Data-based Analysis of the Utilization of Publicly Promoted Charging Infrastructure

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***Abstract*—Zero emission mobility such as electromobility is a key to reduce the CO_2 emissions of the transport sector. In order to increase the acceptance and demand of electromobility a reliable, publicly accessible charging infrastructure is needed. For planning issues as well as for investors the degree of utilization of charging points is important. Yet there is no consistent definition for the degree of utilization of a charging point in literature. This paper presents a set of indicators to measure the utilization of a charging point. Furthermore, these indicators are calculated with data from charging points that are funded by the Federal Program Charging Infrastructure. The analysis compares the indicators and discusses the significance and usability of these indicators. In conclusion, it is important to take several indicators into account as there is no single indicator that provides an overall impression of the utilization of a charging point.**

Keywords—Charging Infrastructure, E-mobility, utilization, indicators, data analysis

I. Introduction

According to the German government's Climate Action Plan 2050 the transport sector must lower its greenhouse gas emissions by 40 - 42% (compared to 1990) by 2030. Still, 20% of the emitted greenhouse gases originate from the transport sector [1]. Promoting electromobility with its electricity supply being generated from renewable energy sources is one measure to achieve this goal.

To increase the acceptance and demand of electromobility a reliable, publicly accessible charging infrastructure is needed. The target number of the national policy framework is 36,000 normal charging points[1] and 7,000 fast charging points[2] by 2020. Moreover, the government coalition claims a target of 100,000 charging points by 2020.

To achieve these goals funding measures by several ministries have been introduced. The funding measures are widely spread, from buyer's premium for the purchase of electric vehicles to the promotion of R&D projects and investment grants for charging infrastructure. The biggest promotion scheme for public charging infrastructure was adopted by the German Ministry of Transport and Digital Infrastructure.

A. *Funding program for electric vehicle charging infrastructure in Germany*

The Federal Program Charging Infrastructure has been initiated in 2017 and will run until 2020 [2]. It provides investment grants for hardware, grid connection or enhancement and installation of publicly accessible charging infrastructure. A budget of €300 million is available, thereof €100 million for AC charging stations and €200 million for DC charging stations.

The Federal Program defines the general framework for investment grants which are awarded only within recurring open calls for application. The calls include the particular definition of the levels of funding, the standard requirements and additional technical requirements. So far four calls have been published in March 2017, September 2017, December 2018 and August 2019. Possible applicants are both natural and legal persons, e.g. private investors or municipalities. As yet over 16,000 charging points, approx. 14.400 normal and 2.300 fast charging points have been promoted.

Beneficiaries must ensure an operational life of at least 6 years after the initial operation. During that time beneficiaries must provide biannual reports to the NOW GmbH twice a year by February 1 and August 1.

B. *Strategic planning of charging infrastructure built-up*

The Federal Program has been launched to accelerate and steer the built-up of public charging stations in order to establish a reliable and nationwide infrastructure in Germany which meets the demand and needs of its users. The target is enabling drivers to travel any distance in Germany without major detours and allocate a sufficient amount of recharging points at locations with high traffic volume of electric vehicles (EVs).

To facilitate the strategic roll-out of charging infrastructure taking especially white spots and heavily frequented traffic areas into account the Ministry of Transport and Digital Infrastructure commissioned the development of a strategic planning tool ("StandortTOOL") that is coordinated by NOW GmbH.

For planning issues, the current utilization of a charging station is crucial. Based on the current utilization the need for additional charging points can be identified. Additionally, utilization is an important key figure for investors to estimate their potential return on investment for charging stations. The profitability of charging infrastructure is key to achieve a market-driven built-up.

In order to assess the utilization of a charging point suitable indicators are needed. In literature there are different approaches: Helmus et al. [3] introduced 13 key performance indicators (KPI) based on a two-step approach with stakeholder involvement. These KPI follow a more general approach and are not limited to measure the utilization of a charging station. Nevertheless, two indicators from [3] were adopted into our own considerations of utilization indicators: "Capacity utilization", described as the percentage of time a

[1] Maximum charging power less or equal 22 kW
[2] Maximum charging power greater than 22 kW

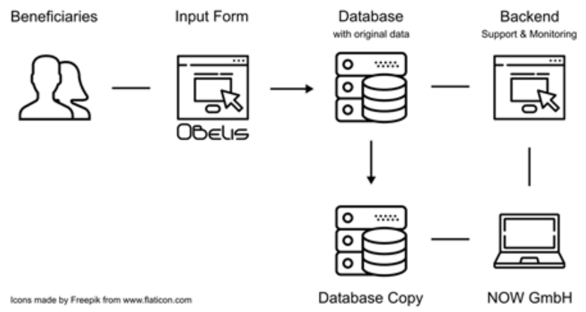


Fig. 1 Structure of data collection

charging station is occupied, and the ratio of energy charged to the potential amount of chargeable energy.

Maase et al. [4] continued the work of [3] and developed five KPIs that are applicable to charging data. Besides the average occupancy, the number of unique users per month, the sums of the number of sessions, the charging or connection time and the charged energy were listed and integrated in their assessment tool.

However, in the literature there is no consistent definition for utilization of a charging station. To contribute to the debate on the measurement of utilization we defined a set of indicators to measure the utilization of a charging station and calculated them with data from charging stations funded by the Federal Program. This paper discusses the significance and robustness of these key values.

II. MATERIALS AND METHODS

The data used in this paper come from the biannual reports submitted by the beneficiaries of the Federal Program. They consist of two parts: Basic data and operation data. The basic data need to be entered once and only updated on change. The operational data need to be reported twice a year. The reports are submitted via the online platform OBELIS. OBELIS, introduced on February 1, 2019, is a web application with forms for basic data input and a file-upload section for submitting operational data.

The basic dataset covers 49 items in seven categories such as initial operation, location, accessibility, technical features, grid connection, expenses and funding amount and pricing model. The operation dataset comprises information on the charging sessions such as start time, end time and the amount of charged energy and the ID of the used charging point.

The original data submitted via OBELIS is saved in a database. Periodically, a copy of the database is transferred to the NOW GmbH and stored locally. The database copy is used for the ongoing analyses. For maintenance and support issues, that require changes of original data, a backend is used. Fig. 1 shows the described structure.

By the end of June 2019, 609 accounts were registered at OBELIS. 2,096 charging stations, 4,344 charging points and 178,461 charging sessions have been recorded.

A. *Data cleansing*

Not all submitted charging session are feasible to be used for analysis. In order to get consistent results, the data is cleansed beforehand. Only complete datasets are used having start time, end time and the amount of charged energy per session. Table 1 summarizes the criteria for data cleansing.

TABLE 1 DATA CLEANSING BOUNDARIES

Dimension	Boundaries
Duration	$1\,minute \leq \Delta t \geq 72\ hours$
Charged energy per session	$100\ Wh < E_{session} > 110{,}000\ Wh$
Overlapping	$t_{i,begin} > t_{i-1,end}$
Average charging power per session	$\frac{E_{session}}{\Delta t} \geq P_{max}$

Charging sessions enter the analysis if their duration is greater than one minute and last no longer than 72 hours. The 72 hours correspond to the timeframe covering e.g. a weekend with the charging starting on Friday and ending on Monday at the same time of day. Charging sessions with both start and end time at midnight are excluded as well as it seems to be very unlikely this being the true start and end time. We assume the time information got lost during at least one step of the data transmission as the logged sessions might have been handled and unintentionally modified by the charge point operator, the backend operator or the beneficiary as it had gone through several steps of data processing.

Moreover, the charged energy must be greater than 100 Wh and less than 110 kWh. The upper border is chosen referring to the biggest known battery in an electric vehicle with a usable capacity of 100 kWh. The sessions of one charging point must not overlap according to the definition of charging points. Additionally, sessions with an average charging power exceeding the maximum power of the charging point are excluded.

B. *Measuring utilization of a charging station*

To measure the utilization of a charging station different key figures can be taken into account. Table 2 shows the information that form the basis for the key values and can be derived from the database with no further calculations and external values.

Table 3 summarizes the parameters and key figures that are described in detail in the following. Besides the symbol, the description, and the unit of the key figure it is specified weather the key figure refers to a charging station (CS), a charging point (CP) or a charging session (Session).

TABLE 2 INFORMATION FROM DATABASE

Symbol	Description	Refers to	Unit
t_{begin}	Start timestamp of each session	Session	-
t_{end}	End timestamp of each session	Session	-
$E_{session}$	Energy charged per session	Session	Wh
P_{max}	Maximum power of charging point	CP	kW
t_{io}	Date of initial operation	CS	-
t_a	Date of granting access to public	CS	-
$t_{rp,start}$	Start reporting period	CS	-
$t_{rp,end}$	Deadline reporting period	CS	-

TABLE 3 CALCULATED FIGURES

Symbol	Description	Refers to	Unit
d_r	Reporting days	CS	d
d_u	Days in use	CS	d
n	Total number of sessions	CS	-
$\bar{n}_{dr}$	Average sessions per reporting day	CS	-
$\bar{n}_{du}$	Average sessions per day in use	CS	-
r_{du}	Day-based utilization rate	CS	%
E_{total}	Total amount of energy charged	CS	kWh
E_{max}	Maximum potential amount of chargeable energy	CP	kWh
$\bar{E}_{dr}$	Average energy charged per reporting day	CS	kWh
$\bar{E}_{du}$	Average energy charged per day in use	CS	kWh
r_E	Energy-based utilization rate	CS	%
t_{total}	Sum charging time	CP	h
r_t	Time-based utilization rate	CP	%
$\bar{P}_{session}$	Average power per session	CP	kW
$\bar{\bar{P}}_{total}$	Mean average power	CP	kW
r_p	Power-based utilization rate	CP	%

The total number of sessions n during the reporting period can be derived from the database without further calculations. In order to make the key figure comparable to other periods of time the average number of sessions per reporting day is calculated. The number of reporting days d_r is calculated as shown in (1).

$$d_r = (t_{rp,end} - \max(t_{rp,start}, t_{io}, t_a)) + 1 \qquad (1)$$

The end of the time period is set to the deadline of the reporting period $t_{rp,end}$. The start point is either the date of the charging station becoming accessible for the public, or – if this date is not existing in the database – the date of the initial operation is used. If the selected date is earlier than the start of the reporting period $t_{rp,start}$ the start of the reporting period marks the first counted reporting day. Consequently, the average number of sessions per reporting day are calculated as shown in (2)

$$\bar{n}_{dr} = \frac{n}{d_r} \qquad (2)$$

As electromobility is in an early stage of adoption it is likely that there are many days with no charging session at all. These days will decrease the average number of sessions per reporting day. Therefore, as another utilization indicator we calculate the average number of charging sessions per "day in use". We define "day in use" as day with at least one charging session at the charging station. The number of days in use d_u is calculated as shown in (3).

$$d_u = \sum d \mid n(d) \geq 1 \qquad (3)$$

The average number of charging sessions per day in use is calculated as in (4).

$$\bar{n}_{du} = \frac{n}{d_u} \qquad (4)$$

The day-based utilization rate can be calculated according to (5).

$$r_{du} = \frac{d_u}{d_r} \cdot 100\% \qquad (5)$$

Neither the number of charging sessions in total, nor the average number of charging sessions per reporting day or per day in use tells anything about the amount of charged energy which might differ a lot depending on the maximum power of a charging point.

Hence, the charged energy is a relevant indicator for the level of utilization. The total amount of energy charged at one charging point is calculated as described in (6). Corresponding to the number of charging sessions the average amount of energy charged per reporting day and energy charged per day in use are calculated as shown in (7) and (8).

$$E_{total} = \sum_n E_{session} \qquad (6)$$

$$\bar{E}_{dr} = \frac{E_{total}}{d_r} \qquad (7)$$

$$\bar{E}_{du} = \frac{E_{total}}{d_u} \qquad (8)$$

Furthermore, the total time a charging point is occupied by an electrical vehicle can be used as a utilization indicator and is calculated as shown in (9).

$$t_{total} = \sum_n t_{end} - t_{begin} \qquad (9)$$

In the next step in (10) the time-based utilization rate is calculated as ratio of occupancy time to the number of reporting days.

$$r_t = \frac{t_{total}}{d_r} \qquad (10)$$

The capacity factor is a common key figure to determine the utilization rate of power plants. As mentioned in [2], the capacity factor is the ratio of energy charged to the potential maximum amount of chargeable energy. Therefore, it can be considered as an energy-based utilization rate.

$$r_E = \frac{E_{total}}{E_{max}} = \frac{E_{total}}{P_{max} \cdot d_r} \qquad (11)$$

Dividing the energy charged per charging session by the duration of the charging session leads to the average power per session as shown in (12). Following (13), the mean average power per charging point can be calculated. Dividing this by the maximum power of the charging point, the power-based utilization rate can be calculated as in (14).

$$\bar{P}_{session} = \frac{E_{session}}{t_{session}} \qquad (12)$$

$$\bar{\bar{P}}_{total} = \frac{1}{n} \cdot \sum_n \bar{P}_{session} \qquad (13)$$

$$r_p = \frac{\bar{\bar{P}}_{total}}{P_{max}} \qquad (14)$$

TABLE 4 SUMMARY OF CALCULATED KEY FIGURES

	d_r	d_u	r_{du}	n	$\bar{n}_{dr}$	$\bar{n}_{du}$	E_{total}	$\bar{E}_{dr}$	$\bar{E}_{du}$	r_E	t_{total}	r_t	$\bar{\bar{P}}_{total}$	r_p
Mean	151	32	15.1%	52	0.33	1.28	587.3 kWh	3.8 kWh	14.6 kWh	0.58%	137 h	3.47%	11.2 kW	36.2%
STD	51	38	16.1%	95	0.56	0.55	1,076.5 kWh	6.4 kWh	9.5 kWh	0.83%	250 h	5.90%	10.3 kW	19.5%
Minimum	11	1	0.2%	1	0.01	1.00	0.1 kWh	0.0 kWh	0.1 kWh	0.00%	0 h	0.00%	0.0 kW	0.1%
25% (Q1)	122	5	3.5%	6	0.05	1.00	56.8 kWh	0.5 kWh	8.3 kWh	0.08%	8 h	0.27%	4.5 kW	20.8%
50% (Q2)	184	16	9.0%	19	0.14	1.10	215.2 kWh	1.6 kWh	12.7 kWh	0.26%	28 h	0.89%	7.7 kW	33.1%
75% (Q3)	184	45	21.4%	56	0.38	1.28	658.0 kWh	4.2 kWh	18.3 kWh	0.73%	128 h	3.63%	13.7 kW	48.8%
Maximum	184	182	97.1%	1,072	5.83	6.73	14,166.7 kWh	77.0 kWh	80.4 kWh	8.49%	2,096 h	51.88%	99.1 kW	99.8%

III. RESULTS AND DISCUSSION

A. *Calculating the key values*

The values for the above described key figures are calculated for the submitted data. Therefore, $t_{rp,end}$ is set to December 31, 2018 and $t_{rp,start}$ is set to July 1, 2018. For the calculation of the key values data from 2,713 charging points could be used after data cleansing. Table 4 summarizes the results.

B. *Avarage key values with time reference*

For better comparability the daily average of the number of charging sessions and the energy charged are looked at instead of the total number of charging sessions. As described above, to calculate the daily average two different time references are used.

Fig. 2 (a) shows the comparison of the average number of charging sessions per reporting day $\bar{n}_{dr}$ and per day in use $\bar{n}_{du}$. The average number of charging sessions per reporting day is considerably low with a median of 0.14 sessions. For the average number of charging sessions per day in use the median increases to 1.10 sessions, which is only slightly higher than the definition in (3) requires. A maximum of 6 charging sessions per reporting day and 7 sessions per day in use occur on average.

Fig. 2 (b) shows the comparison of the average charged energy per reporting day $\bar{E}_{dr}$ and per day in use $\bar{E}_{du}$. The median of the average charged energy per reporting day of 1.6 kWh is noticeable lower than the average charged energy per day in use with a value of 12.7 kWh. In average, a maximum of 77.0 kWh per reporting day and 80.4 kWh per day in use has been charged.

By referring to the total number of sessions or the total charged energy to the number of days in use d_u the days with no charging sessions at all are blanked out. The situation of days with charging sessions is mapped more appropriately. Therefore, the key values that refer to day in use are a good indicator for the utilization when demand has stabilized and a further state of electromobility adoption is reached.

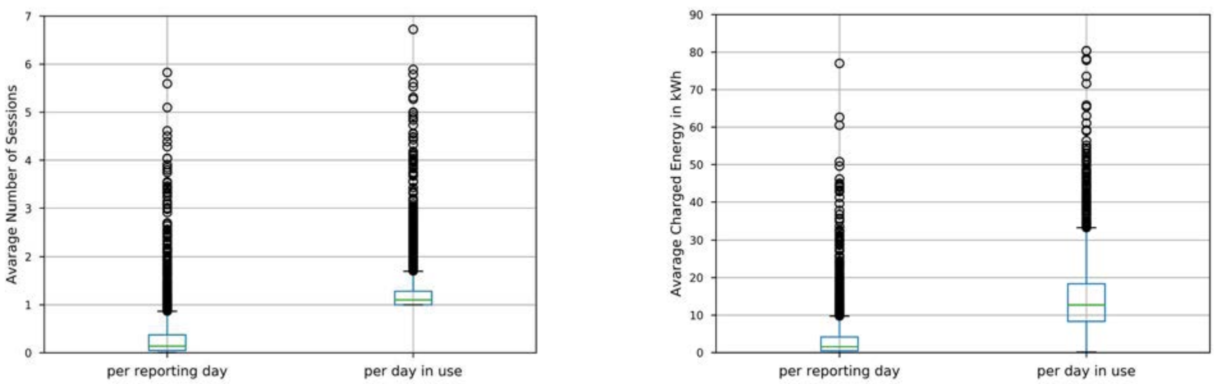
C. *Percentage key values*

Precondition for the calculation of percentage figures is the presence of a maximum value. There is no maximum value for the number of sessions per day.

The maximum value of the total charging time can be assumed as 24 hours a day. Even though, a time-based utilization rate of 100% will not be reached, as there are set-up times between charging sessions.

For the charged energy a maximum value can be calculated too. As defined in (11), the maximum potential amount of chargeable energy is calculated using the maximum power of the charging point times the maximum charging time. By using two maximum values the energy-based utilization rate is quite theoretical, since a charging point will not reach an energy-based utilization rate of 100%. This is also underlined by the results shown in Table 4. The values of the energy-based utilization rate are considerably low with a median of 0.26% and a maximum of 8.49%.

Instead of the charged energy and the energy-based utilization rate, in the following the average charging power and the power-based utilization rate are considered. The maximum value therefore is the maximum power of the charging point, which is a technical feature of the charging station and not a calculated value.



(a) (b)

Fig. 2 Comparison between average number of sessions (a) and average charged energy (b) per reporting day and per day in use

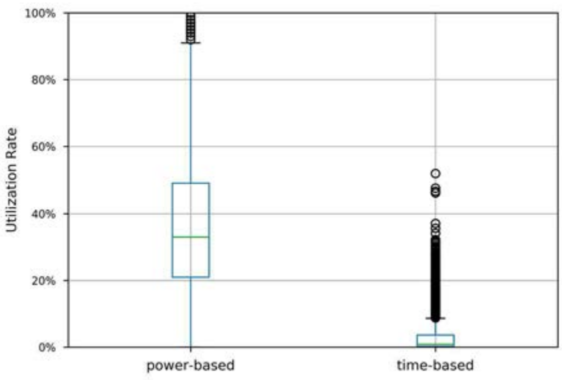


Fig. 3 Boxplot of time-based and power-based utilization rate

Fig. 3 shows boxplots for both the time-based and the power-based utilization rate. The time-based utilization rate, too, has a considerably low median of 0.87%. However, a maximum of 51.88% is reached. In contrast, the power-based utilization rate has a median of 33.1% and a maximum of 99.8% is reached.

The time-based utilization rate is a good indicator for high occupancy time whereas the power-based utilization rate is an indicator for the average efficiency of the charging sessions itself. Together, both values give a good overall impression of the utilization of a charge point. A visualization option is shown in Fig. 4 in which the time-based utilization rate is plotted over the power-based utilization rate. Exemplarily, the datapoints for the 500 charging points with the most charging sessions are depicted.

The plot can be divided into four segments with "low" and "high" for both utilization rates. The positioning in one of these segments allows an individual interpretation of the utilization. In a best-case scenario, both utilization rates are "high". In this case the overall utilization is good and there could be need for additional charging points. If one of the utilization rates is "low" and the other is "high", further analyses are needed. Table 5 shows possible interpretations and considerable actions that could be taken.

A plot such as shown in Fig. 4 can be drawn for a single charging point or for all charging points of one charging station. Moreover, the datapoints from charging points that are located in a certain region or that are operated by the same charge point operator can be illustrated and analyzed together.

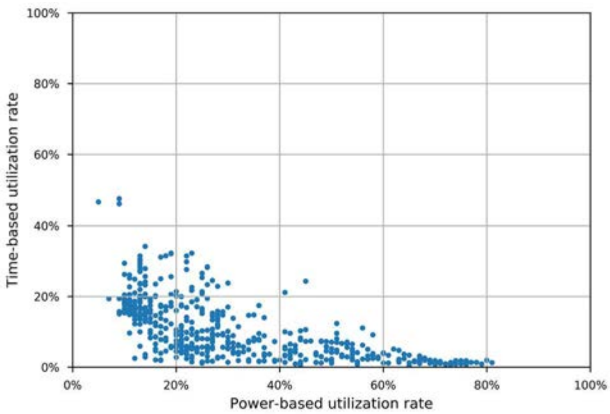


Fig. 4 Time-based over power-based utilization rate

TABLE 5 CONSIDERABLE ACTIONS ACCORDING TO TIME BASED AND POWER-BASED UTILIZATION RATE

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">r_p</td></tr>
<tr><td>"low"</td><td>"high"</td></tr>
<tr><td rowspan="2">r_t</td><td>"low"</td><td>- low total utilization</td><td>- good efficiency of charging sessions
- little number of sessions
- measures to raise awareness of the charging point could be considered</td></tr>
<tr><td>"high"</td><td>- good time-based utilization
- low efficiency of charging sessions
- limitation of charging time could be considered</td><td>- good total utilization
- expansion of the charging site could be considered</td></tr>
</table>

D. *Limits of the analysis*

All average key figures cannot reflect uneven utilization with high peak times, which is characteristic for average values. For having significant average key values, it is important to have a minimum number of charging session. This is not always the case, as electromobility is still in an early state of adoption.

The time-based utilization rate will increase if there are many multi-day charging sessions. However, multi-day charging sessions are a special use case and many charge point operators take action to avoid them such as limiting the maximum charging time.

The power-based utilization rate loses its significance for charging points with high maximum power as there are few EVs that are able to charge with more than 50 kW. Low power-based utilization rates for these charging points should not automatically be ascribed to low utilization of the charging point as the EV is the limiting factor.

For working with the number of sessions as a key figure it is important that sessions are logged correctly. Sometimes sessions are chunked into several lapses of time by the logging unit of the charging station or the backend system. This leads to very short pauses between charging sessions. Theoretically, it is possible to reassemble the lapses of time but there are other possible reasons for short pauses as there are charging stations that allow seamless transition of charging between both connectors of a charging point. A second user can pre-authenticate and the charging station will start the session automatically as soon as the first user's session is finished. This, too, leads to very short pauses between the logged charging sessions that cannot be distinguished from defective loggings.

IV. FUTURE WORK

Future research should consider the borders between "low" and "high" for both the time-based and the power-based utilization rate. Therefore, empirical values of economically viable charging points could serve as a reference.

In addition, the visualization of the time-based and power-based utilization rate as shown in Fig. 4 in combination with other introduced key figures should be enhanced to a "Utilization Scorecard" that might serve as a coherent report on the degree of utilization of a charging point.

V. Conclusion

As shown above, there is no single indicator that provides an overall impression of the utilization of a charging point. When using one key figure individually it is highly important to define precisely how it is determined, as there are various options to calculate an utilization rate. In conclusion, to receive a holistic picture of the degree of utilization of a charging point it is vital to take several key figures into account.

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