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ZERO EMISSION BUSES IN GERMANY'S PUBLIC TRANSPORT

Insights of the Accompanying Research on e-Buses for the German Federal Ministry for Digital and Transport

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Executive Summary

We present insights of the first phase of the accompanying research on electric buses (e-buses) for the the Federal Ministry for Digital and Transport (German: Bundesministerium für Digitales und Verkehr (BMDV)). We focus on the holistic evaluation of the technological and operational readiness of the deployed e-bus systems in Germany including issues such as availability, winter performance and range of e-buses in an operational environment. The basis for our investigations is data from transport operators receiving funding either from BMDV or the federal ministry for the environment (BMUV). We also take a glance on the market situation of e-buses in Germany, which has experienced substantial change during the last two years and is facing even more dramatic changes in the next four years due to regulative measures such as the CVD and the largest subsidizing initiative for e-buses in Germany so far.

Keywords: bus, research, market development, efficiency, charging

1. Introduction

The BMDV has been subsidizing buses with alternative drives for years. Since 2015, the Electric Mobility Funding Directive has promoted not only research and development projects, but also the procurement of buses and the necessary charging infrastructure for operation. In addition, BMDV also promotes the procurement of fuel cell buses via the National Innovation Program Hydrogen and Fuel Cell Technology.

The National Organization for Hydrogen and Fuel Cell Technology (NOW GmbH) is a state-run program company that coordinates and implements support programs for BMDV and advises the ministry. As part of the bus promotion, NOW GmbH coordinates all activities of BMVD.

The aim of the accompanying research is, on the one hand, the detailed analysis and evaluation of buses in use with alternative drives, including usage-specific data and taking into account the requirements for infrastructures, economic issues, operation and acceptance topics. On the other hand, a decision-making aid is to be provided in support of the transport companies or the transport authorities. This should provide assistance in the selection of the correct overall concept for electrically driven buses in the respective network.

In addition, the Federal Government has created a platform for the exchange of information and experience between transport companies, manufacturers, research institutions and the federal ministries involved with the working group “Innovative Drives Bus”, which was jointly initiated by BMDV and BMUV.

This paper is largely based on [2], the official final publication of the findings of the first phase of the accompanying research project. An English version of this is currently in progress and we refer the interested reader to this publication for additional information.

2. Market development

Approximately 80,000 buses (all technologies including diesel) are registered in Germany. More than half of that are used in regular service. In total, at the beginning of the year 2022, the were 1,287 battery and 64 fuel cell buses in Germany (see Figure 1). If we additionally consider new registrations in the first 3 months of 2022, we obtain 1,428 battery and 70 fuel cell buses. The last years have seen a substantial increase in these numbers, e.g. the number of battery buses has more than tripled within the last two years.

Considering the Clean Vehicles Directive (CVD) of the European Union [1] which prescribes for Germany a mandatory share of min. 22.5% of all new city bus registrations being zero emission buses as of August 21 it is estimated that around 1.000 buses per year need to be either hydrogen or fully electric (battery or

Figure 1: Registration numbers of buses with alternative drives in Germany according to drive type [1]

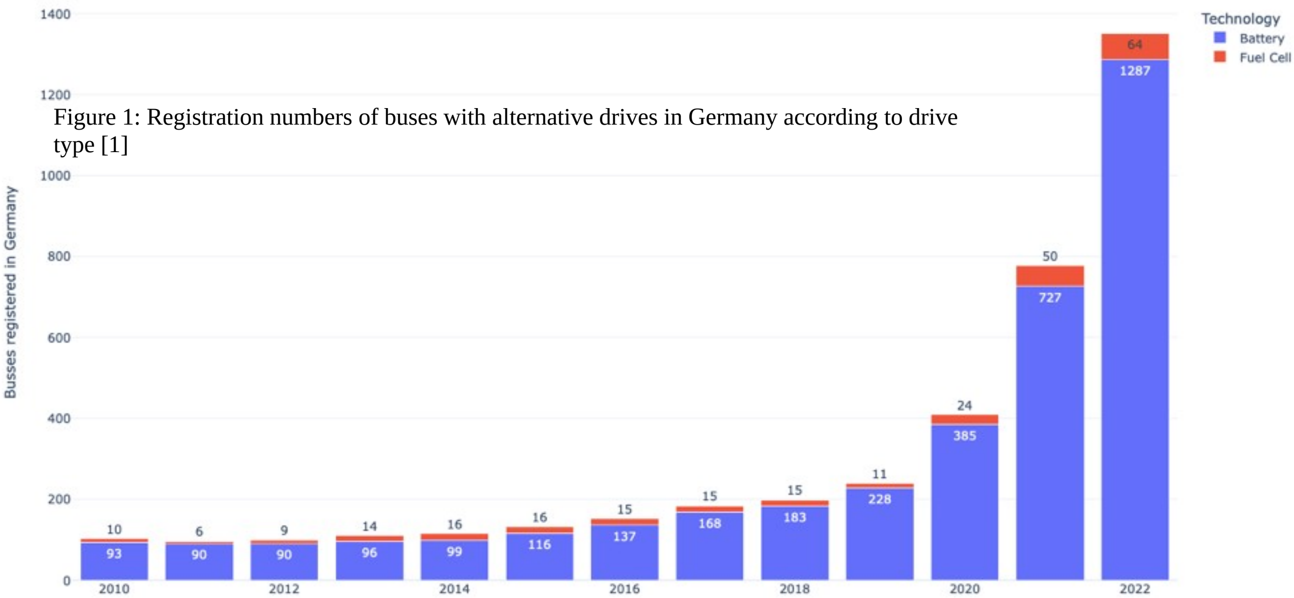

Figure 1: Registration numbers of buses with alternative drives in Germany according to drive type [3]

trolley) buses. In a second step the CVD prescribes an increase of the share of zero emission buses to 32.5% in Germany as of January 2026. This would mean 1,100 to 1,500 new zero emission bus registration per year in Germany alone [2].

Taking this to an EU level the estimated number of zero emission buses put on the streets per year will be in the order of 6,500 from August 2021, repectively around 9,500 from January 2026 onwards.

It is further worth noticing that the CVD also prescribes mandatory shares for so-called clean vehicles, which additionally to zero emission buses also includes e.g. certain gas buses, but not conventional diesel buses. The prescribed shares are 45% in the first phase and 65% in the second phase. As these shares lead transport operators to change their fleets in any case, it is to be expected that more than 22.5% (or 32.5%) of mandatory clean vehicle shares will actually be met by zero emission buses, leading to even higher numbers than mentioned above.

3. E-Bus projects in Germany

Figure 2 provides an overview of zero emission bus projects funded by the BMDV so far. In total, these include 383 electric buses split between 33 transport operators. 311 of the buses are battery electric (including trolley busses) and 70 are hydrogen fuel cell buses. In yellow, orange, and red all battery electric and in blue all hydrogen bus projects are marked. The blank circles represent projects in which the data is not yet complete. The most recent project overview is due to [2].

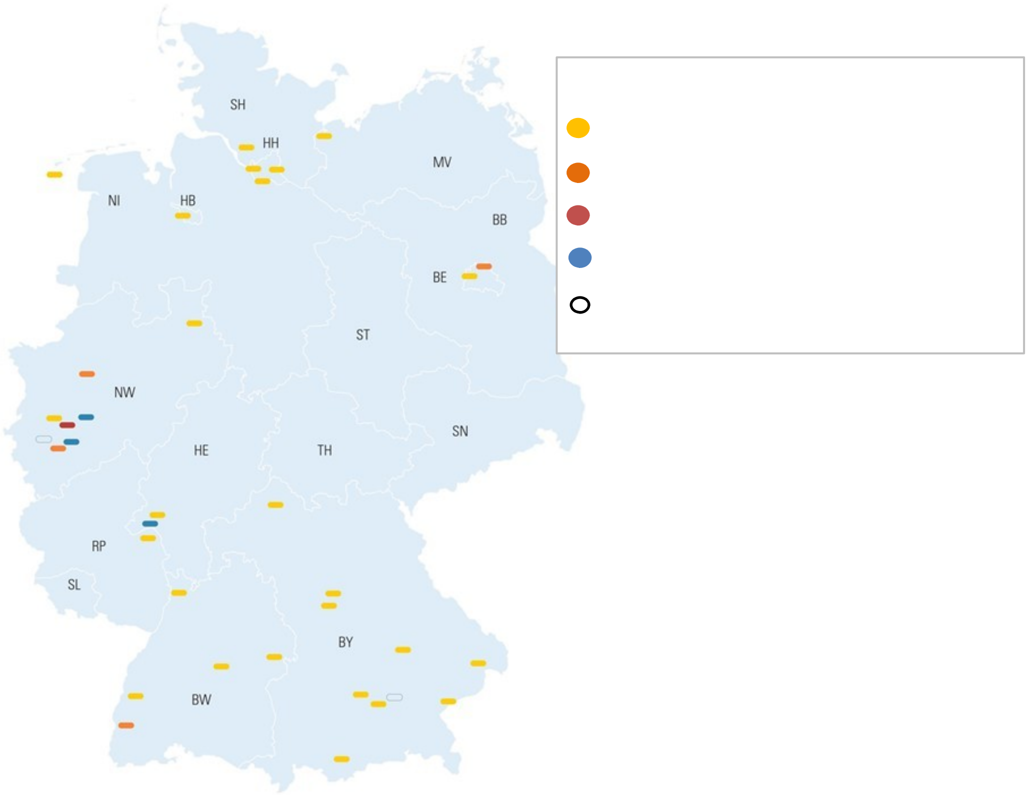

Figure 2: Map of Germany with BMDV funded e-bus projects [2]

In September 2021, a new funding initiative for zero emission buses has been launched by the BMDV of unpredecended potential. Already in a first phase, subsidies for the purchase of 1,600 zero emission buses in total have been granted to 10 different transport operators in Germany.

4. Technical evaluations

In the following, exemplary evaluations from the first phase of the accompanying research for battery electric buses are be presented. In total, the detailed data for 19 transport operators has been evaluated. By detailed data we mean that we have gathered daily performance measurements such as driven distances or consumed electric energy from subsidized buses in their actual operational service. Between February '19 and April '21, such information could be gathered for 176 buses (131 battery electric and 45 fuel cell buses). Not all buses have been in operation or were able to take measurements for the whole time horizon. Therefore we include both the minimum and maximum, as well as the average number of buses that were available for analysis in our graphics. Except for Chapter 4.4, all of this can also be found in [2] and Chapter 4 is due to internal communications with the research team behind [2]. For the purpose of this publication we focus on the insights derived for battery electric buses.

4.1. Distance driven

During the considered time horizon from February '19 to April '21, the operating buses drove a total cumulated driven distance of almost 6.5 million km (5.6 million km of this covered by battery electric vehicles).

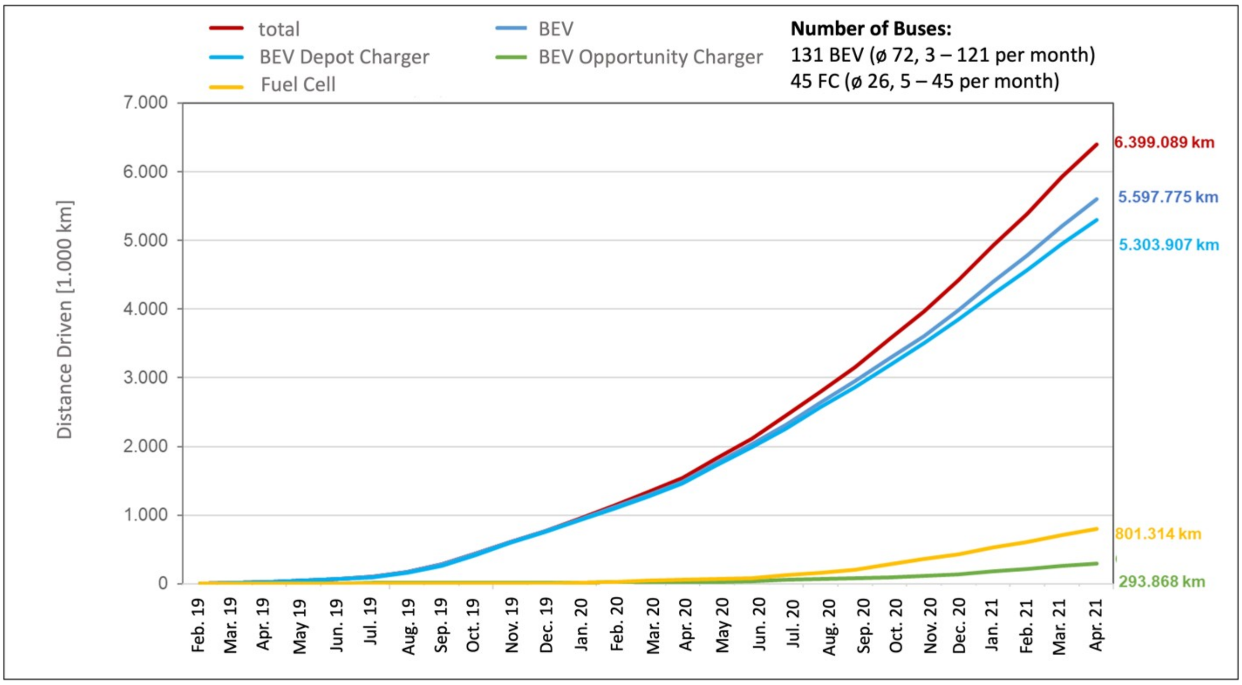

Figure 3: Accumulated total driven distances

Speaking about distances driven, one point of great interest is the average daily distance or daily mileage that an electric bus manages to cover. In our evaluations, we distinguish between depot and opportunity chargers, the first of which are buses that are charged only when they get back to their depot, while the latter are buses that can also be charged on the track. We further differentiate between different sizes of vehicles, the types being midi, solo and articulated buses.

Figure 4 shows the average daily mileages of battery buses. Note that for solo depot chargers one has the largest pool of 103 evaluated buses, making this number the most representative, while for several other subcategories the pool was considerably smaller. In particular, the data for articulated buses lacks generalizability due to the small number of observations.

If we compare those values to what is the goal for daily driven distances, we see that more than 77% of transport operators actually want their battery buses to cover 200 km or more a day. 20% even wish for a daily mileage of 350 km.

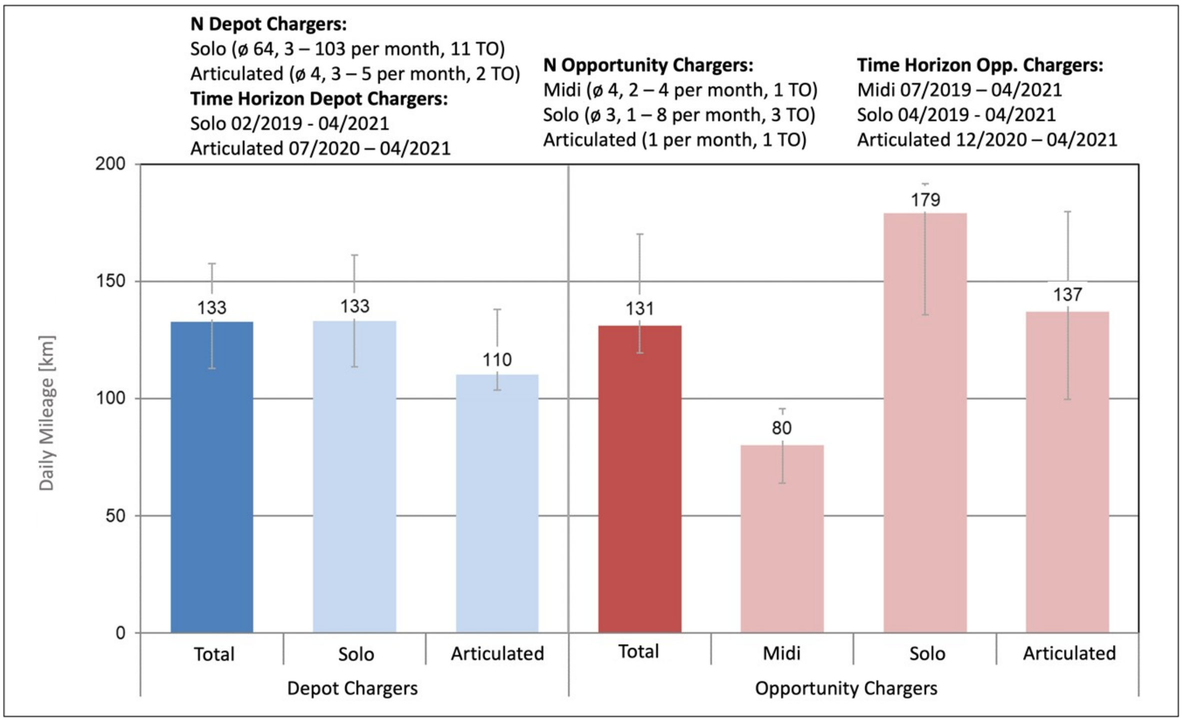

Figure 4: Average daily mileages of battery buses distinguished by charging strategy and bus type

Looking at how the average daily mileages of battery buses develop over time, we see an upward tendency both for depot and opportunity chargers (see Figure 5). This suggests that experience in the employment of battery buses can lead to optimization in this regard. Note that the rather sudden collapse that we see around March ’20 is due to the COVID-19 pandemic.

A central insight derived looking at Figure 4 and Figure 5 is that, while the average daily mileage for the complete time of evaluation of depot chargers exceeds the one of opportunity chargers, one actually has higher mileages for opportunity chargers starting from July ’20.

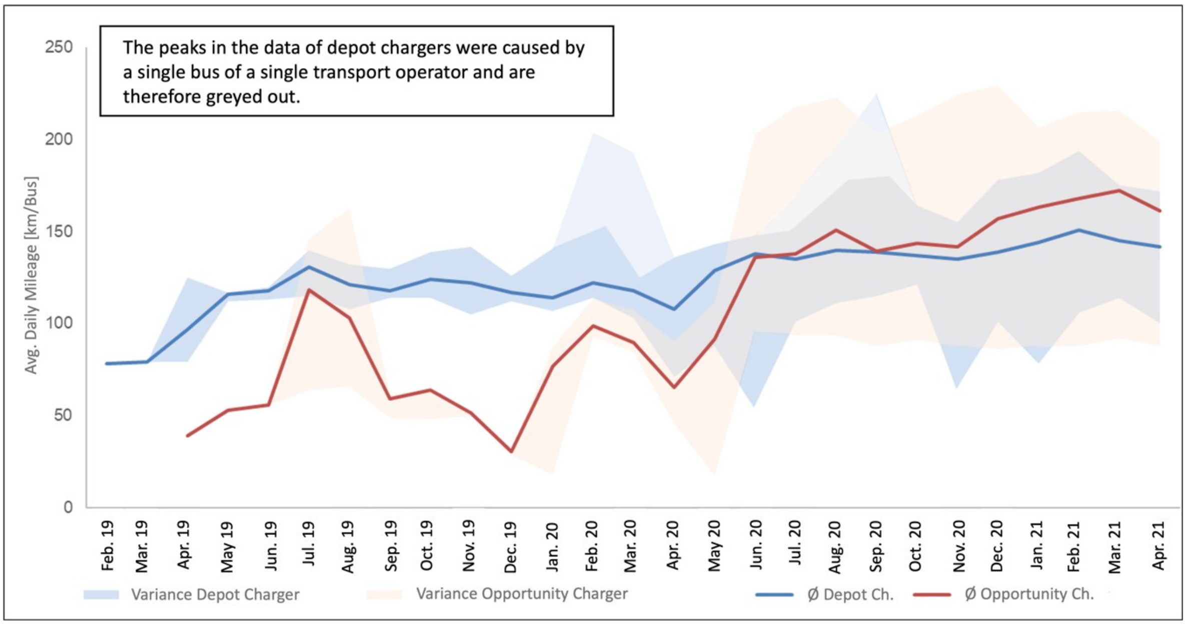

Figure 5: Development of daily mileages over time

4.2. Vehicle availability

18 traffic operators have provided information regarding the availability of their battery electric buses. In total the buses reach an availability of around 87% (see Figure 6). For the vast majority of traffic operators, the availability lies at 90% or above.

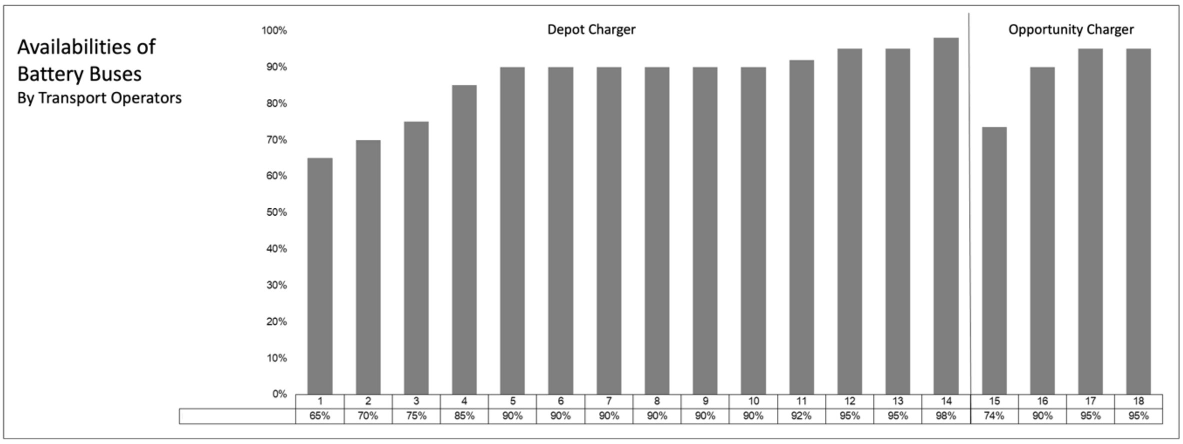

Figure 6: Availability of BEV buses

Another perspective on the operational performance and indirectly also on the availability is provided by the analysis of the average operational days per bus and month, shown in Figure 7. Here solo depot chargers clearly win against any other combination of bus type and charging strategy with 22 operational days per month on average.

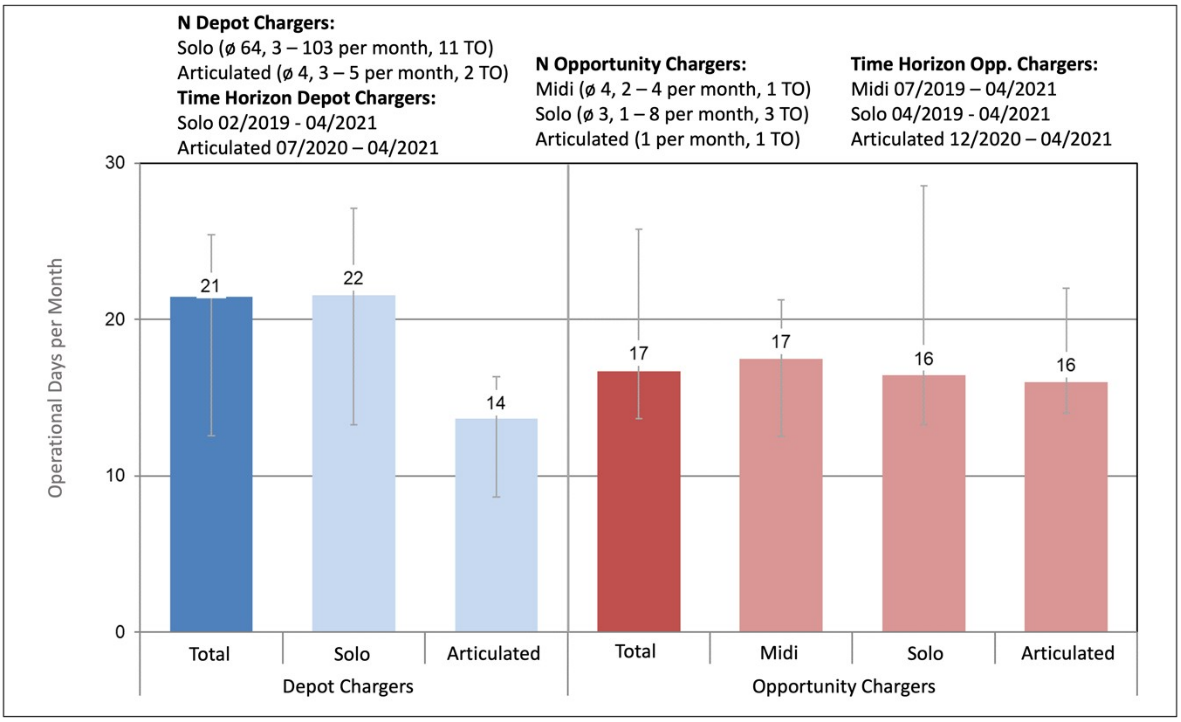

Figure 7: Average monthly days of operation

4.3. Energy consumption

It is a well-known issue of battery electric buses that ranges tend to decrease significantly in colder months, when a lot of the energy in the battery has to be used for heating.

In order to investigate this correlation between energy consumption further, we take an exemplary look at 3-6 buses of one transport operator and view their monthly average specific energy consumption in context of the intermediate temperature of the respective months (Figure 8).

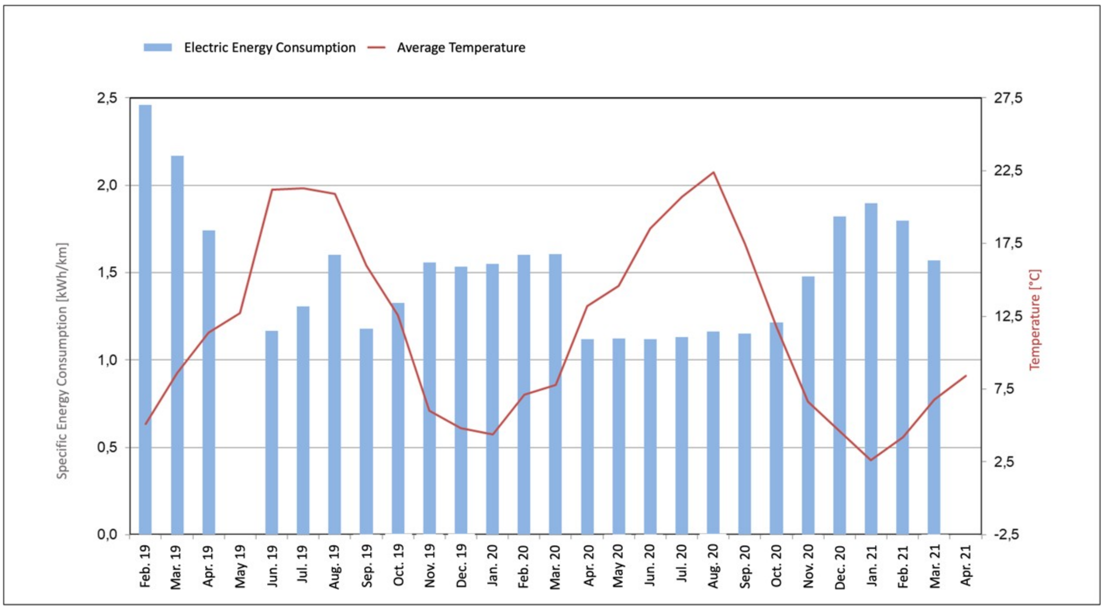

Figure 8: Specific energy consumption of one transport operator

As expected we observe a steep increase in energy consumption during the colder months. In fact we see values that are 20% to 66% above the yearly average of 1.5 kWh/km. This s

One way of tackling this issue is to use diesel powered backup heating systems that take over once temperatures are below a certain point. Figure 9 shows another exemplary analysis of 15 – 30 buses of one transport operator that use such backup systems. In this case we only see a raise of the energy consumption (from the battery) of up to 15% of the yearly average during the colder months (Figure 9). In grey we see the energy that is substituted by burning diesel.

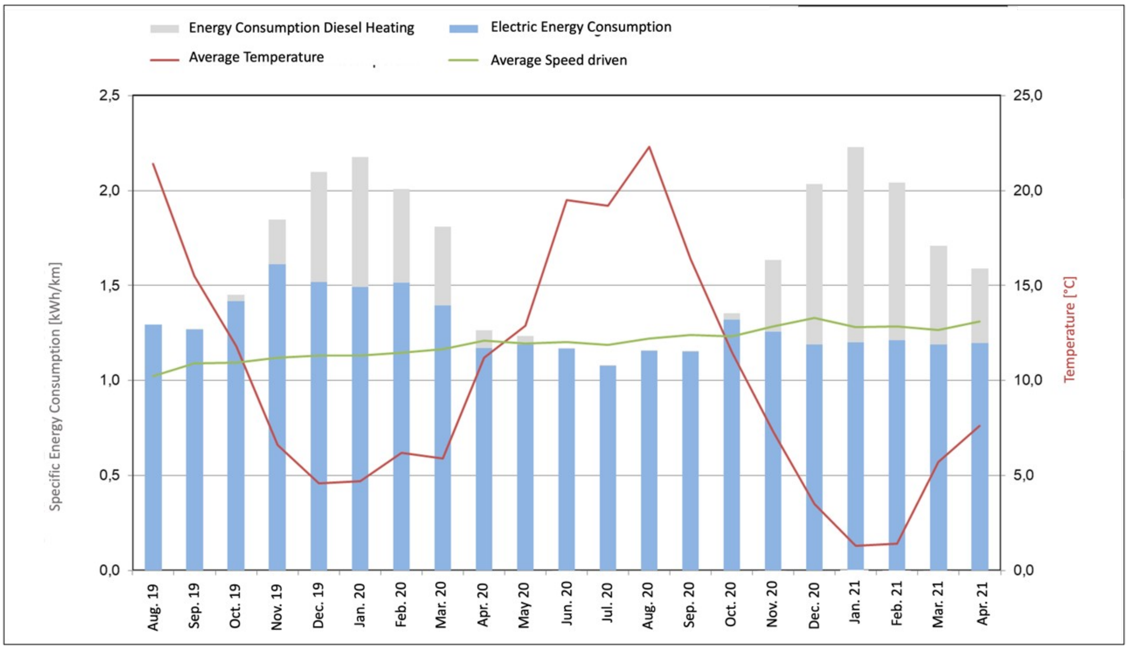

Figure 9: Energy consumption for heating with diesel backup

4.4. Charging

As an exemplary analysis, Error: Reference source not found shows the typical utilisation of in this case 26 charging stations from an anonymous transport operator over one day of operation in October 2019. There are three typical charging peaks from 9-10 am, 1-3 pm and 6-9 pm, using a charging power from about 60 kW up to 140 kW. The different charging power levels are investigated in more detail below.

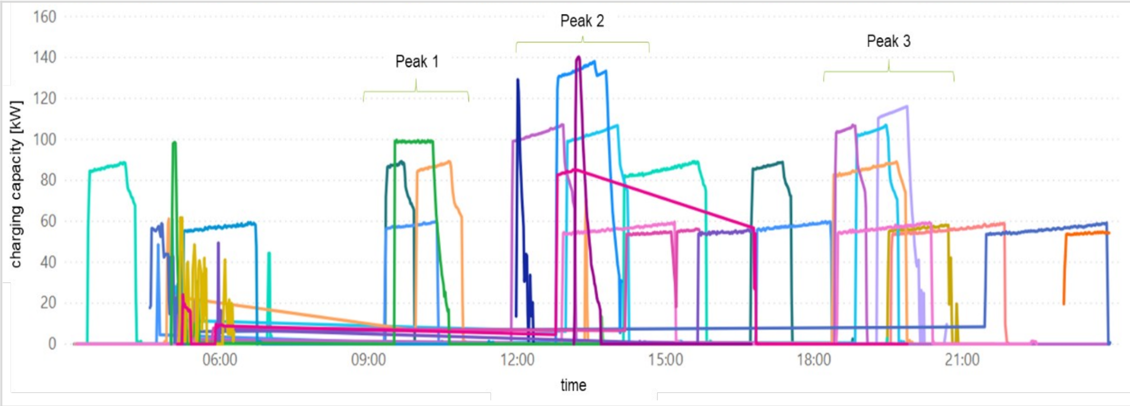

Figure 10: Charging peaks of a charging station over one day

Taking a closer look at one bus, charging three times during one day of operation in Error: Reference source not found, three different courses of charging for each charging process can be observed. The first charging process in the morning with a starting SOC of 63% is running with 140 kW in the beginning and is then reduced to about 60 kW to preserve battery life. The second charging process (starting SOC 72%), also in the morning, is running with only 60 kW from the beginning on, which is likely why there is no need to reduce the charging capacity towards the end of the charging process to preserve the battery. The last charging process takes place in the evening with a SOC of 52% at the start. This charging process is running with a maximum of only 100 kW, but therefore over a longer period of time compared to the first charging process, since the bus will not be needed directly after. Like in the first charging process, the charging power gets reduced towards the end of the charging process to about 70 kW to preserve the battery.

Summarised, this shows how charging stations are reducing their charging capacity, depending on the maximum used power, to preserve the battery, i.e. to extend their lifetime.

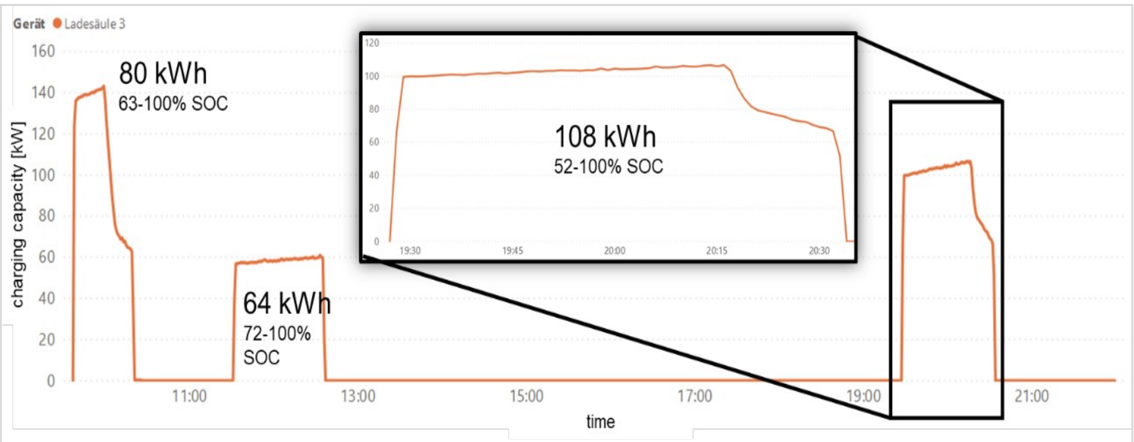

Figure 11: Charging data of one bus during one day of operation

Looking at the data of this particular bus and its charging device, no obvious correlation between the battery SOC at the start of the charging process and the charging power is observed.

5. Conclusion and outlook

The market development shows that the e-bus market in Germany is growing fast. The number of electric buses has more than tripled within the last two years. This is supported to a great extent by federal support measures. In addition, the EU has issued a Clean Vehicles Directive, which requires quotas for alternative drive systems for new registrations from 2021 onwards. Thus, from August 2021 in Germany 45% "clean" buses must be procured [1]. This is bound to lead to a further steep growth of the market. Complementing such regulative measures, the BMDV has started a new funding initiative for buses with alternativ drives last year. In a first phase, subsidies have been granted for almost 1,600 new zero emission buses, exceeding the total number of electric buses currently on Germany’s streets.

The evaluations of the first phase of the accompanying research show that battery buses can already be used in regular operation. However, there are still challenges to be solved regarding the range, as most buses do not meet the expectations of the transport operators in this regard yet. Also the question, whether to decide for battery electric vehicles, fuel cell vehicles, or a combination of both remains challenging.

Accompanying research is an ongoing project and we are confident to not only analyse the further development of performances, but to also optimize the quality of the data as the pool of monitored buses will vastly increase in the future.

References

[1] Clean Vehicle Directive, Directive (EU) 2019/1161 of the European Parliament and of the Council of 20 June 2019 amending Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles. Brussels, 2019.

[2] M. Faltenbacher et al., Abschlussbericht Programmbegleitforschung Innovative Antriebe und Fahrzeuge: Innovative Antriebe im straßengebundenen ÖPNV, Berlin, 2022, https://www.now-gmbh.de/wp-content/uploads/2022/04/NOW_Abschlussbericht_Begleitforschung-Bus.pdf.

[3] Analysis of NOW GmbH of data collected bei the “Kraftfahrtbundesamt” of Germany.

Presenter Biography

Christopher Borger works as a Data Scientist at NOW GmbH in Berlin. He finished his PhD in computational mathematics in 2020 at Otto-von-Guericke University in Magdeburg after receiving his master's in mathematics at TU Munich in 2016. His current work focuses on applying mathematical methods to analyse real life data of buses subsidized via NOW.