be to communicate the target SOC, which shall be reached until a certain point in time.

For the use case “bidirectional charging” the charging station control requires extensive implementations and additional optimization algorithms for the VPP data platform and CPO backend systems. To establish bidirectional charging across the board further adjustments to the legal regulations are necessary. Furthermore, there are many technical challenges involved in the field of bidirectional charging. Currently there are only a few EVs und charging stations that support bidirectional charging. For a rollout across the board further technical advances must be made besides the existing legal questions.

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3 E-BUS CHARGING INTEGRATION (FHG, LSW)

As part of the work package L15-2 (Reducing grid congestion and peak loads in the virtual energy community), recorded data from 21 electric buses used in Leipzig was analysed. The aim of the analysis was to identify a possible reduction in charging power at the fast-charging station at Connewitzer Kreuz (see Figure 7, purple charging station).

By the year 2021 three bus routes of Leipziger Verkehrsbetriebe were electrified, with a total fleet of 21 electric buses. The three electrified bus routes are shown in Figure 7. The first one was bus number 89, which runs from Goethestraße and Leipzig Central Station to Connewitzer Kreuz (Figure 7, purple). The second one was bus number 74, which runs from Nathanaelkirche Lindenau to Sophienhöhe in Holzhausen (Figure 7, green). The last one was bus number 76, which starts at Herzzentrum Leipzig and ends at Naunhofer Straße Probstheida (Figure 7, red).

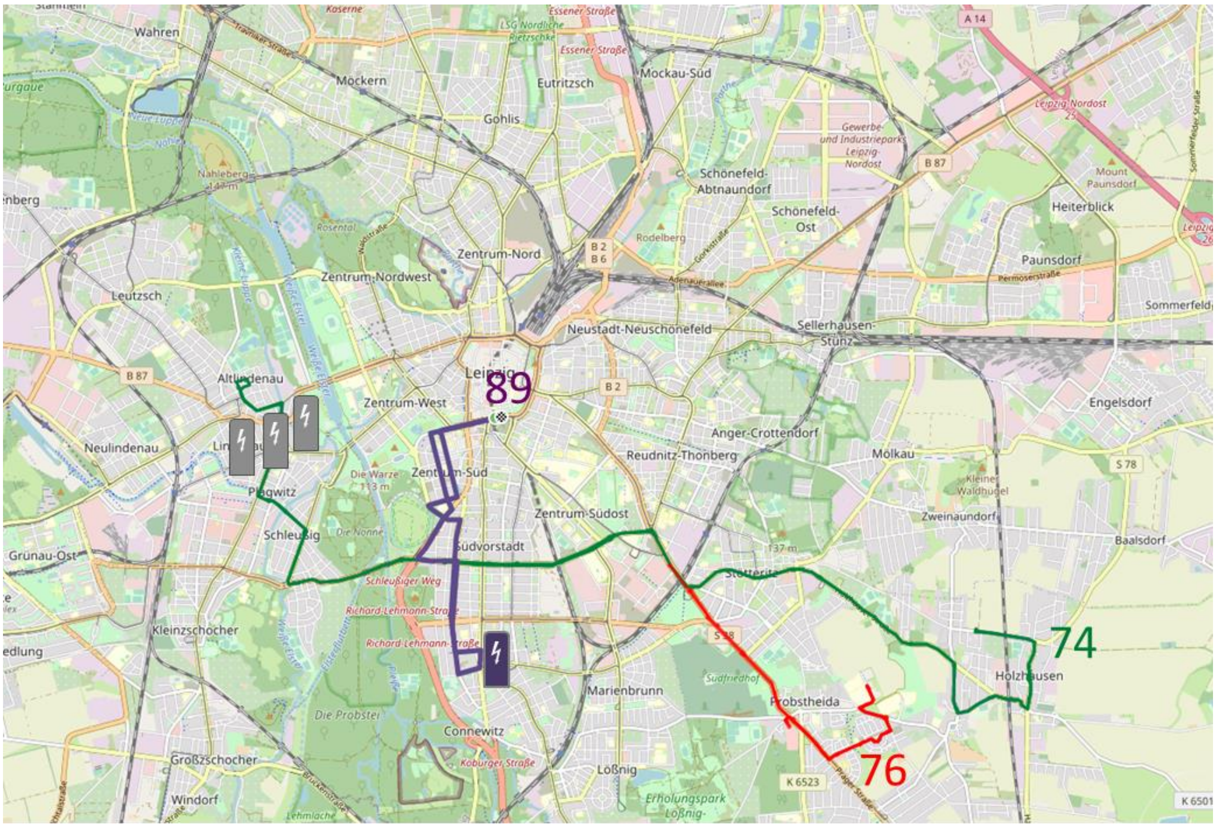

Figure 7: Electrified bus routes in Leipzig (Source: FHG)

In order to operate the electric bus fleet, LVB has modernized the bus depot in Lindenau and installed 10 fast charging stations with a charging power of more than 200 kW per charging point. Figure 7 shows the charging park and its location with grey charging stations. At the depot, the buses can be charged at night during idle times. Additionally, a fast-charging station was built at the Connewitzer Kreuz bus stop. This is shown in Figure 7 as a purple charging station. At this station, the buses can be recharged between two trips without going to the depot. Some of the electric buses are shown in Figure 8.

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Figure 8: Electric buses Leipziger Verkehrsbetriebe (Source: LVB)

3.1 Task description (FHG, LSW)

The 21 electric buses make several trips a day. The start and end times of each trip are collected via the *Leipzig digital platform*. There is always a break between two trips. This break is considered as a potential charging slot at the final stops. The sum of all trips made by an electric bus in one day is called a *day trip*. The distinction between day and day trips is based on the fact that a single electric bus makes up to 21 trips in one day; these trips are referred to as day trip. Overnight, all electric buses are in the depot in Lindenau and this depot stay is also considered as a charging opportunity.

The aim of this task in the first instance was to analyze the given data and map an overview of it. Subsequently, load reduction were created and evaluated. The aspects of the use of the electric buses, the driving and standing times, as well as the duration and number of trips were analysed in detail. Furthermore, charging processes and the change of the SOC within a day trip were considered. Subsequently, the load reduction potential at the Connewitzer Kreuz was examined and the individual trips were assigned to bus routes. The focus of this analysis was on the fast charging station at Connewitzer Kreuz, which is also the final stop on route 89. Therefore, the trips assigned to the bus number 89 were considered in more detail.

3.2 Implementation, demonstration and impact (FHG)

In the first step of the data analysis, aspects were examined that best represent the overall situation. The majority of the 21 electric buses were put into operation in June 2021. At the beginning of deployment of the electric buses, there was a larger deviation in the use of the electric vehicles, which became smaller over the period under consideration. In July 2022, the average use of the electric buses was 19 days. The continuous smooth driving operation is covered by the average use of the electric buses of 19 days in July 2022. For smooth driving operations, it is necessary to plan a buffer regarding possible technical faults, maintenance work, additional requirements due to construction sites or diversions. Driving operations are also restricted at weekends, during school holidays and on public holidays, and therefore fewer vehicles are required for this.

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The average number of trips made by a single electric bus in one day was 12 trips. This number has not changed significantly during the period. However, changes were observed in the trip duration, which increased from 1.09 h in August 2021 to 1.23 h in August 2022. This increase is due to the later introduction of bus number 74. The trip duration of bus number 89 has not changed over the period under consideration. The average consumption of a trip is approx. 9 % of the total battery capacity.

The break durations between trips have increased from approx. 10 minutes to approx. 12 minutes since August 2021. Within 85 % of these breaks, charging is carried out at the terminal stops and an average of 11 % SOC (24 kWh) is charged. The nightly depot stop lasts between 4 and 10 hours in approx. 50 % of the cases. In approx. 50 % of the cases, this duration is over 10 hours. During this stay, a charging process is carried out in 50 % of the cases, which corresponds to an average increase of the SOC by 10 % (22 kWh) per electric bus. The low charging volumes are due to the delayed opening of the Lindenau depot.

At the beginning of each daily trip, the electric buses are rarely fully charged. In 77 % of the cases, the electric buses are charged to at least 80 % of the SOC before the day trips. The SOC values at the beginning and end of each day trip are on average 86 % at the start and 77 % at the end. In approx. 55 % of all day trips, a trip of bus route number 89 is operated.

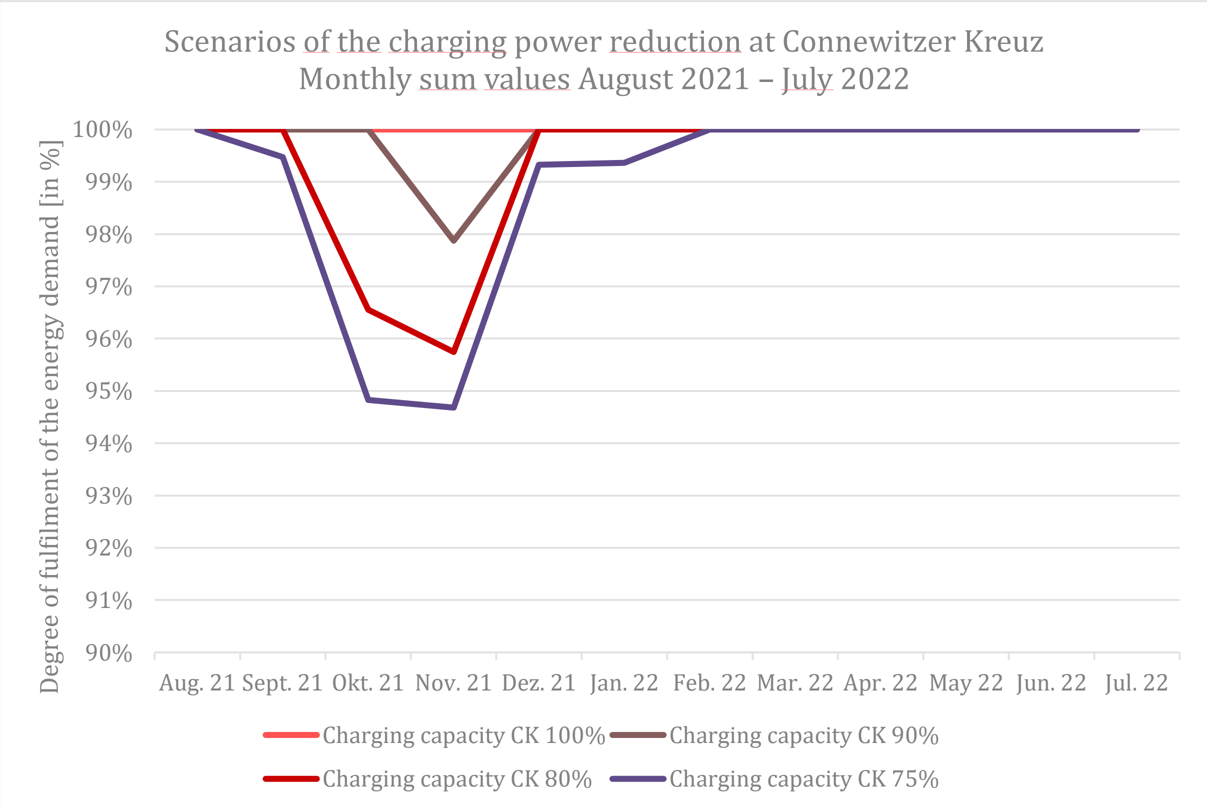

Figure 9: Scenarios of charging power reduction at Connewitzer Kreuz (Source: FHG)

As part of the work package, it was investigated to what extent a reduction in charging power at Connewitzer Kreuz would be possible based on the available data and historical trips. It was investigated whether the required amount of energy for a day would be charged even with reduced charging power. Different scenarios were examined for this purpose. Reductions to a charging capacity of less than 75 % were ruled out, as the energy supply is insufficient in these cases. The results are presented in Figure 9. This figure shows in how many percent of the trips

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in each month the charging amount would have been sufficient for completing the day trips. For each day trip, it is then determined whether the charge is sufficient for consumption. In this case, sufficient means than an electric bus arrives at the depot at the end of the day with an SOC higher than 10 %. If the SOC falls below 10 %, the charged energy is insufficient for the day trip.

In the scenarios of a reduction in charging capacity to 80% and 90%, there are already day trips when the energy supply is insufficient. The four cases analysed in the 90 %-scenario can all be attributed to the month of November 2021. In the 80% scenario, day trips with insufficient energy can be attributed to the months of October and November 2021. In the 75% scenario, this is extended to include the months of September and December 2021, as well as January 2022. Following this analysis, Leipziger Verkehrsbetriebe examines the individual days on which the SOC fell below 10%. Depending on which causes are responsible for these shortfalls, this is taken into account when deciding whether to reduce the charging load at the charging station at Connewitzer Kreuz.

Through this knowledge, based on the given data, a significant reduction of the Connewitzer Kreuz charging capacity at the charging station is not recommended. However, a reduction of the charging power is conceivable if changes are made in the process. By adapting the operating processes or the associated IT systems, operational safety can still be guaranteed. The current infrastructure does not allow for dynamic adjustment of the charging power for charging processes. With an intelligent charging and load management system and the integration of the IT systems, both the SOC and the timetable of a vehicle could be taken into account during charging processes and the charging power could be adjusted dynamically and automatically accordingly. In that case, additional use cases such as the consideration of locally generated PV electricity or the consideration of further boundary conditions are also possible. This can make a positive contribution to grid security and stability.

In the long term, Leipziger Verkehrsbetriebe plans to reduce the charging capacity at Connewitzer Kreuz to 75% of the original capacity. In the event that the required battery buffer is not reached, bus drivers in this scenario will contact the control centre of the public transport company, and the charging power will be manually increased for the individual charging process. This ensures operational safety and a contribution to the reduction of peak loads at Connewitzer Kreuz is also implemented in regular operation.

As already mentioned, the evaluation did not show a great potential for charging load reduction for the charging station at Connewitzer Kreuz. However, at the charging station at Herzzentrum Leipzig (bus route 76), a potential for charging load reduction was identified and a static reduction from 320 kW to 200 kW was implemented. The reduction has led to a greater reduction in SOC during the day. As a result, the buses arrive at the depot at the end of the day with a lower SOC and more energy must be charged. The first results show that the critical SOC values are not undercut and thus the load reduction is successful. In the current operation, no automated charging power reductions have been carried out yet. If a vehicle falls below the minimum SOC, the driver contacts the control centre and a decision is made between two variants on how to proceed. Either the vehicle is charged unscheduled and the trip starts late or the vehicle is replaced by a substitute vehicle. However, LVB wants to avoid both variants, as neither delays nor additional costs due to vehicle replacement are desirable.

In the next step, further analyses could be carried out to investigate and simulate the potential of charging stations with different charging capacities. The extent to which additional buses or even all buses can be replaced by electric buses could also be investigated. This could then identify potential not only for the city of Leipzig, but also for network operators, for example.

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Possible advantages may be that there are lower peak loads during the day and more charging at night. Whether and under which conditions this can be beneficial could be investigated in further analyses.

3.3 Replication potential of demonstrated solutions (FHG)

The methodology applied is replicable for other routes or cities. For this, the necessary interfaces would first have to be implemented and the bus data retrieved. If the data of possible new lines are provided on the same platform as the data for bus number 89, the effort for additional lines is low. Otherwise, additional expenses may occur for the integration of the data.

For the adaptation to other lines or cities, adjustments in the scripts are also necessary. Adjustments are required in particular for the following aspects:

- **Master data buses:** The buses used in Leipzig currently all have the same master data and technical specification. Therefore no differentiation is made between bus types. If other or different bus types were to be used, the algorithms would have to be adapted.
- **Data format:** The scripts are tailored to the given data formats (date, time, degrees of longitude and latitude etc.). To process the data, the same data format is required. It is also necessary that the scope and level of detail of the data input are the same. Otherwise the scripts have to be adjusted.
- **Bus routes:** Currently, algorithms can only identify the predefined routes. For differentiation beyond this, the methodology must be either expanded or even developed from scratch.
- **Review period:** The current scripts explicitly examine the observation period of one year. In order to obtain evaluations over other time periods, their adjustment is necessary.

3.4 Concept for the implementation of load management in the bus depot (FHG)

In addition to the charging processes at the Connewitzer Kreuz, the bus depot with its depot chargers offers big potential for implementing intelligent charging. The long idle time of the buses at night offers a high degree of flexibility. The depot's charging stations are connected to a charging station backend system that controls charging operations. This currently does not consider external signals. In the following, an architecture and an approach are described to explain how these can be considered for the charging processes in the future. The corresponding architectural design is shown in Figure 10.

Figure 10 shows the three main components und functionalities to implement the load balanced charging in the bus depot:

- The **CS-BE** (charging station backend) is shown on the left side. It is the described system the depot's charging stations are connected to. Control the charging transactions and provides a frontend to manage the charging stations. Furthermore, it stores the master data of the buses and charging stations and is able to consider the buses' needs due to disposition and schedule.

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- The **VPP data platform** is shown on the right side and aggregates the data that (local) energy producers, consumers and grid elements provide. In Figure 10 three buildings, one PV module, one battery and the power grid are connected to the VPP data platform. The VPP data platform is able to generate predictions (e.g. price or emission) and provides these predictions for several use cases. For example, the VPP data platform predicts a provision of a lot of energy via the photovoltaic module.
- The **optimization algorithm** is shown in the middle and is connected to both, charging station backend and VPP data platform. It is able to aggregate the relevant input data and determine (optimum) charging schedules for the buses in the depot, based on the predictions provided by the VPP data platform and the disposition schedule of LVB. The optimization algorithm sends the charging schedules to the charging station backend, that in turn controls the charging processes and charging loads.

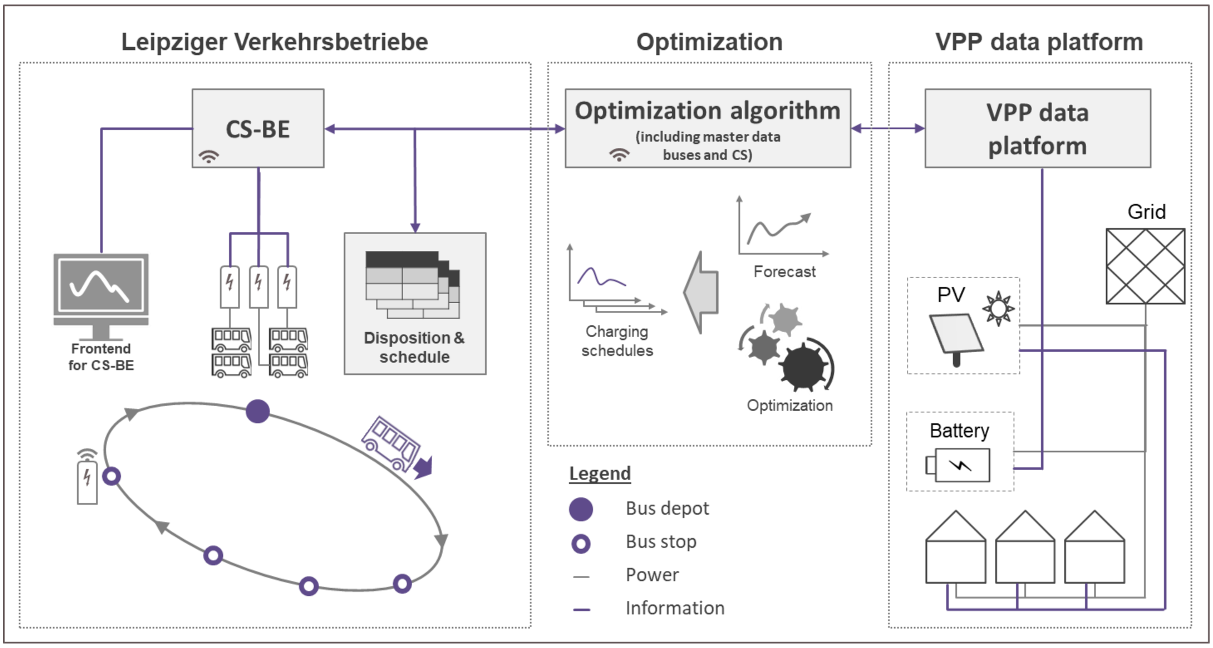

Figure 10: Load management in the bus depot (Source: FHG)

Depending on the functionality of the components there are two options of communication:

1) The optimization algorithm is merely a data consumer and the data flow is unidirectional. The signals generated by the VPP data platform are considered for optimization.
2) Data flow is bidirectional and signals are given by both systems, optimization algorithm and VPP data platform. Market mechanisms could be implemented and the allocation becomes more efficient, since the VPP considers optimizations results.

To implement such a load management system, all three listed components would either have to be further developed or rewritten. At present, there are no necessary functionalities. In addition, the necessary data, interfaces and algorithms would first have to be developed conceptually. Therefore, it is highly unlikely that this system will be implemented soon. However, in the future, forecast-based load management and system integration of the systems could provide efficient use of locally generated electricity and contribute to grid stability.

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4 BI-DIRECTIONAL CHARGING FOR MICRO GRID STABILISATION (CEN, SEE)

The Baumwollspinnerei in Leipzig is a historic site dating back to the late 18th century (see Figure 11). Up until the 1990s, cotton was still processed at this site. The site of almost 30,000m² consists of several brick buildings and halls, which have distinct architectural characteristics depending on their use at the time (cotton storage, processing hall, training building, etc.). CENERO Energy GmbH serves the site as an energy supplier and service provider. In this jurisdiction, CENERO participates in the SPARCs project and supervises all measures carried out on the Baumwollspinnerei demo district. Within the framework of SPARCs, the two largest buildings on the site, Hall 14 and Hall 18, are being equipped with future-oriented technologies. A bidirectional charging station with a technically compatible BMWi3 prototype was installed in the immediate vicinity of Hall 18 accordingly. The challenge here is to combine the volatile energy flows of a bidirectional charging station with existing local infrastructure. Together with a digital load and charging management, the grid is to be supported by additional storage capacity represented by the battery of a bidirectional electric car, e.g. by coping with peak loads of electricity demand with electricity from the car battery.

Figure 11: View of the Spinnerei block (Source: CEN)

4.1 Task description (CEN, SEE)

In this task, we demonstrate the use of bidirectional charging to stabilise the microgrid by integrating the e-mobility platform and its integral charging optimisation. In addition to installing the technical components, an intelligent and digital charge management was implemented. Furthermore, algorithms for charging optimisation are being extended and evaluated to enable the grid-serving bidirectional charging of electric vehicle fleets. The goal of the task is to demonstrate bidirectional charging to stabilise a microgrid based on load and supply data without limiting the comfort of mobility.

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The scope of application of the task is shown in the following figure:

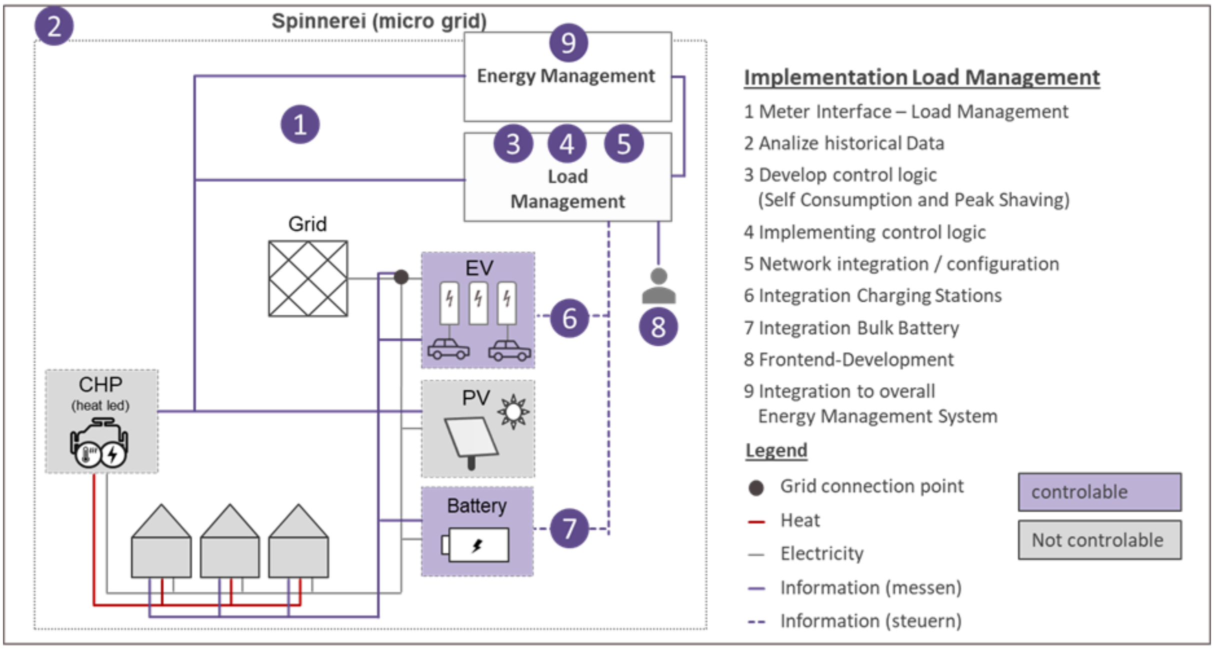

Figure 12: Architectural design to implement bidirectional charging (Source: CEN)

4.2 Implementation and demonstration (CEN, SEE)

The system consisting of an electric car and a wallbox, both capable of bidirectional flows, is installed on site and connected to a digital load management system that controls the energy flows according to supply and demand and the frequency of the grid. This allows scenarios such as discharging the vehicle to stabilise the grid, should local electrical load peaks occur. In addition, the car can be used as a temporary storage facility during times of surplus power generation on site. Demand-oriented use of the car for everyday mobility is achieved via the control hierarchy of the digital charging management, which ensures a minimum battery level in all scenarios. The charging station and the bidirectional vehicle are shown in Figure 13.

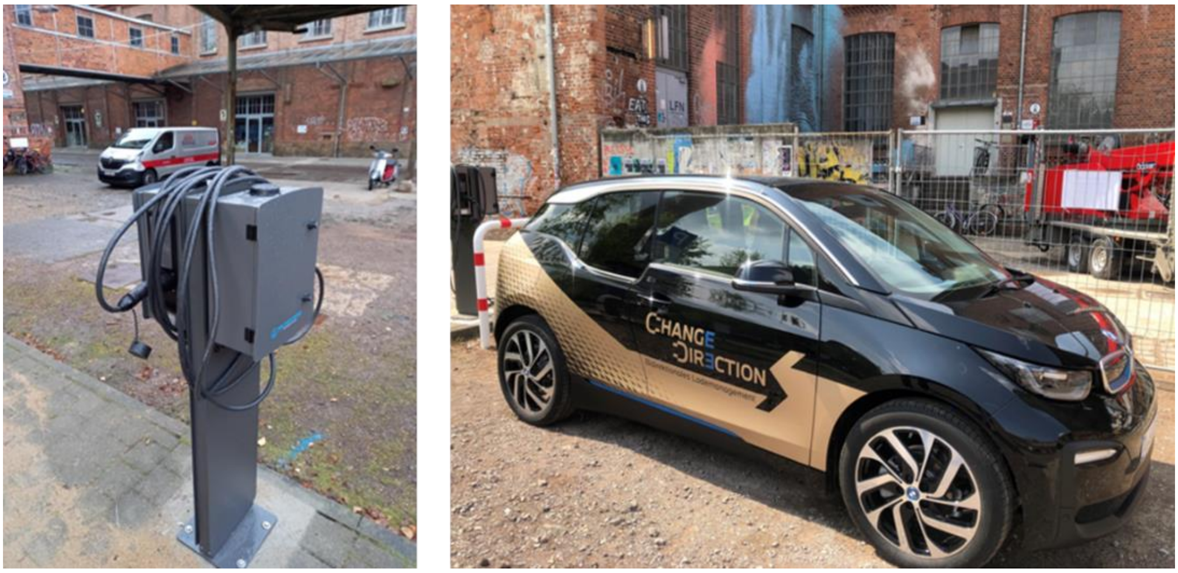

Figure 13: Charging station and BMWi3 (Source: CEN)

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4.3 Impact (CEN, SEE)

At this point in time, the impact of the BDC concept can still be considered fairly insignificant. However, progress lies in the development of important technical foundations. The potential of bidirectional charging lies in the scalability of the concept. The high initial investment in a digital load management system for the implementation of the scenarios can be expanded to include additional charging points in the future. The addition of additional bidirectional capacities leads to significant advantages for grid operation. However, for this, the load management must be included and adapted accordingly to ensure a sensible interconnection of the area network and additional electric vehicles. Furthermore, the legal framework, regulations and billing concepts are not yet very advanced in Europe. We expect that projects like this will have a positive impact in this respect and help to clarify and establish these issues. We hope that it will also further promote and encourage the development and production of bi-directional EVs and their compatible wallboxes, so that this concept can be expanded in the future.

4.4 Replication potential of demonstrated solutions (CEN, SEE)

Once a digital load management system is installed on a site, there is a high potential for the expansion of a bidirectional charging concept on site, as a foundation of knowledge on the local infrastructure and the specific features for implementation has already been developed. Replication to other locations requires a detailed analysis of the local conditions and possible application scenarios. Therefore, it is difficult to make a general statement about the potential for replication. However, since electricity storage systems have significant relevance for grid stability in increasingly complex grid structures consisting of volatile generators and consumers, it can be assumed that the introduction of temporary storage capacities through bidirectional EVs can be considered in a variety of grid structures. For possible application scenarios, however, it ultimately makes a big difference whether bidirectional charging is implemented in the context of a company fleet or in a private household.

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5 Conclusions (ALL)

5.1 Summary of achievements (LSW, CEN, FHG)

Within work package 4.4, several topics and demonstrations were implemented. First the developments regarding E-bus integration were presented. The possibility of reducing the charging power at Connewitzer Kreuz was examined. However, after consulting with Leipziger Verkehrsbetriebe, the charging power could not be reduced due to operations restrictions. Furthermore, a concept for the implementation of an integrated charging and load management system for intelligent charging of electric buses was described.

The approach to implement load-balanced fleet management was described. The corresponding developments help improve the Leipzig charging infrastructure by upgrading it to intelligent charging and enable future use cases through it. The developments enable grid-resilient charging, allowing the implementation of new business models for electric mobility.

Regarding the implementations on the Baumwollspinnerei, an important milestone was the initial roll-out of the bidirectional charging concept. As a result of the site analysis and implementation of a digital charging and load management system required for this, bidirectional charging options can be expanded or installed more efficiently both at the Baumwollspinnerei and at other CENERO sites. The expansion of e-mobility as an integral part of the German mobility turnaround will also further promote the possibilities for upscaling bidirectional concepts.

5.2 Impacts (LSW, CEN, FHG)

In regard to the Leipziger App and charging infrastructure, we have experienced a substantial increase in charging station utilization and positive feedback on the app. LSW is able to build value added services on top of the intelligent charging infrastructure. For instance, the new CMS allows charging protocols and remuneration of public charging point and LSW-managed wallboxes in private homes to be handled the same way. This allows a wide-spread integration of e-mobility users in the city’s mobility ecosystem.

One of the biggest challenges was to find a European vehicle manufacturer that offers EVs with bidirectional compatibility. Many vehicles are already technically equipped for such use cases, but the vehicle software must be compatible with the charging station in order for the two components to be able to communicate. Since bidirectional charging is still in the beginning of its development in Europe, the range of corresponding concepts was very limited at the outset of the project, and research and coordination with possible concept partners was extremely time-consuming. In the end, however, the system consisting of a KOSTAL wallbox and a BMWi3 was realised successfully.

5.3 Other conclusions and lessons learnt (LSW, CEN, FHG)

Especially the implementations and developments on the Baumwollspinnerei demo site offer other conclusions and lessons learnt. The implementation of a local bidirectional EV charging concept in Germany faces several challenges. Firstly, the lack of infrastructure for bidirectional charging makes it difficult for EV owners to find charging stations that support it. Secondly, the cost of retrofitting existing charging stations and installing new ones can be high, which may discourage some operators from making the switch to bidirectional charging. Third, the

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grid infrastructure in some regions may not be suitable for bidirectional charging, which can result in reliability and stability problems.

Additionally, the legal framework for bidirectional charging in Germany is still in its early stages, and there are currently no clear regulations regarding the use of EVs as mobile energy storage devices. This can create confusion and uncertainty among operators and consumers, which can hinder the growth of the bidirectional charging market.

Furthermore, the compatibility of different charging systems and devices can also be a challenge, as some EVs may not be able to use bidirectional charging stations due to compatibility issues. Finally, consumer education and awareness about the benefits and potential drawbacks of bidirectional charging are essential for its widespread adoption, as many people are still unfamiliar with this concept.

Despite these challenges, the implementation of a local bidirectional EV charging concept in Germany holds significant potential for improving energy efficiency, reducing carbon emissions, and enabling more widespread use of EVs. With the right policies and investments, it is possible to overcome these challenges and make bidirectional charging a reality in Germany.

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