project eLISA-BW: intelligent control of electric charging infrastructure in Baden-Württemberg

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Abstract

As the ramp-up of e-mobility progresses additional challenges arise. One is the challenge to provide enough charging infrastructure with sufficient power and energy. This is also a challenge for the power grid, which has to supply the charging infrastructure. Additional investments seem to be necessary to expand the power grid. One possibility to avoid additional costs is to introduce an intelligent load management, that prevents overloading of the power grid. In the project eLISA-BW an intelligent charging management will be implemented in a municipal car park in Karlsruhe. The intelligent charging management therefore uses different data to identify the available power from the power grid and also the need of the electric vehicles. The project focuses on the car fleet of the regional council which is the main user of the charging infrastructure. This paper wants to introduce this project and also show some results from the evaluation of the fleet data and also give an overview on the technical issues.

1 Motivation and Introduction

In the recent political discussions, the transport sector moves into the focus of the environmental protection politics. According to the climate protection report [1], the CO2 equivalents has risen compared to the levels in 1990. Therefore, this sector offers a high potential to give a contribution on the reduction of the CO2 emissions. The German government aims to reduce the CO2 emissions on the transport sector by 40 to 42 % until 2030, which is determined in the climate protection plan 2050 [2]. To achieve the goal of sustainable mobility it seems inevitable to support the further ramp up of the E-Mobility.

The project eLISA-BW, which is described in the following pages is realized in Karlsruhe, in the south west of Germany. **Figure 1** shows on the left side the growth in stock for vehicles with electric engine, through the last years in the city of Karlsruhe and also the district of Karlsruhe, that surrounds the city. The stock is composed of mostly hybrid electrical vehicles (HEV), Plug-In-Hybrids (PHEV) and battery electric vehicles (BEV). On the right side particular the growth of BEVs is shown for the recent years. For both diagrams the total number of vehicles is published at the 1st January for each year according to the Kraftfahrt-Bundesamt [3]. It is quite obvious, that there is a disproportionate growth for electric vehicles in that region. Assuming polynomial growth (degree 2) this will yield to a total number of more than 2.500 BEVs in the city of Karlsruhe and district of Karlsruhe each. The project eLISA-BW has a scheduled duration from July 2019 to September 2021. During this term the absolute number of BEVs therefore would increase by the factor of 3.4. This will also increase the need for charging infrastructure and also for charging energy and power, which will have effects on the power grid.

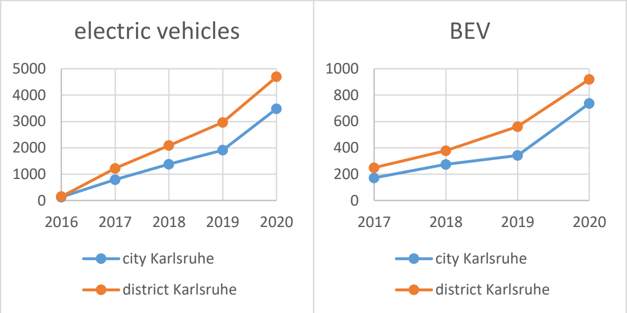

Figure 1: Number of battery electric cars in Karlsruhe from 2017 to 2020 [3]

New challenges arise, as the BEV users intend to use their vehicles at any time they need it and therefore, it has to be charged till the beginning of a journey. If many vehicles are plugged in at the same time, a high charging power is requested which could overload the local power grid. One solution to meet the requirements of the vehicle users is to extend the local power grid by adding more "copper". This would yield to higher infrastructure costs. Another solution that avoid these costs is the integration of an intelligent charging management, which distributes the charging power appropriately. In that way, all vehicles are charged sufficiently till the beginning of the next journey. Furthermore, it is prevented that the available grid power is not exceeded. For this reason, the project eLISA-BW was initiated, which will be introduced in the next pages.

2 The project eLISA-BW

The project eLISA-BW was initiated by the Center for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW), the German Aerospace Center (DLR) and the parking operator Parkraumgesellschaft Baden-Württemberg (PBW). The acronym eLISA-BW stands for "elektrische Ladeinfrastruktur steuern und anbinden in Baden-Württemberg", which could be translated to intelligent control and connectin of electric charging infrastructure in Baden-Württemberg.

The intention of the project was to solve a real problem: In an existing parking garage more charging points should be installed without overloading the local power grid and without curtailing the maximum possible charging power. Therefore, the introduction of intelligent charging management was favoured by using different data sources. Another scope of the project was the dissemination of the experiences from the project and the results. Therefore, a workshop should be organised and at the end of the project a guideline for parking area operators should be written.

The scheduled timeline is from July 2019 to September 2021. Besides the ZSW and the DLR also the PBW, the region council of Karlsruhe (RPK), the Baden-Württemberg State Office of Property and Construction (VuB), AVAT and Siemens take part in the project. The project was funded by the Baden-Württemberg Ministry of the Environment, Climate Protection and the Energy Sector in the funding program INPUT.

The use case for the project is located in the center of Karlsruhe. The parking garage Waldhornstraße of the PBW is opened 24 hours daily for the public with 222 parking slots. The whole parking area is in the basement level. The RPK uses this parking garage for their fleet. Before the project started there have been 3 charging stations with 6 charging points in total in the parking garage. Theoretically each charging point has a charging power of 22 kW. As the RPK intends to electrify their fleet, the number of charging points has to be increased by 8 additional points. The crucial factor is the grid connection point, which is limited to roundabout 154 kW. Besides the charging points also all other consumers of the parking garage like lighting and operating equipment are supplied by this grid connection point. Instead of installing more "copper" the idea behind the project was to implement an intelligent load management.

In **Figure 2** the structure of the project is shown. There are three phases of the project: First the analysis of the local characteristics and the development of the concept and also the installation of the measurement concept. Second the launch and the testing of the system and third the validation and optimisation. Based on the validation data from the measurements the concept should be optimised two times during the project.

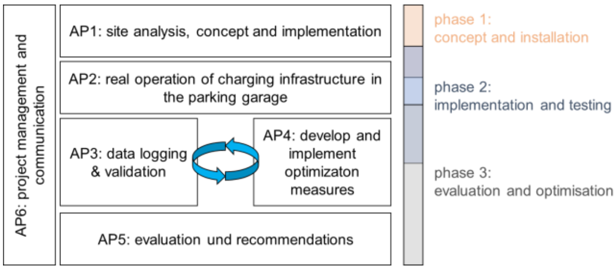

Figure 2: working schedule of the project eLISA-BW

3 Evaluation of the vehicle fleet

When the project started, the fleet of the regional council Karlsruhe comprised twelve vehicles, which can be differentiated by the drive technology. In addition to seven diesel vehicles, four PHEVs and one full BEV are used. To expand the data basis for the BEVs three more vehicles, which were used before the project started, are considered as well.

First of all, the number of round trips of every single vehicle is evaluated. A round trip means the cycle of a vehicle, which starts in the parking garage and ends there. Based on the evaluation of the vehicle logbooks, **Figure 3** presents the number of round trips of every single vehicle. Besides Diesel 7, BEV 1, 2 and 3 the vehicles were in operation between 11/2018 to 10/2019.

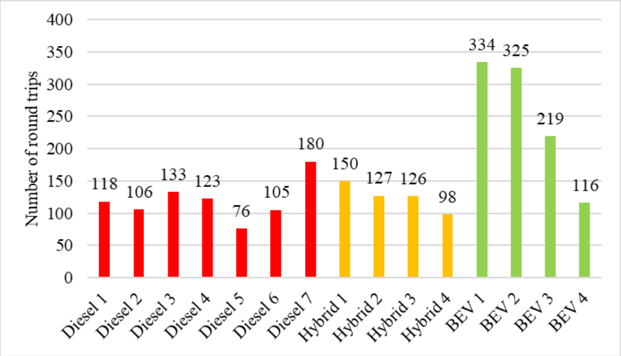

Figure 3: Number of round trips single vehicles according to the data set

In the group of diesel vehicles number 3 was used for the most round-trips and 5 for the fewest. The hybrid vehicles show a descending behaviour whereas Hybrid 1 covered 150 and Hybrid 98 round trips. The number of round trips for the BEVs seems quite high compared to the other vehicle groups. As mentioned before this can be explained by the varying operation time, only BEV 4 was driven within the one-year period. It comes to a comparable number of 116 round trips, which exactly correspond to the average, if the excluded vehicles aren't considered.

Summarising for the on-going evaluation the data of 2.336 round-trips are available.

Based on the definiton of round-trips the average driving distances were determined, which are illustrated in **Figure 4.** The overall average driving distance for the single vehicles is 159 km, marked with the black line. All diesel vehicles are above the average value, with a range from 165 km (Diesel 4) to 282 km (Diesel7). The group of the PHEVs is divided Hybrid 1 and 2 are below the average value and Hybrid 2 and 4 above. With 222 km Hybrid 4 shows the highest average driving distance.

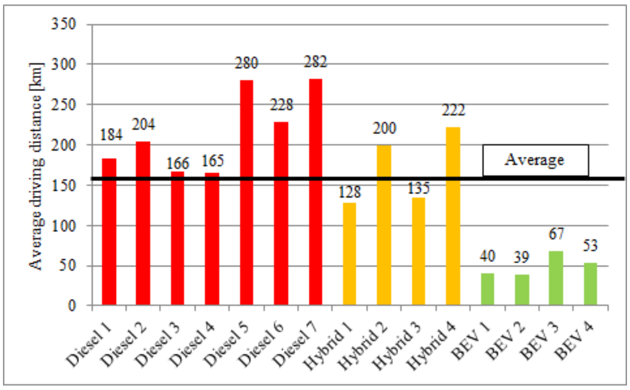

Figure 4: Average driving distance of single vehicles

It is obvious that all BEVs are clearly below the average value. The largest deviation with a factor of 4 is given by BEV 2. In general, it can be suggested that the BEVs were mainly used for round-trips with shorter driving distances. From this a sustainable behaviour from the user can be assumed. Furthermore, it can be noted that there is still potential for the future to increase the average driving distances, because presently available BEVs have a much greater range.

For the development of an intelligent charging system two import factors are the presence and absence time of the vehicles. The bar chart in **Figure 5** visualizes the average round-trip and parking time for every vehicle.

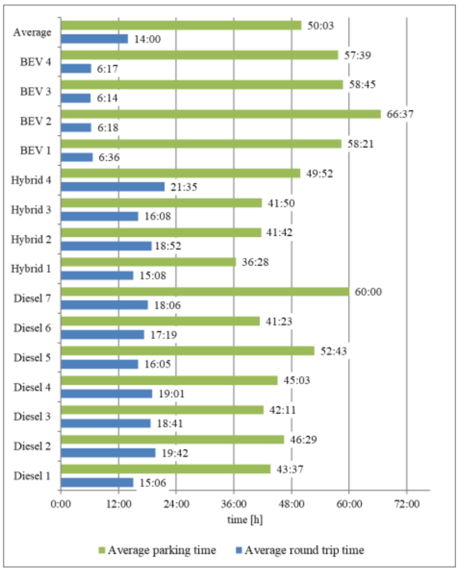

Figure 5: Comparison between average parking and round-trip time

In general, it is striking that the average parking time is much longer. There is a simple explanation for this, the vehicle fleet is primary used on weekdays and on the weekends the vehicles stay in the parking garage. Considering the average round-trip time, it is conspicuous that apart from the BEVs the absence time for the diesel and PHEVs is longer than an ordinary working day. It can be assumed that the vehicles sometimes are booked for longer time periods and didn't return from the round-trips at the end of a working day. Summarising the average ratio between the round-trip and parking time is nearly 3.5. The lowest factor is given by Hybrid 2 with 2.2 and the highest by BEV 2 with 10.5, which is three times above the average.

3.1.1 Electrification potential of the fleet

The main objective of this chapter is to identify the electrification potential of the existing fleet. Especially how many of the diesel and hybrid vehicles could be replaced by BEVs. The key requirement is that the users don't have to change their behavior in the handling of the vehicles. The restrictions should be as small as possible.

To evaluate the electrification potential three reference vehicles, based on the current state of the art are introduced. To represent the compact class the Nissan Leaf e^{+} and the new VW ID 3 were selected. The third vehicle in the category of sport utility vehicles (SUV) is the Audi e-tron. Table 1 shows the most significant technical features of the reference vehicles.

Technical Data	**ID.3**	**Leaf e**	**e-tron**
Battery capacity [kWh]	58	62	71
Electric range [km]	408 (WLTP)	385 (WLTP)	312 (WLTP)
Electric consumption [kWh/100km]	≈15 (WLTP)	≈18.5 (WLTP)	≈23.75 (WLTP)
Max. AC charging power [kW]	11	6.6	11

Table 1: Technical features of the reference vehicles

The technical informations are all taken from the manufactures data sheets. It can be expected that the consumption in real-life traffic is somewhat higher and therefore the total range lower. For the further investigations the manufactures data are sufficient, since no other data is available.

To find out which vehicles could be replaced, the driving distances were analyzed more precisely. For a better data quality round-trips with a disproportionate absence time and related driving distance were filtered out. Afterwards for both vehicle groups diesel and the PHEVs the quartiles of the driving distances were calculated. This resulted in the two boxplots presented in **Figure 6**.

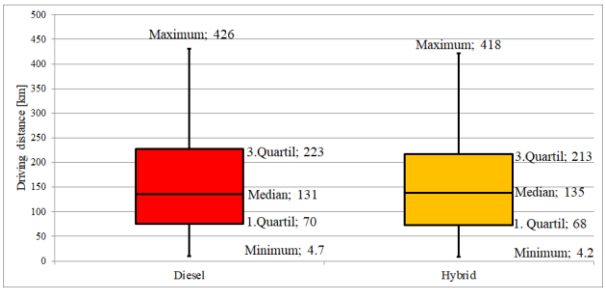

Figure 6: Driving distance quartiles of Diesel and Hybrid vehicles

The first thing you can notice is that both boxplots are almost identical. Excluding the median of the PHEVs the other static values are slightly lower compared with the diesel boxplot. The biggest difference of 10 km is between the third quartile values. This leads to the finding that for both vehicle groups the same driving profiles were performed by the users.

In the next step it is necessary to compare the ranges of the reference vehicles from Table 1 with the boxplot values. Starting with the maximum, none of the reference vehicles would be able to cover the needed distance without recharging. From the third quartile downwards, all reference vehicles can meet the required driving distances for both vehicle groups, which means a coverage of 75 % of the round-trips.

Following for both vehicle groups it was determined how many of the round-trips are non-coverable by the reference vehicles. Therefore, the interval between the maximum range and the calculated maximum from the boxplots was considered. In **Figure 7** the bar chart represents the obtained results.

Only a small proportion (<1 %) of round-trips for both vehicle groups cannot be covered by the reference vehicles ID 3 and Nissan Leaf e^{+}. This means that both vehicles would be a suitable alternative to replace the diesel vehicles and the PHEVs. The situation for the e-tron is a slightly different. Because of the higher energy consumption, the percentage of non-coverable round-trips increases. For the diesel vehicles 4.67 % and for the PHEVs 6.16 % cannot be carried out. According to this the e-tron isn't unsuitable, with the opportunity of recharging this reference vehicle is also a good alternative.

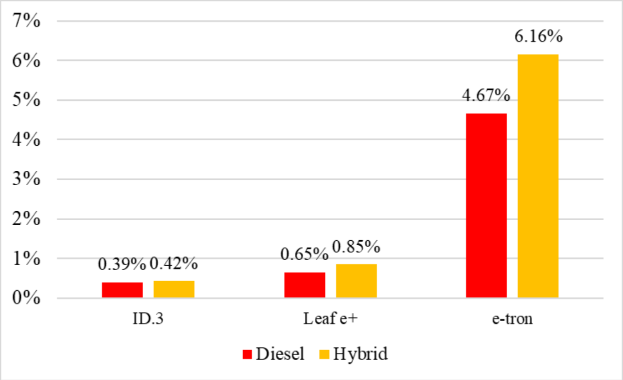

Figure 7: Percentage of round trips that cannot be performed with the reference vehicles

3.1.2 Potential of the charging infrastructure

The car park itself provides 14 charging points for electric vehicles. Each of them is technically able to supply 22 kW charging power. Due to the limitations of the local power grid, it is not possible to provide 22 kW for every charging point at the same time. Therefore, the charging points are currently limited up to 11 kW or less. The fleet of the RPK is not the only user of the charging points. Part of the charging points is opened to the public also.

In the past chapter, it became clear, that most of the journeys are also feasible with electric cars. Considering this it seems obvious, that most of the diesel cars and PHEVs should be replaced by electric cars. The arising question is how the charging infrastructure can cope with the expansion of the electric car fleet. Therefore, the journeys recently conducted by diesel cars and PHEVs have been evaluated regarding their recharging power needs. As shown in **Figure 4** these journeys are typically longer. The needed charging energy is accordingly also higher.

In the first step, all these journeys have been evaluated regarding their distances and the subsequent parking period. This period from the beginning of a journey to the end of the following parking period is called service-to-service (S2S)-period. Considering the average energy consumption of the already introduced reference vehicles the energy value for every journey was calculated, which would be necessary to regain the energy level before starting the journey. The immediately following parking period of each journey was determined and assuming a continuous charging, the average charging power was calculated for each combination of a journey and following parking period.

In the case, the determined charging power exceeds the maximum charging power of the vehicle, the charging power was limited to the maximum possible value. Average values covering all respective S2S-periods were calculated for every car and each reference vehicle, which are shown in **Figure 8**. To get an idea of the range of the individual charging power values, the range is also illustrated with black bars. The amount of the S2S-periods, within the charging power, would exceed the maximum charging power of the vehicle is shown in **Figure 9**.

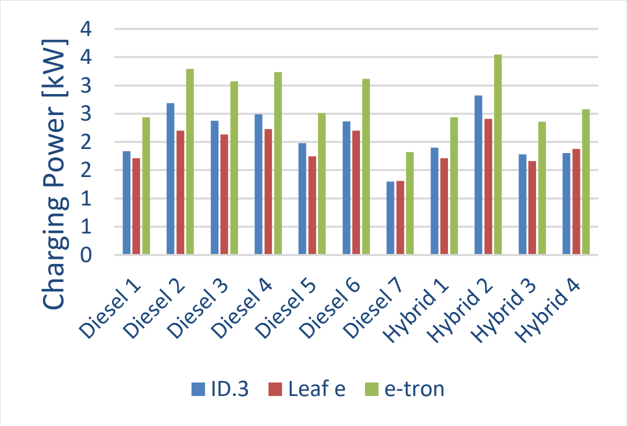

Figure 8: Calculated average charging power of the vehicles

It gets evident that the average charging power is a function of the charging power abilities and also of the average energy consumption of the cars. The Leaf e+ has a lower charging power of 6,6 kW and therefore the percentage of S2S-periods with not fulfilling the recharging criterion is higher than with the other cars. On the other hand, the average charging power is lower. The ID.3 and the e-tron both have a maximum charging power of 11 kW. The main difference is the higher average energy consumption of the e-tron. This results in a higher number of S2S-periods that are not sufficient for recharging and a higher average charging power.

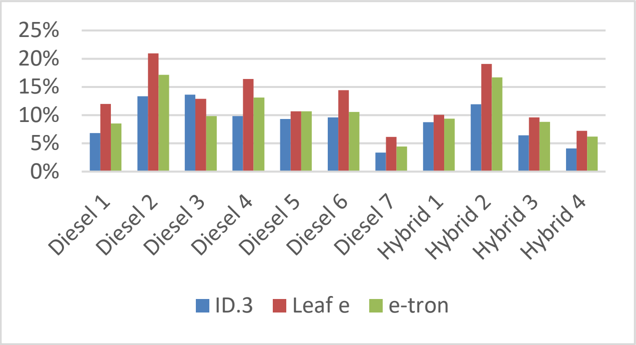

Figure 9: Determined percentage of S2S periods that cannot be recharged

This evaluation illustrates the correlation between the average energy consumption of a vehicle and its effect on the occupancy of the charging infrastructure. Hence, it is beneficial to compose fleets with energy-efficient vehicles when having limitations at the charging infrastructure. It became also evident, that with a higher maximum charging power it is possible to reduce the number of trips, that can´t start with a recharged vehicle. This is important when having a great number of long round trips with a short corresponding parking time.

This evaluation does not imply the effects of simultaneity of the charging processes. When having all charging processes starting together in the same time period the charging infrastructure will be overloaded. In order to prevent these situations, it is either possible to spread the charging events serially or to reduce the level of charging power when having enough parking time for all vehicles. During the project such a system will be developed and it will be evaluated afterwards how efficient this system was. In a first step, this evaluation in this paper indicates, that the fleets vehicles could also be replaced by electric vehicles without overloading the charging infrastructure.

4 Intelligent load management

In order for the vehicles that are possible to be converted to an electric drive, according to the study, a corresponding charging infrastructure is also necessary for their operation. Even before the project was planned, it became clear that the existing charging infrastructure consisting of 3 charging stations with 2 charging points of 22 kW each would not be sufficient for the additional demand from the RPK vehicles. An additional need for charging infrastructure amounting to 8 charging points was identified by the PBW.

Simulations by ZSW showed that both static and dynamic charging management would not be sufficient for satisfactory operation. The reason for this is that with both a first-come-first-server method and equally distributed charging, the vehicles that urgently need a charge due to an upcoming booking charge not necessarily first.

For this reason, it was decided to develop an intelligent charging management system as part of the funding project. The system should use the information on current charging processes, current performance measurement data, and booking data to determine performance targets for the charging processes.

So that current power measurements could be used by the charging management, power meters were installed in the corresponding distribution cabinets. They measure the grid connection point, the old and the new charging stations as well as another large consumer (**Figure 10** red line). Furthermore, a connection has been established between the RPK fleet booking program and the charging management system to transfer booking data. This connection (**Figure 10** blue line) allows the charging management system to use booking times and required mileage.

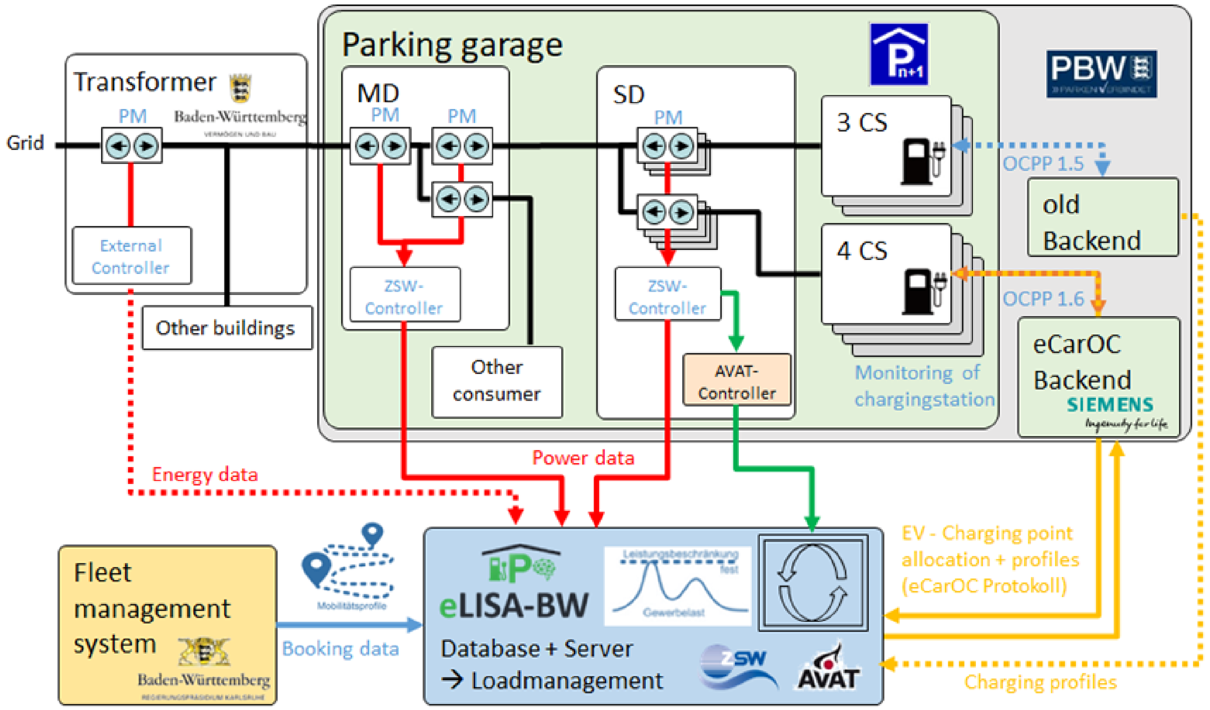

Figure 10: eLISA-BW Concept for intelligent charging management
(MD - Main distribution, SD - Sub distribution, CS - charging station, PM - Power Measurement)

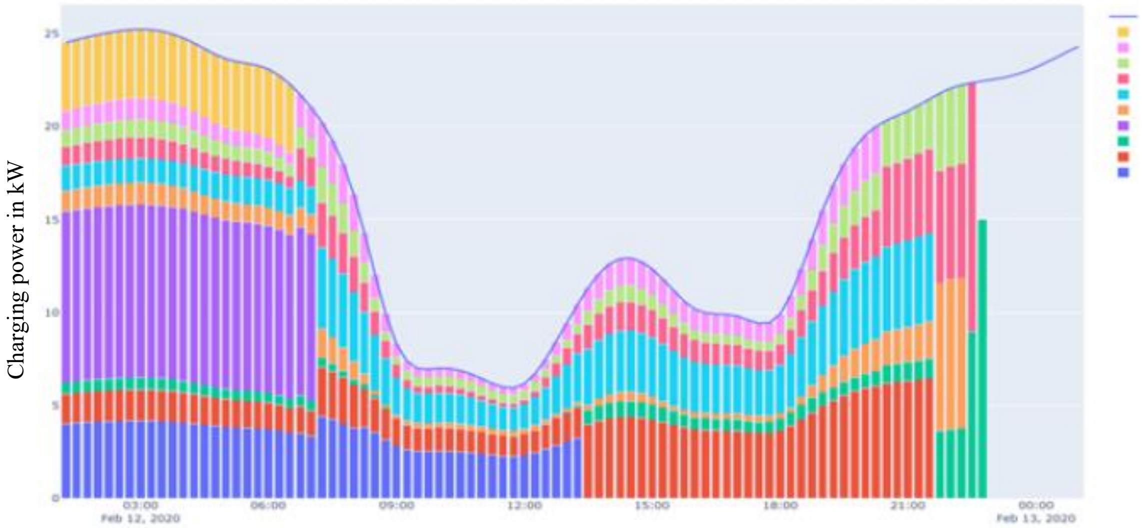

Figure 11: Simulated charging plan with variable power limitation (blue line) and individual plans for 10 charging points for a 24 h horizon

Also, a connection (**Figure 10** yellow line) was established between the charging management and the backend, as the charging infrastructure only receives control signals from the backend.

The charging management system uses this data to generate a charging plan for a time horizon of 24 hours. A simulated charging plan is shown in **Figure 11**. It can be seen from the simulated charging plan that a higher charging power is made available at charging points where vehicles are charging that are needed next. At other charging points, however, the charging power is reduced. The functionality of the charging management system will be verified during a 6-month test.

5 Literature

[1] Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, „Klimaschutzbericht 2019", online available at Klimaschutzbericht 2019 (bmu.de), access on 01/2021

[2] Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, „Klimaschutzplan 2050", online available at Klimaschutzplan 2050 - Klimaschutzpolitische Grundsätze und Ziele der Bundesregierung (bmu.de), access on 01/2021

[3] Federal Motor Transport Authority (KBA), „Der Fahrzeugbestand im Überblick", online available at Kraftfahrt-Bundesamt - Produkte der Statistik - Bestand nach Zulassungsbezirken (FZ 1) (kba.de), access on 02/2021