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Selected Results of the Scientific Accompanying Research of the E-Mobility Model Region "e-pendler in niederösterreich" (AUSTRIA)

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Abstract

This paper describes selected results of the scientific accompanying research of the e-mobility model region "e-pendler in niederösterreich" which is a co-financed model region of the Climate and Energy Fund in Austria and the province of Lower Austria. The purpose of the project is to evaluate the usability of electric vehicles for commuters in Austria. For this, a group of thirty-seven participants were analyzed. With the derived charging profiles and traffic analysis important statements for future problems are possible.
The research is divided into three parts. First of all, the commuters' behavior is considered. As second part specific charging profiles are analyzed and the effect of the charging power on the switching point (change from constant current phase to constant voltage phase) is shown. At last the impact of the EV's on the distribution grid is investigated.

Keywords: Demonstration, Energy Consumption, Fleet, Market, Simulation

1 Introduction

The Austrian Climate and Energy Fund has been promoting and supporting the development and spread of electric vehicles (EV) in Austria since 2008 with numerous tools, including the "EV model regions" program. Over the years, seven model regions of electric mobility were launched in Austria in order to develop new mobility models and test the everyday usability of electric vehicles using renewable energy sources. The result of these efforts is a comprehensive body of technical, organizational and economic know-how. The location of the EV model regions in Austria are shown in Figure 1, they are:

- **Vorarlberg** (VLOTTE, calls 2008 and 2009)
- **Salzburg** (ElectroDrive Salzburg, call 2009)

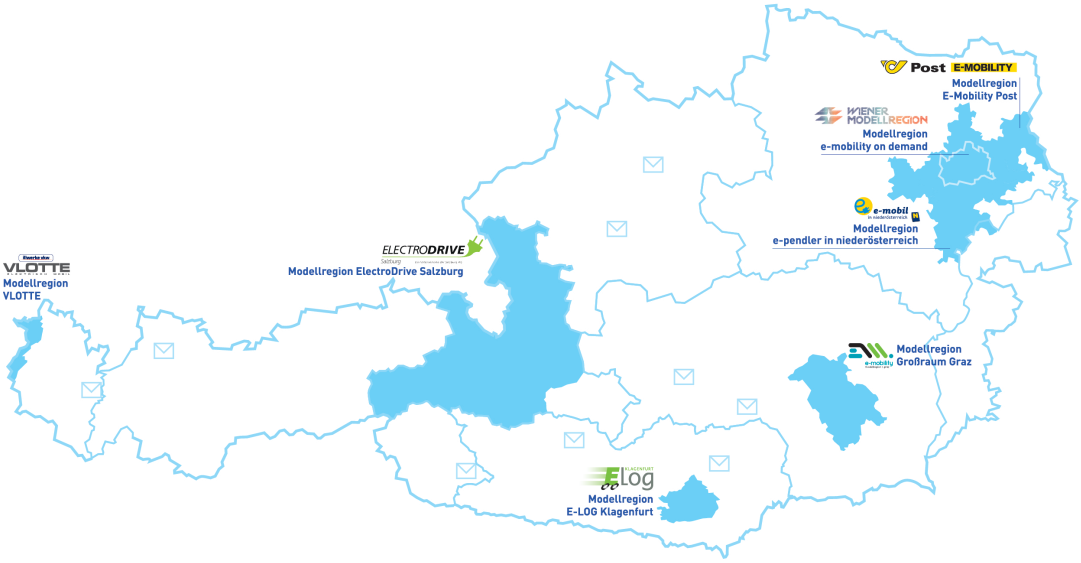


Figure 1: Location of the EV model regions in Austria [1]

- **Vienna** (e-mobility on demand, call 2010)
- **Graz** (e-mobility Graz, call 2010)
- **Lower Austria** (e-pendler in niederösterreich, call 2011)
- **Carinthia** (E-LOG Klagenfurt, call 2011)
- **Vienna** (E-Mobility Post, call 2011)

At the start of the project, every model region develops a comprehensive mobility concept with an operating company set up for this purpose. The focus is on the use of electric vehicles; the necessary charging infrastructure must be developed. 100 % of the electricity required must be provided from renewable sources and be generated in newly installed plants in the particular model region. Every model region must ensure transparency through regular monitoring of the development and accompanying research [2].

2 Project "e-pendler in niederösterreich"

The project "e-pendler in niederösterreich" is a cofinanced EV model region of the Climate and Energy Fund in Austria. Partners of this project are the utility companies (EVN AG, Wiener Netze GmbH), financial firm (Raiffeisen Leasing GmbH) as well as research institutions (Herry Consult GmbH and TU Wien). The model region includes the southern attraction zone of Vienna (federal capital of the Austrian Republic) and consists of 49 communities, with a total of 296.000 inhabitants. However, the population of this area is growing continuously and therefore the mobility demand will be growing as well. The concept of the project is based on the integration of electric vehicles into individual transport and shifting commuter traffic to public transport. In order to make the implementation as efficient as possible, all aspects of electric mobility (vehicle and components, charging station and renewable electricity supply) should come from one provider. This model project will be a valuable example particularly for rural areas close to large urban agglomerations [3].

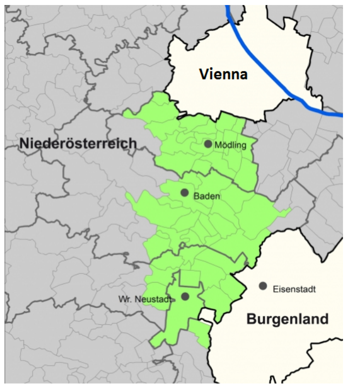


Figure 2: The model region is located south of Vienna.

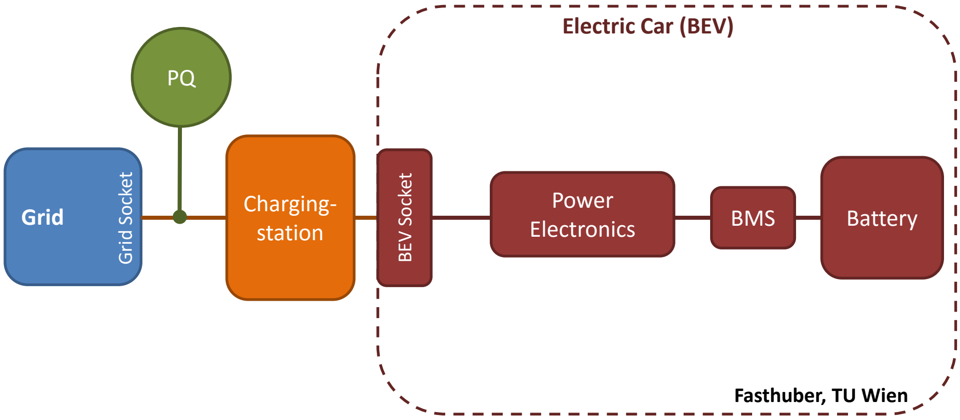


Figure 3: Location of the involved measurement elements.

The goals of the accompanying research activities can be summarized as follows:

- Analysis of consumer behavior and user acceptance for electric vehicles
- Monitoring and evaluation (technical and organizational) of the e-mobility model region
- Examination of the transport and environmental effects
- Investigation of the charging infrastructure, the charging behavior and the energy source impact

The following chapters describe the methodology and results of the accompanying research by the TU Wien relevant work packages.

3 Methods and approaches

3.1 Driving behaviors

For the evaluation, thirty-seven randomly chosen project participants were analyzed. The data were obtained with log-books over a minimum of four weeks and in addition also from the specific online platforms of the electric vehicles (EV's). With this approach it was possible to get the state of charge (SOC) of the battery, the location of the car (home, workplace, park-and-ride, leisure etc.), the mileage and the date and time of each trip start and end. So we get enough data to analyze the commuter behavior concerning charging and traffic profiles. The collected data were checked for plausibility and were then further processed with MATLAB software. For this operation an object-oriented script was written to be able to analyze as many participants as needed.

3.2 Charging profiles

Single measurements of specific car parameters have been performed to identify their charging and discharching characteristics. With these investigations and the results from the driving behaviors of the commuters it was possible to simulate the impact of EVs with a high penetration in the EV model region. Figure 3 shows the installation arrangement for our charging measurements. As you can see, the logger for the power consumption and the power quality parameters is located between the grid and the charging station (PQ). So the losses of the charging station are also included in the measurement.

3.3 Impact of EV's on the distribution grid

3.3.1 Model settlement

To calculate the impact of electric vehicles on the low voltage gird, the model settlement of the completed research project “aDSM” [4] was selected. The goal of the model settlement was to represent the overall Austrian residential structure. The synthetic low voltage (LV) grid consists of a rural and an urban area. Based on an Austrian survey, the number of buildings, the type of these buildings, the number of households per building (hh/bldg) and the number of people per household (pp/hh) are known. By defining the number of inhabitants of the settlement, all other characteristics are defined. The Number of 300 people was chosen. Therefore the load in the settlement matches typical values for a single MV/LV transformer. Figure 4 shows the compilation of the model settlement. The 300 people live in 126 households within 60 buildings. So there are 2.1 households per building, 2.4 people per household and 5.0 people per building [5].

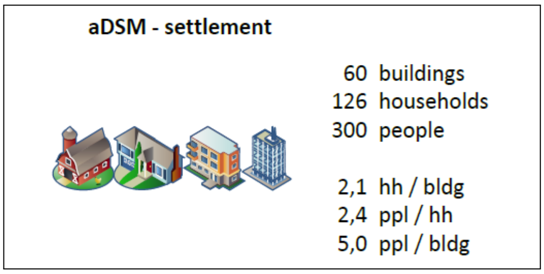


Figure 4: Austria mapped on a settlement with 300 inhabitants

3.3.2 Power grid structure of the model settlement

The aim of this step was, to build a low voltage grid for the model settlement. The typical distances between buildings are based on practical experiences. The structure of the network is determined by the parameter “load density”. At low load densities, as for example can occur in rural areas, radial networks are preferred. This network configuration consists of a series of branched lines which are supplied from a common power unit. An alternative form is the openly operated ring network. This topology is often found in areas with higher load densities (e.g. urban areas) and therefor, preferably cables are used. During normal network operation a separation point in the middle remains open. Figure 5 shows the basic structure of the model network. The model settlement represents the Austrian building and living conditions. Therefore, the different network types should also be found in the grid model. In practice, one network station will be either in a more rural or in a more urban region. So there’ll be only one of the two shown network types. For analysis reasons, in the model grid the two types are combined for one station like shown in figure 5.

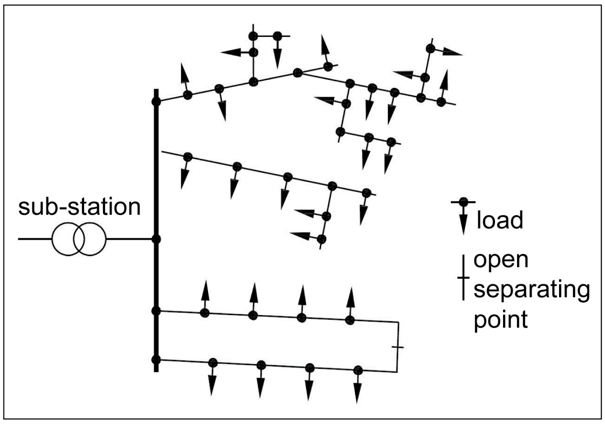


Figure 5: Grid topology - radial network (upper feeder) and open ring (lower feeder)[5]

As the scale drawing of the model village shows (see figure 6), a building configuration was found such that all requirements are met. Roads and buildings were drawn with the assumed size. In the rural area (lower right part of Figure 6) a “village arrangement” can be seen. Here occurs a mixture of relatively densely populated one-and two-family houses and small farms. In the left area, the case of a distant farm is covered. For the distribution system operating these distant farm buildings are very important.

3.3.3 Device equipment in households

Synthetic load profiles are generated by using the device equipment of households as well as the operation probabilities. As a result of the tool [6] for each device in the 126 households a synthetic annual

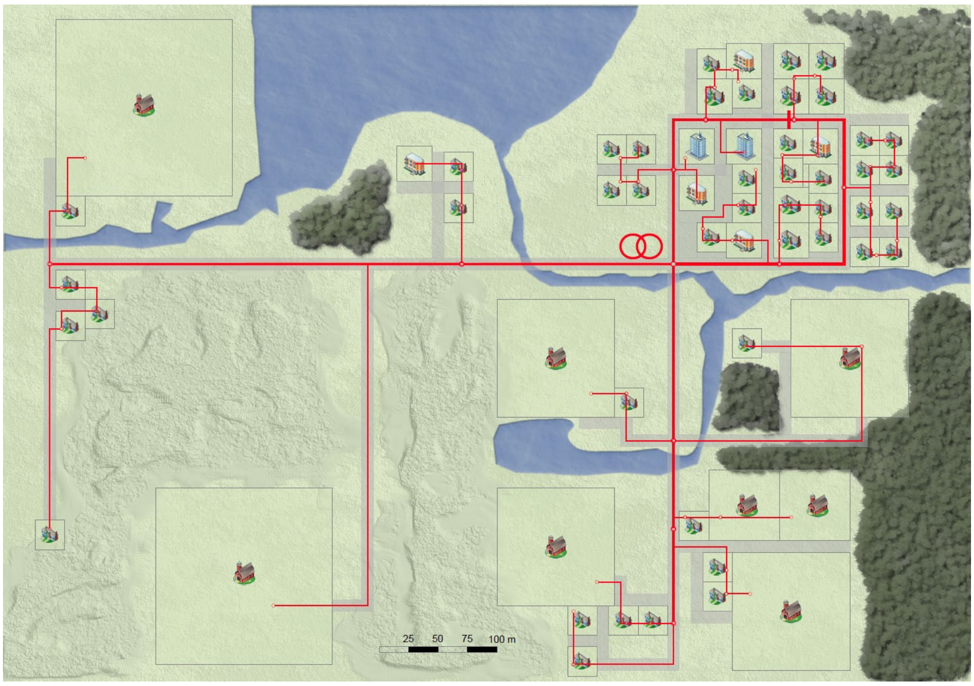


Figure 6: True-scale plan of the model settlement

load profile is available. The time resolution for this is one minute. Due to the underlying stochastic, the synthetic profiles represent the consumption characteristics of actually measured load profiles of individual households. For the entire settlement the resulting energy demand is 536 MWh/a (without electric vehicles).

3.3.4 Scenarios for the penetration of electric vehicles

For the penetration of electric vehicles, the penetration rates were defined based on the results of the study "ELEKTRA" [7]. For the level of motorization (number of cars per 1,000 inhabitants), the values were determined according to the publication in [8]. For comparison a reference scenario without electric vehicles was created. The number of electric cars in the model settlement, which results from the number of people, the degree of penetration and the number of vehicles can be found in table 1.

Table 1: Scenarios for the penetration of electric vehicles

	Penetration	Level of motorization	Number of vehicles
Reference scenario "basic"	0 %	—	0
Scenario "mid" (2030)	40.6 %	65.4 %	80
Scenario "high" (2050)	98.6 %	73.7 %	216

3.3.5 Stochastic modeling of charging profiles

With the help of data from the driving behavior analysis was possible to generate stochastic charging profiles for the electric vehicles. Based on these profiles an additional charging demand of around 140 MWh/a (scenario "mid") or 377 MWh/a (scenario "high") is obtained for the entire settlement . For the following network simulations 216 charging profiles per scenario were generated over an entire year (taking into account the various e-vehicles of the model region). The load profiles thus represent the behavior of the private participant in the model region. One of the generated charging profiles is shown

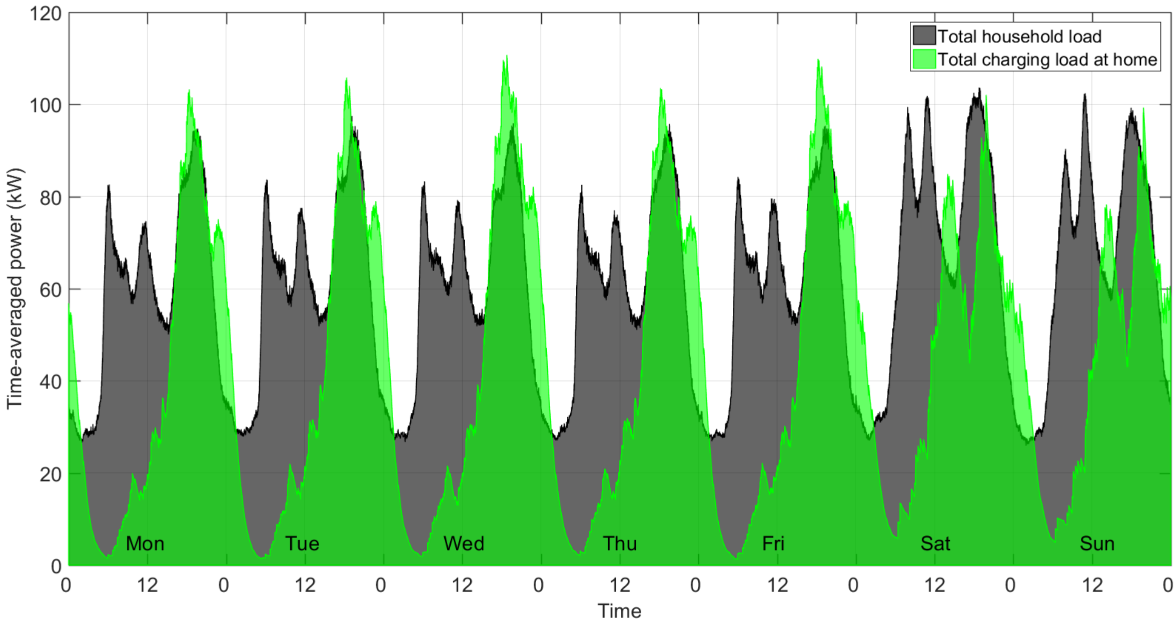


Figure 7: Averaged charging profile of stochastic generated EV loads (one week, 216 electric vehicles, charging power: $3.7\,\mathrm{kW}$ single phase, location "Home")

in figure 7. For comparison, the averaged total household load profile of the model settlement is also added.

3.3.6 Grid simulation

The previously mentioned model settlement was used for the analysis of the impact of the EV's in the low voltage grid. For the simulation the software tool NEPLAN was used. The load flow calculations were performed with 15-minute-maximum values of the loads for a calendar year (device equipment as well as electric vehicles). In addition to the three scenarios of different charging power ($3.7\,\mathrm{kW}$, $11\,\mathrm{kW}$ and $22\,\mathrm{kW}$) and the three scenarios of electric vehicle penetration ("basic", "mid" and "high") there was also varied the distribution of electric vehicles in the low voltage grid. The following two cases were studied:

"Distributed EV loads"
The electric vehicles are distributed according to the people per building and household.

"Concentrated EV loads"
The electric vehicles will be connected from the farthest point of the transformer for each line (at the end oft the power line).

4 Results and conclusions

4.1 Driving behaviors

Data source of following analysis are the mentioned thirty-seven randomly chosen project participants of the model region. One of the results is that the mean distance of a single trip is approximately 14 km and the mean distance of a daily travel (total trips of a day cumulated) is 42 km. A closer look at figure 8 shows that $90\,\%$ of the single trips a shorter than 35 km (maximum is 129 km) and $90\,\%$ of the daily trips are shorter than 93 km (maximum is 220 km). Today's electric cars have a range of about 150 to 200 km (manufacturer specifications).

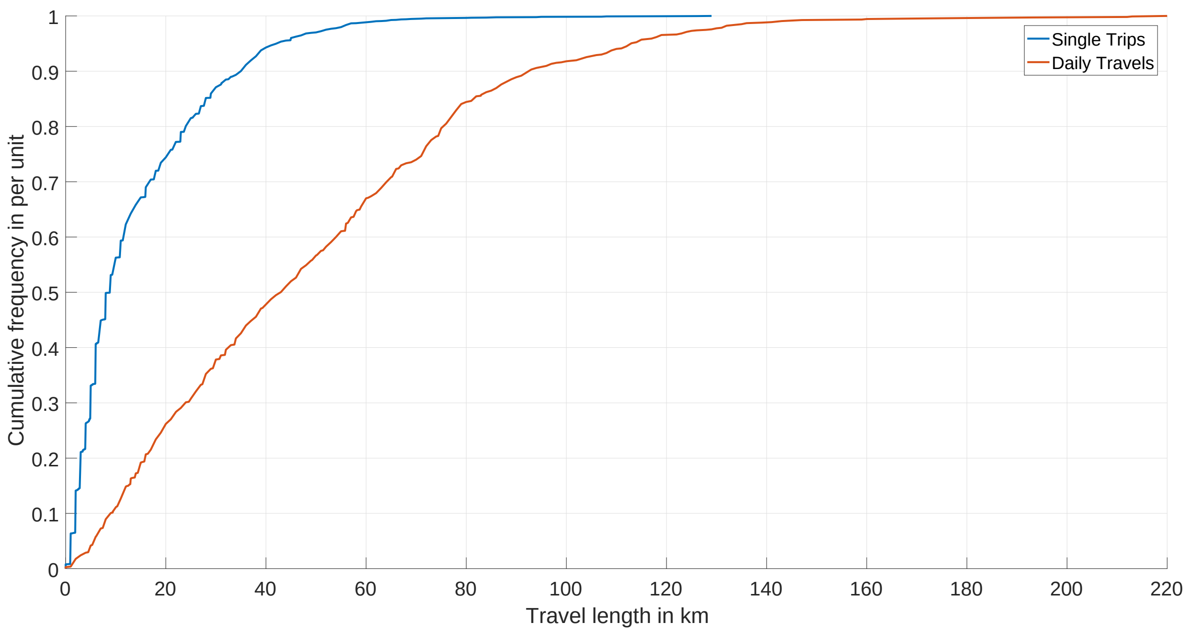
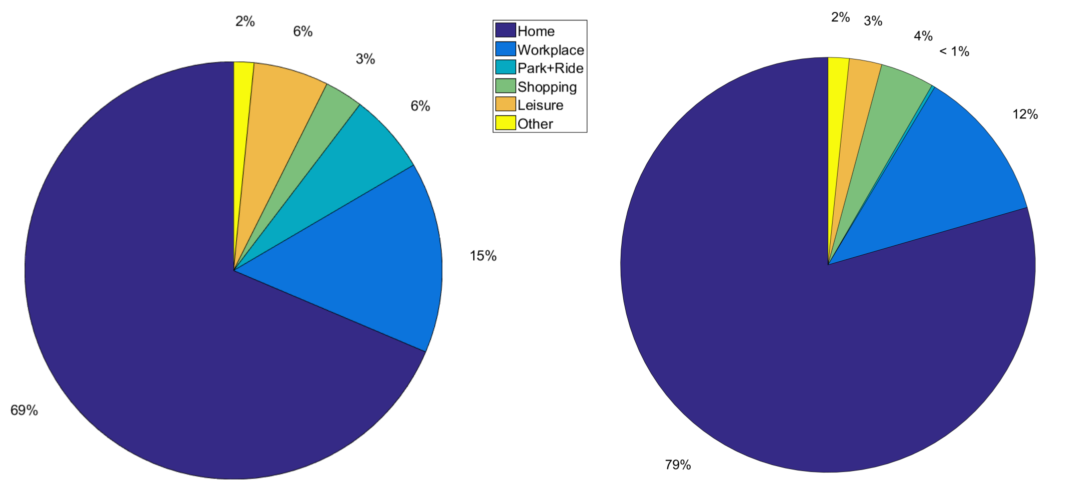


Figure 8: Cumulative frequencies of trips and daily travels over the travel length

The average consumption over all participants is about $14.15\,\mathrm{kWh}/100\mathrm{km}$ and on average, the commuters drove 2.91 trips per day. However, most of the time the vehicles are not used (only $5\,\%$ per day or $72\,\mathrm{min}$). When not in use, EV's are located about $69\,\%$ of the time at home where about three quarters of the charging processes has been started. $15\,\%$ of the parking locations are at work and $12\,\%$ loaded there. A further $6\,\%$ of the parking period was performed at Park & Ride or train stations. However, less than one percent was charging at a Park & Ride or train station. The remaining positions were divided on shopping, leisure, and other locations (see figure 9). With this information, suitable locations for the charging infrastructure can be derived for the future.
Figure 10 shows the frequency distribution of the different locations over all days. The white area shows the probability of all commuters which drive a vehicle at this moment. The load profile of a single household in combination with the mean load profile of a single phase charged electric car causes load peaks of this household in the evening hours, which could lead to overload problems in the distribution network (see section 3.3.5 - figure 7).

4.2 Charging profiles

Today's batteries are usually charged with the so-called CCCV method. First, the cells are charged with constant current (CV). If the battery cells reach the end-of-charge voltage (switchover point), the charging mode switch to constant voltage charging and the charging power decrease exponentially. This switchover point depends on the charging power and the temperature of the battery pack. The higher the charging power the sooner the switchover point is reached (in the optimum battery temperature range of 20-40°C) [9].
One result of the measurements is illustrated in figure 11. It shows a comparison of four full charging procedures with different charging powers at different battery temperatures with a Nissan Leaf (nominal capacity $24\,\mathrm{kWh}$). With a charging power of $22\,\mathrm{kW}$ and a "warm" battery (vehicle has been run empty and then it was loaded immediately) the switchover point was reached later than the "cold" one (vehicle was parked over the night and loaded in the morning hours). Furthermore you can see that the switchover point with a $50\,\mathrm{kW}$ ("warm") charging power compared with the $22\,\mathrm{kW}$ charging power is clearly set down in relation to the SOC. When charging with $50\,\mathrm{kW}$ charging power ("cold") you would now ex-



(a) Share of the parking duration based on different locations

(b) Distribution of locations where a charging process has been started

Figure 9: Pie-Charts of the parking and charging locations.

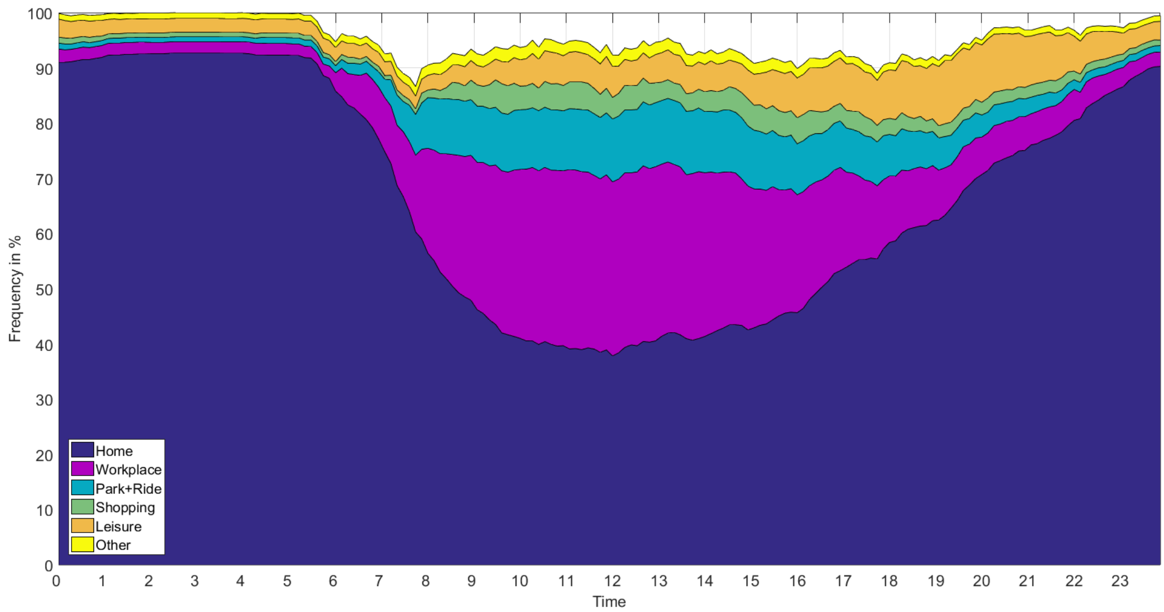


Figure 10: Frequency distribution of the different locations over all days

Table 2: Measurement data of the Nissan Leaf (24 kWh) full charges

	22 kW ”cold”	22 kW ”warm”	50 kW ”cold”	50 kW ”warm”
Date	2015.12.17	2015.12.16	2015.12.16	2015.12.15
Time-Start	09:33	14:17	09:15	14:59
Time-End	11:15	16:00	10:54	16:07
SOC-Start	6.9 % (13.6 %)	– (12.9 %)	– (15.1 %)	1.3 % (15.6 %)
SOC-End	100 % (91.2 %)	100 % (88.9 %)	100 % (94.20 %)	100 % (95.6 %)
Temp.-Start	5.4 °C (11.8 °C)	6.9 °C (28 °C)	5.3 °C (13.3 °C)	5.0 °C (30.5 °C)
Temp.-End	5.5 °C (19.6 °C)	7.5 °C (30.4 °C)	6.8 °C (22.3 °C)	4.3 °C (38.6 °C)
Switching Point	64.3 % SOC	74.3 % SOC	56.9 % SOC	47.0 % SOC

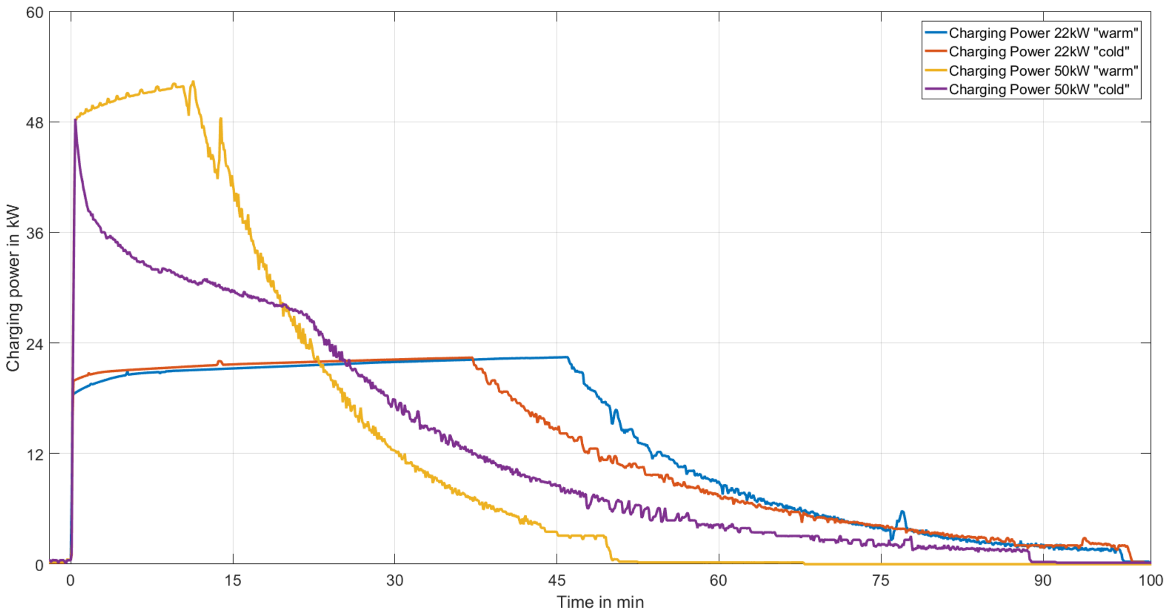


Figure 11: Comparison of various full charging profiles with a Nissan Leaf (different charging power and battery temperatures)

pect the switchover point also earlier. However, the battery management system (BMS) is limiting the charging power because of the relative low temperatures. The discharge is determined by the specific electrochemical cell kinetics which is manifested by an increased internal resistance of the cell and a reduced discharge capacity. When the allowable maximum charging current is exceeded, this can lead to deposition of metallic lithium on the negative electrode. Through this ”Lithium-plating” may cause permanent damage to the battery, which is why a constant and reliable control of temperature and loading performance by the BMS is necessary [10]. Table 2 gives an overview of the measurement data. The values in brackets have been identified with a software application in combination with a OBD2-Scanner.

4.3 Impact of EV's on the distribution grid

In figure 12, the line utilization based on the thermal current limit is shown for various scenarios. In addition, two red boundary lines are drawn. The first at $100\,\%$ and the second at $70\,\%$ utilization. The lower limit applies at the power lines of the openly operated ring, as it can be found in cities. The upper limit applies in rural area. As you can see, the first problems accour in the grid if the charging power is at least $11\,\mathrm{kW}$. If the position of the charging points are concentrated (for example at the end of the power line) then the limits are violated much earlier.

In figure 13, the node voltage in percentage of the nominal voltage ($U_N = 400\,\mathrm{V}$) is shown for the network node with the lowest voltage value (rural area). If the charging power is at least $11\,\mathrm{kW}$, the first nodes are violating the $88\,\%$ limit. The diagram shows again the clear problem with high EV concentrations on individual network nodes.

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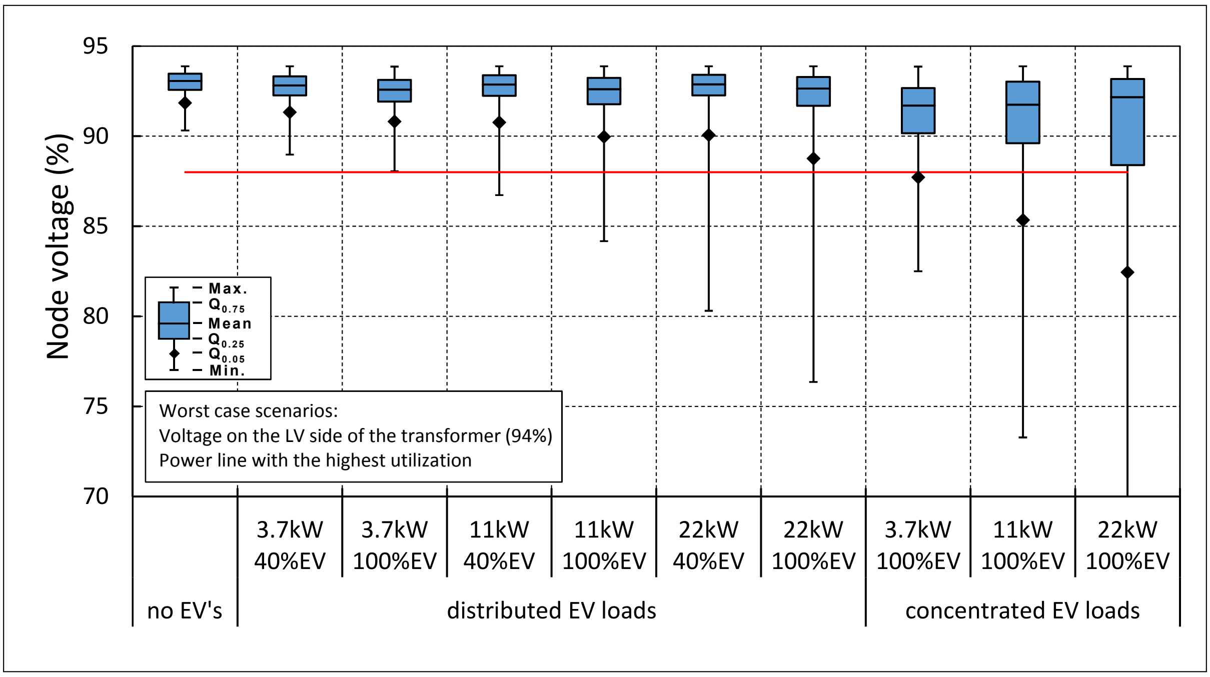

Figure 12: Power line utilization at different scenarios

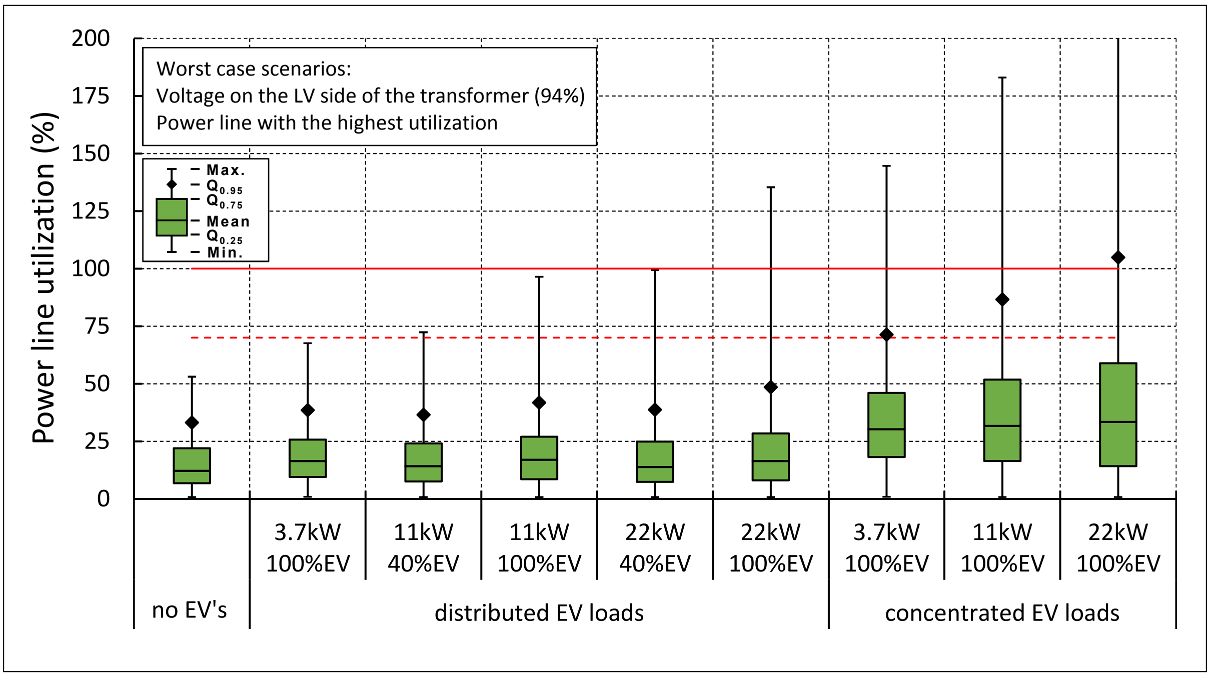

Figure 13: Node voltage at different scenarios

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