Development and electrification of the truck segment in Hamburg by 2050

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***Abstract* – By 2050, the European Union aims to reduce CO_2 emissions in the transport sector by 90%. Truck manufacturers must reduce the CO_2 emissions of their fleets in the European Union by 15% by 2025 and 30% by 2030. Consequently, the transition to zero-emission vehicles is necessary to meet these conditions. Changes to the type of vehicle engine and its associated infrastructure are inevitable. In anticipation of these transformations, this article examines the further development of trucks in the city of Hamburg. The current situation in Hamburg is assessed and future technological scenarios that can be expected for electric trucks with the necessary charging infrastructure are examined. An accompanying forecast until 2050 is also presented. In order to prepare for a smooth energy transition and the electrification of vehicle fleets, the paper also introduces possible load profiles caused by the load on Hamburg's power grid. By the end of the paper, recommendations to the respective distribution grid operators in Hamburg are proposed.**

Keywords – Electric Truck, Charging Infrastructure, Ramp-up Scenario, Load Profile

NOMENCLATURE

p	Growth rate
x_{year} in units	Amount in a year
$N_{truck,year}$ in units	Number of trucks in a year
P in MW	Power in megawatts
VAN_{share} in units	Factor of N1 class trucks

I. INTRODUCTION

The European Union, including Germany, set the goal of achieving climate neutrality by 2050 and by the decision of the European Council of December 2020 to reduce greenhouse gas emissions by 55% by 2030 (compared to 1990 emission levels). Trucks currently require a 30% reduction by 2030. In addition, manufacturers have announced a target of 100% zero-emission truck sales by 2040 [1].

The city of Hamburg is characterised as a hub with a large number of logistics companies with a wide range of activities, including serving the biggest seaport in Germany and the second biggest container port in Europe. The Hamburg logistics industry is one of the largest employers in the metropolitan region interested in developing the transport system, especially the truck segment.

The Federal Motor Transport Authority in Germany ("Das Kraftfahrt-Bundesamt") refers to trucks (lorries) as "motor vehicles for the carriage of goods or for special purposes". Such vehicles belong to vehicle category N of the Regulation (EU) 2018/858 of the European Parliament and of the Council, designed and constructed primarily for the carriage of goods, with at least 4 wheels, including special purpose vehicles [2]. The classification distinguishes vehicles for the transport of goods with a permissible total mass:

- Class N1: total mass up to 3.5 tons.
- Class N2: total mass of more than 3.5 tons up to 12 tons.
- Class N3: total mass greater than 12 tons.

Class N1 trucks are normally called vans or transporters, depending on the type of cabin. The difference in load capacity has a significant effect on the truck model, therefore N2 and N3 trucks are normally the so-called heavy trucks. Class N3 trucks also include semi-trailer or road tractors that meet the conditions for heavy-duty transport. An exception is truck-mounted cranes - these are vehicles in class N3 that are not intended for the transport of goods and are equipped with a crane with a permissible load moment of 400 kNm or more.

Since the differences in the total mass of trucks are considerable depending on the class, electric trucks are divided into two groups [3]:

- E-Van/Transporter: class N1 trucks (light duty).
- E-Truck: class N2/N3 trucks (medium and heavy duty).

To avoid confusion, the term "electric truck" refers to both groups in the following chapters are discussed separately only when necessary. The above classification is visually demonstrated in FIGURE 1.

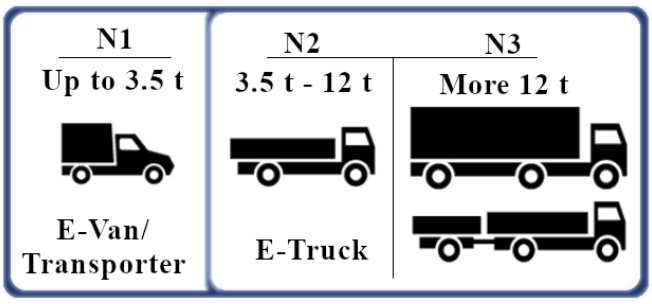

FIGURE 1: CLASSIFICATION OF TRUCKS BY TYPE BASED ON THE REGULATION (EU) 2018/858.

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The proposed classification allows for a more accurate assessment of the prospects for electrification of the truck segment in Hamburg and throughout Germany, since the total weight of a truck determines the possible charging capacity for trucks.

Based on the objectives set, this paper analyzes and proposes:

- Current state of affairs in the city of Hamburg based on the statistics of officially registered trucks in the city over the past decades, including electric ones. The distribution of trucks in the boroughs of Hamburg is also taken into account (see Chapter II).
- Development of the truck segment in Hamburg in order to smoothly implement the plans outlined above, taking into account the necessary charging infrastructure for the electrification of the truck depot (see Chapter III) and forecasting the number of zero-emission trucks and ramp-up scenarios for 2050 (see Chapter IV).
- Estimation of potential overall load profiles from electric trucks in Hamburg for the year 2050, taking into account the need to expand the charging infrastructure for the operation of electric trucks (see Chapter V).

In the summary, the results of the paper are summed up and recommendations for the timely implementation of truck depot electrification plans to avoid possible negative consequences, such as a shortage of charging stations and capacity for electric trucks, are presented.

II. Trucking Statistics in Hamburg

Statistics from the Federal Motor Transport Authority from 2000 to 2023 indicate a rapid increase in the number of trucks registered in Hamburg. This growth has been particularly visible since 2008 and continues unabated. As of January 2022, there are 69,394 registered trucks in the Hamburg city area, including electric trucks. There are currently 1202 electric trucks registered in the city, which is only 1.73% of the total. Furthermore, strong jumps in the growth of electric trucks have been observed since 2018, indicating growth trends [4].

TABLE I: DISTRIBUTION OF TRUCKS BY BOROUGH OF HAMBURG AS OF JANUARY 1, 2019 [5].

Borough of Hamburg	*Percentage of registered trucks*
Hamburg-Mitte	26.7 %
Wandsbek	19.4 %
Hamburg-Nord	19 %
Altona	9.7 %
Bergedorf	9.2 %
Eimsbüttel	8.6 %
Harburg	7.3 %

The Federal Motor Transport Authority further states that by 2022 around 90% of all trucks registered in Hamburg belong to the class N1 trucks. At the same time, trucks of class N3 (with a total weight of 12 tonnes or more) account for only 2% [4]. Consequently, trucks with a total weight of up to 3.5 tonnes overwhelmingly dominate in Hamburg. Accordingly, most electric trucks also belong to the N1 class of road freight transport, i.e. the E-Van/Transporter group.

The statistics of the Senate of the Free and Hanseatic City of Hamburg show the number of registered trucks (the provided data also include buses, tractors and other motor vehicles) in the individual boroughs of Hamburg. The number of truck registrations, sorted by Hamburg boroughs in FIGURE 2. Hamburg-Mitte (26.7%), Hamburg-Nord and Wandsbek (each around 19%) have the most registered road freight transport (see TABLE I), predominantly in the centre and north-east of Hamburg [5].

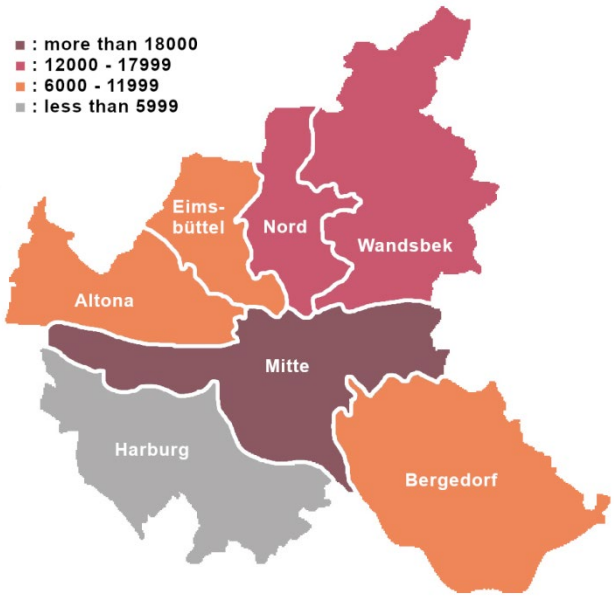


FIGURE 2: DISTRIBUTION OF TRUCKS BY BOROUGH OF HAMBURG AS OF JANUARY 1, 2019 IN NUMBERS.

According to research by the Institute for Energy and Environmental Research (IFEU), a significant share of new registrations of electric trucks, especially tractor units and semi-trailers (the class N3 trucks), is not expected until 2030. However, traffic growth will continue. Consequently, the growth of interest in various state and commercial enterprises towards the electrification of the depot is being carried out [6].

III. Truck Depot Electrification

Based on current market trends, it is evident that electric trucks are the preferred technology for decarbonising road freight transport for urban and regional delivery. Although progress is being made, uncertainty remains about the resulting sales volume of electric trucks that will be seen on the road in the 2020s, partly due to the current lack of a strategic approach to electric truck charging. Currently, there are three different charging use cases:

- Depot charging: Overnight charging at the depot of the company, equipped for the maintenance of electric vehicles.
- Destination charging: Charging at distribution centres during the day when loading and unloading goods.
- Public charging: Charging during the daytime or at night in places that are publicly accessible to trucks, which correspond to existing parking hours. For example, interchanges for lunch breaks, rest areas and ports when trucks are queuing.

These solutions are increasingly being discussed by industry experts and accurately describe situations in which an

electric truck can be expected to charge [7]. Depot charging is expected to predominate in the early stages of electrification, and reliance on public charging will increase as longer journeys are electrified. Initially, depot charging can cover about 70-80% of truck charging needs, and the use of private depot charging stations is being promoted, starting from urban hubs [7].

For all electric truck charging categories, especially public and destination charging stations, there should be some granularity in the power categorization of the infrastructure, distinguishing chargers based on their power P_{load}:

- $P_{\text{load}} < 350$ kW: class N1 trucks.
- $350 \text{ kW} \leq P_{\text{load}} \leq 600$ kW: class N2 trucks.
- $600 \text{ kW} \leq P_{\text{load}} \leq 1$ MW: class N2 and N3 trucks.
- $1 \text{ MW} < P_{\text{load}}$: class N3 trucks.

With regard to the charging infrastructure for E-Vans/Transporters (the class N1), the "Allgemeiner Deutscher Automobil-Club (ADAC)" highlights the following charging options [8]:

- Alternating current (AC) charging with 7, 11 or 22 kW allows charging times between 2.5 and 8 hours.
- Direct current (DC) with 50 kW shortens the 80 percent charge to 60 minutes. The maximum power is specified as 57 to 198 kW, depending on the E-Van/Transporter model.

In the charging infrastructure for E-Trucks (N2/N3), large trucks can be charged in two fundamentally different ways depending on the model and application [9]:

- Power charging (battery electric trucks up to 26 t, 200-300 km travel range): Low power charging (100-150 kW), fast charging (up to 500 kW) and high power charging (up to 1 MW).
- Overhead power line charging (trolley trucks are up to 40 t, require the current collector, but have an unlimited travel range): required power is 130 kW.

The decentralised development of fast charging stations in the first phase of electrification is more flexible than overhead power line corridors and comes with fewer barriers, including battery electric trucks with stationary charging for the long haul [9]. Battery electric trucks have the option of charging statically with a plug or dynamically while driving with an overhead line system, rail or induction system. Both static and dynamic charging may coexist in the future [10].

TABLE II: LIST OF SEVERAL COMPANIES THAT HAVE EXPRESSED PUBLIC INTEREST IN ELECTRIFYING TRUCK DEPOTS [6].

Field of activity	***Company***
Parking operator	APCOA PARKING Deutschland GmbH
Charging infrastructure	Allego GmbH
Electromobility	Iveco Group, Nikola Corporation, innogy eMobility Solutions GmbH
Car dealer	Auto Wichert GmbH
Energy supply	Shell Deutschland Oil GmbH
Retail business	Lidl Dienstleistung GmbH & Co. KG
Hotel business	Privathotel Lindtner Hamburg GmbH
Waste disposal	Buhck GmbH & Co. KG

The companies of Hamburg are interested in the process of electrification of their truck depots. A list of some companies is presented in the TABLE II. As an example, the food logistics company Nagel-Group in Hamburg is starting practical tests of Mercedes-Benz eActros trucks to deliver chilled food to customers in the center of Hamburg. In cooperation with IVECO and the Nikola Corporation, the Port of Hamburg also wants to have an electric truck fleet with models such as the Nikola Tre E-LKW. Group of models are already available for sale and are presented in the TABLE III. Accordingly, the process of electrification has already begun.

TABLE III: POPULAR ELECTRIC TRUCK MODELS FOR 2022.

Truck model	***Truck mass***	***Charging power***	***Travel range***	***Max. speed***
Nikola Tre E-LKW	37 tons	240 kW	560 km	120 km/h
Mercedes-Benz eActros	18 tons	160 kW	200 km	89 km/h
Volvo FH Electric	40 tons	250 kW	343 km	80 km/h
Scania 45 R Electric	40 tons	375 kW	350 km	80 km/h
MAN eTGM	26 tons	150 kW	190 km	85 km/h
Opel Vivaro-e Combi M	2.1 tons	7.4 kW	250 km	130 km/h
Volkswagen e-Crafter	3.5 tons	40 kW	160 km	90 km/h

A. Alternatives to the electric truck

Consideration of alternative technologies is necessary to evaluate the cost and effectiveness of replacing and using a new truck depot. Alternatives for battery electric trucks include:

- Hydrogen fuel cell trucks.
- Conventional gas trucks.
- Conventional internal combustion engine trucks.

The choice of technology is being widely considered. In this case, the most promising alternative to battery electric trucks is hydrogen technology. However, studies by various scientific institutions and companies ([7], [11]-[13]) indicate that even hydrogen technology is too expensive to operate hydrogen fuel cell trucks, and therefore the future truck market is likely to be dominated by battery electric trucks. In general, the IFEU forecast on the future use of fuel cell trucks shows that this type of truck is unprofitable [11]. The study from [7] of the shown overall efficiency of different technological pathways (see TABLE IV) points to the predominant advantage of direct depot electrification.

TABLE IV: EFFICIENCY OF DIFFERENT TECHNOLOGICAL PATHWAYS FOR 2020 AND 2050 [7].

Technology	***Efficiency for 2020***	***Expected Efficiency for 2050***
Direct electrification	77 %	81 %
Hydrogen	33 %	42 %
Synthetic gas	21 %	28 %
Synthetic fuels	21 %	27 %

Furthermore, research by [14] claims that the direct use of electricity in electric trucks is significantly more energy efficient than the use of hydrogen or synthetic diesel fuel. Accordingly, the development of an electric truck depot and the necessary infrastructure for charging is a high priority.

IV. Ramp-up Scenarios for Truck Depots

In order to predict possible growth in the number of trucks and anticipate a potential year of full electrification of the truck depot, ramp-up scenarios for trucks in Hamburg by 2050 are being considered. The projected overall growth rate for trucks and the electrification of truck operations is calculated from the statistics of [4] and the calculation of the overall growth rate p:

$$p = \left(\frac{x_n}{x_0}\right)^{\frac{1}{n}} - 1 \quad (1)$$

Here is the initial amount x_0, which is replaced by x_n over a period of time n. This method is used by the Fraunhofer Institute for Systems and Innovation Research to predict the development of the charging infrastructure [15]. The Equation (1) is adapted to calculate the growth rate of the number of registered trucks in Hamburg p_{Lkw}:

$$p_{\mathrm{Lkw}} = \left(\frac{x_{2022}}{x_{2000}}\right)^{\frac{1}{22}} - 1 \quad (2)$$

$$x_{\mathrm{year+1}} = (1 + p_{\mathrm{Lkw}}) \cdot x_{\mathrm{year}} \quad (3)$$

Using the number of trucks for 2000 and 2022 (x_{2000} and x_{2022}) in steps per year, the growth rate p_{Lkw} of trucks is calculated. Due to various unforeseen factors influencing the growth in the number of freight transports, ramp-up scenarios of ±33% are used:

$$x_{\mathrm{year+1,33\%}} = \left(1 + \frac{4}{3} \cdot p_{\mathrm{Lkw}}\right) \cdot x_{\mathrm{year}} \quad (4)$$

$$x_{\mathrm{year+1,-33\%}} = \left(1 + \frac{2}{3} \cdot p_{\mathrm{Lkw}}\right) \cdot x_{\mathrm{year}} \quad (5)$$

The scenarios of the minimum and maximum corridor ±33% were similarly used according to the principle from [16].

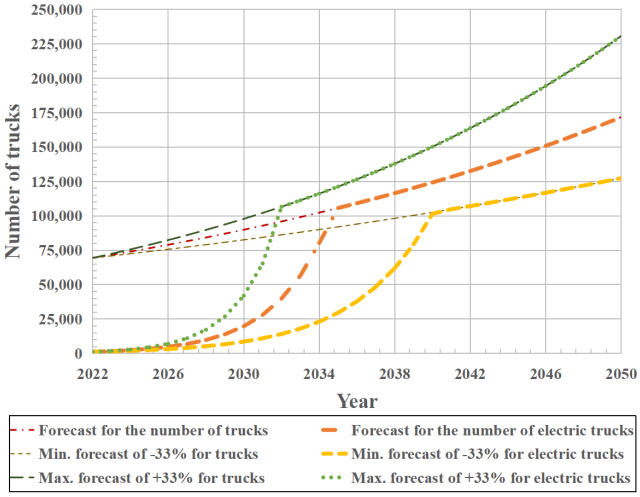


Figure 3: Forecast of the number of trucks in Hamburg up to 2050 based on growth factors.

Three ramp-up scenarios for truck depots of Hamburg are shown in Figure 3, including the electrification perspective based on current trends. In the most positive scenario, full electrification of trucks of all classes is possible by 2032, in the pessimistic case - only by 2040. The average scenario foresees full electrification by 2035, which is also in line with the assumption of the European Federation of Transport and Environment (T&E) study [7]. The forecast indicates that by 2050 all road freight transport in Hamburg will be electric, and therefore comply with the principles of zero emissions [1] in all scenarios. The number of registered trucks in Hamburg until 2050, depending on the scenario, is shown in Table V. As the electrification of trucks is in the foreground, the expansion of the charging infrastructure comes with it.

Table V: The number of trucks registered in Hamburg by 2050.

Ramp-up scenarios	*Number of trucks*
Maximal scenario	230,634
Average scenario	171,635
Minimal scenario	127,327

The vast majority of existing charging points for 2020 (see Figure 4) are only suitable for charging E-Vans/Transporters (up to 300 kW). Given the number of registered trucks in the Wandsbek borough, it is already worth building more charging stations there, in parallel expanding the charging infrastructure in other boroughs. Given the electric vehicle ramp-up scenario up to 2050, existing charging infrastructure will not be sufficient, making expansion of this infrastructure for all classes of electric vehicles inevitable. Therefore, future load, required capacity and reserve needs to be taken into account.

V. Load Scenarios for Electric Trucks

As of June 2021, around 1300 public charging points are available in Hamburg [13]. The distribution of charging points by borough in Hamburg for 2020 shows that boroughs of Hamburg-Mitte and Hamburg-Nord have the most available charging points (see Figure 4). By the end of 2020, a total of 103 semi-public charging points at 45 stations are built in Hamburg [6]. Moreover, 35 charging points are located in the borough of Hamburg-Mitte [13].

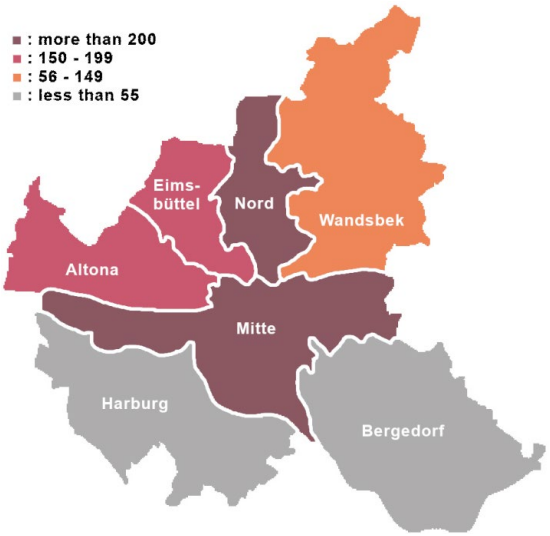
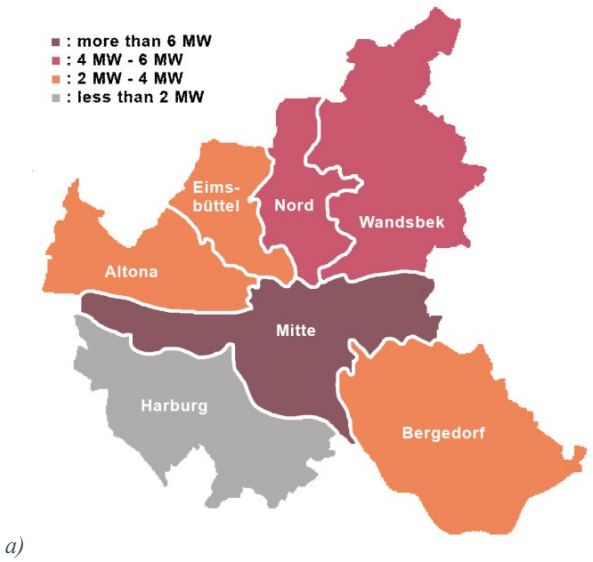


Figure 4: Distribution of charging points according to Hamburg boroughs for 2020 in numbers [6].

To predict the potential load from electric trucks, the meta-study [16] assumes a load distribution based on the share of commercial and municipal electric vehicles (in Table VI). As the charging capacity is limited to 150 kW, the total power required to charge all registered E-Vans/Transporters in Hamburg is considered first:

$$P_{\mathrm{N1,2050}} = N_{\mathrm{Lkw,2050}} \cdot VAN_{\mathrm{Share}} \cdot P_{\mathrm{Anteil}} \quad (6)$$



a)

b)

c)

FIGURE 5: PROJECTION OF THE TOTAL PEAK DEMAND FOR THE HAMBURG BOROUGHS BY ELECTRIC TRUCK CHARGING IN 2050 (A - AVERAGE, B - MAXIMAL, C - MINIMAL SCENARIOS).

with $P_{Anteil} = (0.15 \cdot 150 + 0.15 \cdot 11 + 0.7 \cdot 3.7)$ and $VAN_{Share} = 0.9$ (approx. 90% of all trucks belong to class N1). Accordingly, $N_{Lkw,2050}$ shows the number of all trucks registered in Hamburg.

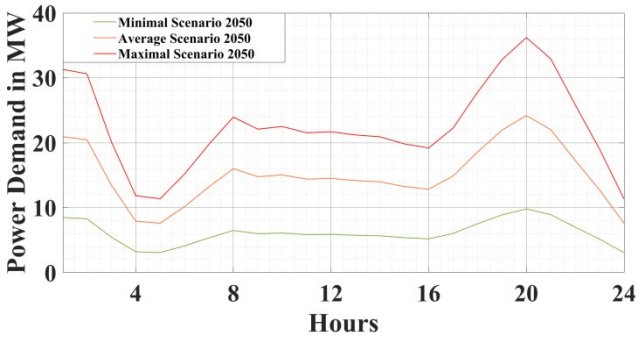


FIGURE 6: TOTAL LOAD PROFILES FROM ELECTRIC TRUCKS IN HAMBURG FOR 2050.

Looking at the Fraunhofer Institute's development scenarios for class N2/N3 truck charging infrastructure $P_{N2/N3,2030}$ until 2030 [17] and the growth rate of the share of electric trucks in Hamburg p_{Lkw}:

$$P_{\mathrm{N2/N3,2050}} = (1 + p_{\mathrm{Lkw}})^{20} \cdot P_{\mathrm{N2/N3,2030}} \qquad (7)$$

It leads to the forecast for 2050 and the load profiles (see FIGURE 6), which forms a general scenario for all electric trucks, taking into account the growth rate of trucks registered in Hamburg:

$$P_{\mathrm{Lkw,2050}} = P_{\mathrm{N1,2050}} + P_{\mathrm{N2/N3,2050}} \qquad (8)$$

TABLE VI: CHARGING SCHEDULE OF COMMERCIAL AND MUNICIPAL ELECTRIC VEHICLE FLEETS [7],[16].

Percentage of trucks	*Charging time*	*Location*	*Charging capacity*
70 %	At nighttime	Depot	3.7 kW
15 %	At daytime	Depot	11 kW
15 %	At daytime	Charging station	150 kW

Results of peak load scenarios for the year 2050 in relation to truck type are shown in TABLE VII. Moreover, 3 scenarios based on the minimum and maximum corridor with a projection of the total peak demand in 2050 are shown in FIGURE 5. The scenarios are generated based on the derived Equation (8), the daily load profile of commercial and municipal electric vehicles from [16] and the night charging profile from [18]. Charging profiles for electric trucks are also integrated based on research [19]. The generated forecast shows that the highest loads are predicted in the city center (Hamburg-Mitte) and in the north (Wandsbek, Hamburg-Nord, Eimsbüttel, Altona), especially in the maximal scenario. High loads on the power grid are expected in the evening (7-9 pm) and at midnight during night charging. A significant part of the load is charging N2 and N3 class trucks. For this reason, distancing the charging of large (N2/N3) trucks in favor of overhead power line charging infrastructure should not be ruled out. Regardless of the scenario, the central part of the city will experience the greatest load on the grid (more that 6 MW). An expansion of the Wandsbek charging infrastructure would already be highly desirable.

TABLE VII: PEAK LOAD OF ELECTRIC TRUCKS IN HAMBURG FOR 2050.

Peak load scenarios	*Peak load of N1 trucks*	*Peak load of N2/N3 trucks*	*Total peak load*
Maximal scenario	5.6 MW	30.8 MW	36.2 MW
Average scenario	4.1 MW	20.1 MW	24.2 MW
Minimal scenario	3.1 MW	6.7 MW	9.8 MW

From an overview of the reserves of substations and free transformer capacities in the boroughs of Hamburg, provided by Stromnetz-Hamburg [20], it follows that the reserve for the charging infrastructure for electric trucks is sufficient at the moment, but taking into account the load from other vehicles, the development of reserve capacities is necessary. The capacity reserve in the north of the Wandsbek area needs to be increased as early as possible to avoid grid overloads. In addition, attention should be paid to the city center, as the load on this area will definitely increase. The reserves of substations in the Western part of the city are sufficient at the moment. Summing up, all potential loads should be taken into account along with the load from the electric truck depot needed for further analysis.

VI. CONCLUSIONS AND RECOMMENDATIONS

The paper analyzed the current state of affairs in the City of Hamburg based on statistics of officially registered trucks in the city over the last decades, including electric trucks. The distribution of trucks in Hamburg has been taken into account and a forecast of the development of the truck segment in Hamburg, including the number of zero-emission trucks, has been carried out with consideration of the necessary electrification of the truck fleet. Accordingly, three scenarios for a potential overall load profile of electric trucks for the year 2050 have been calculated, considering the need to expand the charging infrastructure for electric trucks.

The number of charging stations and available transformer capacity for charging electric trucks and the potential network congestion must be taken into account in order to avoid potential negative consequences. Guidelines are therefore offered to the responsible institutions.

The paper concludes with recommendations for the timely implementation of electrification plans for truck depots:

- Number of available substations and reserve expansion to be considered as early as possible, as reserves of substations and free transformer capacities will inevitably be convenient in the coming decades. It is assumed that by 2050 the load from electric trucks in the city centre (Hamburg-Mitte) and northern Hamburg (Hamburg-Nord and Wandsbek) will amount to more than 6 megawatts per borough in a worst-case scenario to ensure the stable operation of the power grid.
- Expansion of the substation reserve in the coming years in the Wandsbek district is necessary (of substations in several areas of the region below 10 megawatts). At the same time, attention needs to be paid to the central part of Hamburg, while controlling the substation reserve in all Hamburg boroughs.
- Construction of new charging stations for electric trucks in the city area, especially in Hamburg-Mitte, Hamburg-Nord and Wandsbek, is obligatory, as the number of registered trucks in these areas is expected to grow rapidly along with the electrification of truck depots.
- Consideration of distancing the charging of a certain proportion of N2/N3 trucks in favour of overhead power line charging infrastructure outside Hamburg is welcome in order to reduce the load on the city sub-stations.
- A concerted campaign to call for transport depot electrification among commercial and government logistic companies should be carried out in order to accelerate the process of successful electrification.

In order to successfully electrify the truck segment in Hamburg and achieve the zero-emissions goals as early as 2035, measures must be taken as quickly as possible to expand the charging infrastructure and the substation reserves.

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