Electrification of Taxi Fleets in China and Germany

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Electrification of Taxi Fleets in China and Germany – Status Quo and Policy Recommendations

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List of Abbreviations

AC	Alternating Current
ADAC	German Automobile Club
BaaS	Battery-as-a-Service
BAFA	Federal Office of Economics and Export Control
BMDV	Federal Ministry for Digital and Transport (as of 2021)
BMVI	Federal Ministry for Transport and Digital Infrastructure (until 2021)
BYD	Build Your Dreams (Chinese Automobile Enterprise)
CAAM	Chinese Association of Automobile Manufacturers
CATL	Contemporary Amperex Technology Limited (Battery manufacturer)
CNY	Renminbi (Chinese Yuan)
CO_2	Carbon Dioxide
DC	Direct Current
EU	European Union
EUR	Euro
EVCIPA	China Electric Vehicle Charging Infrastucture Promotion Alliance
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GPS	Global Positioning System
ICC	International Council on Clean Transportation
IEA	International Environment Agency
ISI	Fraunhofer Institute for Systems and Innovation Research
LEVC	London Electric Vehicle Company
km	Kilometre

kW	Kilowatt
kWh	Kilowatt-hour
Mil	Million
NDRC	National Development and Reform Commission
NEV	New Energy Vehicle
NIP	National Hydrogen and Fuel Cell Technology Innovation Program
ÖPNV	Public Transport
UITP	International Association of Public Transport
t	Ton
TALAKO	Taxi Charging Concept for Electric Taxis in Public Spaces
TCO	Total Cost of Ownership
WELMO	Funding Program for Business-Related Electromobility

Executive Summary

The electrification of large vehicle fleets, especially taxi fleets, is a necessary component for achieving international and national climate targets. This measure can also make an important contribution to reducing particulate matter and noise pollution in cities. The size of the taxi fleets in the People's Republic of China and the Federal Republic of Germany differ significantly. While the entire Chinese fleet consists of around 1.4 million vehicles, of which 9.5 % are already electrified, a total of around 55,000 vehicles are currently in operation in Germany. Only a fraction of these run on an electric drive. In China, local governments are increasingly intervening in the design of urban taxi fleets through regulatory measures by setting binding specifications for the size of the vehicle fleet and the drive technologies to be used. With Taiyuan and Shenzhen, China is home to the first two cities in the world to have fully electrified their taxi fleets at a rapid pace with the support of the government. In Taiyuan around 8,300 conventional taxis were replaced by electric cars within eight months in 2016. The southern Chinese industrial metropolis of Shenzhen also electrified its entire taxi fleet consisting of around 22,000 vehicles by 2019. Even though these rapid conversions were made possible especially due to the political framework conditions in China, it is still possible to derive generally applicable operational and political findings for Germany. One of the key findings of this report indicates that, in order to make rapid progress in the sustainable transition of taxi fleets, besides promoting the acquisition of electric vehicles, the (charging) infrastructure required for electric vehicles in particular must be expanded. In terms of the charging technologies used, the potential and opportunities of the battery swapping concept as an additional option to wired charging should not be disregarded and should be further examined. The introduction of a label for electric taxis would also lead to a clear differentiation from conventional taxis with combustion engines. At the same time, vehicles labelled as climate-friendly could gain a competitive advantage among those consumers who are sensitive toward environmental issues. From a political point of view, it would be particularly advisable to examine measures to limit new registration of taxis to those with electric engines, provided this is within the legal framework. A corresponding regulation could, for example, take place via taxi concessions. Support programs such as those in Hamburg and Berlin, as well as a price cap for charging electricity, would also lead to more planning security for taxi drivers nationwide and create additional incentives.

1 Introduction

As part of its „Fit for 55“ package of climate measures, the European Commission has passed a ban on newly registered passenger cars with internal combustion engines from 2035 onwards (ZEIT Online 2021). This was endorsed by the European Parliament and the European Council in June 2022.[1] Following these decisions, the end of the combustion engine technology in vehicles in countries of the European Union (EU) is in sight. Although citizens will still be allowed to drive vehicles with internal combustion engines after 2035, it still means that European car manufacturers will concentrate fully on developing new energy vehicles (NEVs)[2]. The resulting changes will affect both private households and commercial fleet operators. In Germany, fleet vehicles account for around two-thirds of all new registrations (Becker 2022), making the electrification of larger vehicle fleets an important starting point for achieving climate targets in the transport sector. In the following, this report will focus on the electrification of taxi fleets, which would bring several advantages. On the one hand, electrified taxis can make a decisive contribution to improving air quality and thus the health of citizens through their predominant use in cities. In addition, the presence of electrified taxis in the cityscape can increase the perception and thus the acceptance of electric vehicles (Bernard et al. 2021, p. 12; Bauer et al. 2021, p. 1). On the other hand, battery electric engines face separate challenges in the taxi industry: Often, trips and thus trip distances cannot be planned in advance. Furthermore, taxi standing times of taxis are unpredictable, whilst constant operational readiness is necessary (Bundesverband Taxi und Mietwagen e.V. 2021, p. 3).

In the People‘s Republic of China, the path to a climate-neutral society is also a high priority of the country‘s leadership. In 2020, President Xi Jinping announced extensive climate protection measures aimed at peaking the country‘s greenhouse gas (GHG) emissions in 2030 and achieving carbon neutrality by 2060 (Climate Action Tracker 2022). The transport sector accounts for approximately 10 % of national greenhouse gas emissions in China, with most emissions in this sector occurring in the country´s major cities (Xu and Xu 2021), where 60 % of the Chinese population is already living. Analysts predict that by 2030, more than one billion people in China could live in major cities (Ye et al. 2020, p.13). The electrification of public transport, but also of large private taxi fleets, promises to improve air quality and would contribute to climate protection measures. As the world‘s largest market for and ma-

[1] However, there is to be an exemption for the registration of vehicles that can be run on synthetic fuels. Synthetic fuels are liquid energy carriers that are synthetically produced using renewable energy and re-generative resources (ADAC 2022).
[2] The term NEV includes battery-electric vehicles as well as plug-in hybrids and fuel cell vehicles.

nufacturer of battery electric vehicles (BEVs), the People‘s Republic is in a good position to electrify its taxi fleets. With the cities of Shenzhen and Taiyuan, the country also is home to the world‘s first examples of cities that have already electrified their entire taxi fleets.

In the course of the implementation of the project „Sino-German Cooperation on Mobility and Fuels Strategy as a Contribution to the Transport Transition“ of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, this report presents approaches to the electrification of taxi fleets using the example of major Chinese and German cities. After a brief introduction to the various charging options for battery electric vehicles, the third chapter examines the objectives of the electrification of taxi fleets in China and examples of best practice. The fourth chapter analyses the structure of the German taxi industry, addresses demands of German taxi associations regarding the electrification of taxi fleets, and also presents best practice examples from Germany. Finally, the last chapter derives generally applicable recommendations for action at the operational and political level for the electrification of taxi fleets.

2 Charging Technologies for Battery Electric Vehicles

While there is already consensus on the need for a massive expansion of charging infrastructure for BEVs, it is still unclear which charging technology will prevail. Currently, there are three competing technologies: wired charging, battery swapping and inductive charging, which will be presented briefly in the following chapter.

2.1 Wired Charging

Accumulators of battery electric vehicles, hereafter referred to as electric cars or electric vehicles, can only be charged using direct current (DC). The alternating current (AC) taken from the electricity grid for this purpose must therefore be converted into direct current - either via the on-board charger in the vehicle (AC charging) or via a rectifier in the charging station (DC charging). DC charging stations can charge electric cars significantly faster due to higher charging powers. The charging time is calculated using the capacity of the vehicle battery and the charging power provided by the charging station (Freie und Hansestadt Hamburg 2021, p. 19). A vehicle with a battery capacity of 60 kWh, for example, can be charged in just under six hours at an AC charging station with 11 kW charging power, in just over an hour at a DC charging station with 50 kW, and in less than 30 minutes at a DC charging station with 150 kW. The capacity of the charging pole determines the duration of the charging process. The battery management system of the electric vehicle is an important component for controlling the charging processes and assessing the battery condition (ADAC 2021). So far, cable-wired charging is the dominant charging technology in Germany. The main disadvantage is the long time required for AC charging, whereas frequent and incomplete DC charging can be detrimental to the life cycle of the battery (Henßler 2020).

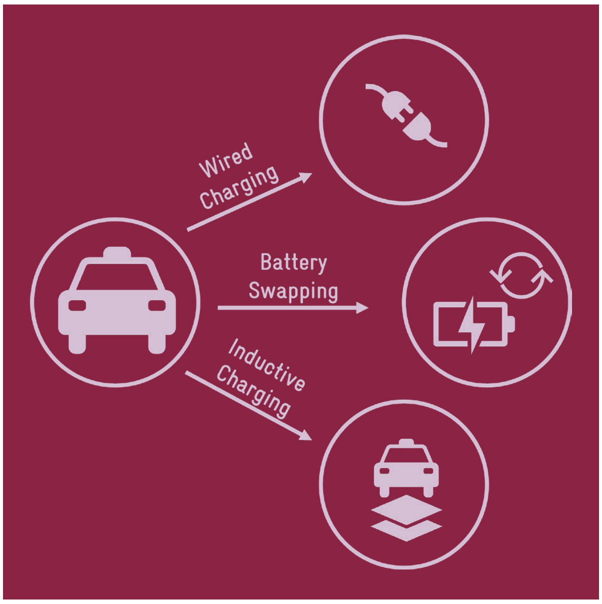

Figure 1: Charging technologies for Electric vehicles

2.2 Battery Swapping

Battery swapping refers to the replacement of the discharged vehicle battery with a fully charged energy storage unit. This is done automatically within a few minutes at a container-like station. The prerequisite for using this system is standardised vehicle equipment. For this, the battery must sit in a universal case that can be replaced automatically in the battery replacement station. Depending on the vehicle manufacturer, different types of cases and batteries exist, which makes it difficult to standardise the technology. To date, users of battery swapping systems have to head to the swapping stations of their respective vehicle manufacturers. The key advantages of this technology are the short time required for the fully automated swapping and the longer battery life cycle resulting from the lower number of charging cycles and the removal of frequent rapid charging. Accordingly, battery swapping stations enable anti-cyclical and climate-friendly charging. In addition, the batteries stored in the battery swapping stations can be used as energy storage devices to stabilise the power grid, for example during demand peaks by controlled charging and discharging of the batteries stored at the station. Furthermore, the possibility of flexible battery leasing leads to significantly lower vehicle acquisition costs for the consumers. On the other hand, there are higher acquisition costs for the battery swapping station operator and greater raw material requirements since more batteries have to be acquired a priori. Another disadvantage is that users are tied to the local battery swapping station of their own vehicle manufacturer.[3] At the same time, the stations could be especially attractive for people without access to charging facilities in their immediate vicinity.

In China, battery swapping has been shaped in particular by the company NIO and its „Battery-as-a-Service" (BaaS) approach. As a part of various subscriptions, different battery capacities are available to customers, which influence the range of the vehicle (NIO 2020). Battery swapping stations of the company NIO are built as containers, they occupy an area of approximately three parking spaces and hold five to 13 batteries. The containers are often placed in public parking lots or at gas stations.[4] Due to the lack of standardisation

[3] The study "Recharging systems and business operations to improve the economics of electrified taxi fleets" by Hsieh et al. (2020) examines the economics of battery swapping stations using various scenarios and calculations on a per-mile basis. In addition, the study highlights various business models related to battery swapping and the purchase of multiple vehicles and derives recommendations for the expansion of the technology and for fleet operators in general.

[4] At NIO battery swapping stations, only batteries of company-owned vehicles can be swapped. Other manu-facturers such as Aulton or Contemporary Amperex Technology Limited (CATL) aim to make their services available to vehicles of different manufacturers. According to Yang (2022), the cost of setting up a battery swapping station in China ranges from EUR 220,000 to EUR 600,000. According to an article in the Berliner Morgenpost Online (2022), the costs in Germany would be between EUR 800,000 and EUR 1 million.general.

in the field of battery swapping up to date, there are currently no uniform technical standards, thus significantly hindering the market breakthrough of this technology (Yang 2022). The first initiatives of the Chinese government involve the introduction of regulations that define the maximum number of replacement cycles for a battery, which can be seen as a first step towards standardisation. China already had 1,298 battery exchange stations nationwide by the end of 2021 (Evinchina 2022) and is pursuing the goal of having built at least 1,000 more stations by the end of 2022, and possibly more than 8,000 stations in total with the support of six private-sector companies (China5e 2022). In January 2022, the National Development and Reform Commission of the People‘s Republic of China (NDRC), together with nine other ministries, published the „Implementation Recommendations for Further Improving the Service Guarantee for Electric Vehicle Charging Infrastructure“ (NDRC 2022). Among others, this statement points out that the further expansion of battery swapping stations should be promoted through the development of general swapping standards. More than 26,000 stations are to be built by 2025. Battery swapping hence currently enjoys both political support as well as economic boost in China (China5e 2022).

The battery swapping market is currently gaining momentum thanks to market entries from companies such as battery manufacturer CATL and energy company Shell. For example, CATL established a first battery swapping station for trucks and a first station for cars in China in early 2022 (CATL 2022). The application of battery swapping for trucks and heavy-duty vehicles is at an exploratory stage in China, although the first battery swapping station in Wuhan with 50 electric trucks from the Baowu Group has been in operation since June 2022 (The People‘s Government of Wuhan Municipality 2022). This shows that China is already piloting electric trucks with battery swapping technology commercially. In addition, Chinese automaker NIO and Shell signed a strategic cooperation agreement to build joint battery swapping stations in China and Europe in late 2021 (Shell 2021). According to NIO, the latter foresees to establish more than 4,000 stations by 2025, of which 1,000 will be outside China. NIO has already opened its first stations outside China in Oslo, Norway (Bernard et al. 2021, p. 10) and plans to open more stations in Germany, Denmark, the Netherlands, and Sweden in 2022 (Pluta 2022). In Germany, the major car manufacturers have so far paid little attention to battery swapping, especially because Germany is primarily focusing on the expansion of comprehensive charging infrastructure. As part of its Climate Protection Program 2030, the German government is focusing on the goal of establishing one million publicly accessible charging points by that year, including the creation of a nationwide fast charging network (Federal Ministry of Transport and Digital Infrastructure (BMVI) 2019). It is questionable whether German car companies will be able to maintain their dismissive position toward battery swapping concepts considering international developments. In Berlin, the joint venture Infradianba, consisting of the German company Inframobility and the Chinese global market leader in battery swapping, Aulton Dianba, is momentarily planning to open a station specifically for MG ZS EV electric taxis (Kisling 2022). In the long term, Infradianba plans to offer battery swapping for vehicles from different manufacturers as a bundle. Therefore, only the vehicle´s frame would have to be standardised for the swapping process. In total, the company is working with 16 car manufacturers in China and plans to offer battery swaps for 30 different vehicle models.

2.3 Inductive Charging

A further charging option that could be used at taxi stations in particular is inductive charging. This technology is also known as wireless charging. With inductive charging, the electric vehicle comes to a standstill above a charging plate with coil and inverter built into the floor. The vehicle floor contains a charging receiver that converts the electrical voltage induced by the charging plate into direct current for the battery (Deutsche Kommission Elektrotechnik 2021, p.23). The energy can thus be transmitted without contact. Various research projects are currently underway, such as those of Volkswagen Group America, which aim to increase the charging power for inductive charging of electric cars from 6.6 kW to 120 kW. This would significantly speed up the charging process (Zippmann 2022). In China, initial approaches are being pursued to standardise inductive charging processes (Busch 2020).

Hove and Sandalow (2019, p. 39) emphasise the advantages of wireless charging in their report „Electric Vehicle Charging in China and the United States“. Advantages of the technology include, for example, ease of use, unobtrusive installation in the ground, and time savings with appropriate performance. Therefore, the technology has a great application potential for the taxi sector. In Germany, the pilot project „Taxi charging concept for electric taxis in public spaces (TALAKO)“ with underground inductive charging strips represents an initial approach. The German Federal Ministry of Economics and Technology funded the construction of a pilot facility in Cologne for inductive charging with EUR 2 million. The inductive charging station located at Cologne central station went into operation in May 2022, where an electric vehicle from the London Electric Vehicle Company (LEVC) is being used. The implementation phase lasted until September 2022, and the energy company RheinEnergie AG has already promised to continue operations beyond the end of the test phase (TALKO 2022).[5] For inductive charging, however, electric vehicles must be equipped with a corresponding charging receiver, which would have to be retrofitted to older electric vehicles if the technology became widespread. The Fraunhofer Institute for Systems and Innovation Research (ISI) estimated that the use of inductive charging in the private sector would cost at least EUR 6,000 per system more than wired charging, which would result from retrofitting the vehicle and building an inductive charging device (Schraven et al. 2010, p.22). High costs for the construction of inductive charging devices, the slow charging speed, lack of safety concepts and low efficiency of the charging process are currently hampering widespread application of the technologies, which might become more significant later stages of development in the medium to long-term future.

In Germany, quite similar to China, only a few taxis run on hydrogen. However, both countries have identified this energy source as a key technology for the transport sector. In its „Medium and long-term plan for the development of hydrogen energy industry“ (2021-2035), the People‘s Republic has defined the goal of bringing 50,000 fuel cell vehicles (FCVs) on the market by 2025. It is also pursuing ambitious plans to expand the hydrogen filling station infrastructure (National Energy Administration 2022). Correspondingly, hydrogen is playing an increasingly important role as an energy carrier for the transport sector in Germany as well. With the „National Hydrogen and Fuel Cell Technology Innovation Program“ (NIP), the German Federal Ministry of Digital Affairs and Transport has been promoting the market preparation and market ramp-up of fuel cell vehicles since 2006 (Federal Ministry of Transport and Digital Infrastructure 2020). Many funding programmes of the federal ministries to transform the transport sector are aimed not only at BEVs but also at fuel cell vehicles. Driven by this, political and financial commitment more fuel cell taxis could operate in the two countries in the future.

[5] Further information on the project and research results can be found at https://talako.uni-due.de/.

3 Taxi Industry in China

Traffic in major Chinese cities has led to devastating air pollution due to the large quantity of passenger car vehicles (China Vehicle Environment Management 2018). In 2021, the country held the 22nd rank in a worldwide comparison of air quality, in which the first ranking country has the worst air quality (IQAir 2021). The Chinese government implemented several policies in recent years, such as the introduction of low-emission and environmental zones [6], to improve air quality. Further measures included vehicle restrictions in peak times, promotion of and subsidies for new energy vehicles, or tightening rules for vehicles with large exhaust fumes. Furthermore, the Chinese government defined goals to lower greenhouse gas and particulate matter emissions in the 14th Five-Year Plan. The concentration of particulate matter in cities, for example, shall be reduced by 10 % until 2025.

China is home to the largest market for electric mobility worldwide. The number of NEVs amounted to a total of 4.92 million at the end of 2020 (He und Jin 2021) and rose significantly, according to data from the Ministry for Public Security to 8.92 million vehicles in March 2022 (Ministry for Public Security of the People´s Republic of China 2022). Of these, around 7.25 million were battery electric vehicles. Forecasts of the Chinese Association of Automobile Manufacturers (CAAM) predict that sales of NEVs in 2022 will rise by 42 % in a year-on-year comparison and account for some 18 % of total vehicle sales. It is also very likely that China will either reach or overfulfil its national goals of a 20 % NEV share in total vehicle sales until 2025 and 40 % until 2030 (Qian 2022). In the segment of battery electric passenger cars Chinese manufacturers such as BYD (18%), SAIC GM Wuling (12%) and Tesla (12%) represent the leading companies in the first half of 2022.[7]

3.1 Status Quo

In China, a distinction is made between two types of taxis: On the one hand, there are taxis defined according to the German understanding (in Chinese „巡游出租车“ or „conventional taxi“), which are hailed on the streets or directly at taxi stands and can also be reserved via the Internet or smartphone apps. These conventional taxis are characterised by a uniform logo, colour, and number plates. On the other hand, new taxi service providers have entered the market in recent years whose services can only be ordered online via apps (“网约车” or “online-hailing taxi” in Chinese). The drivers usually use their private vehicles. Depending on the „comfort selection“,

[6] In the so-called “National Pilot Zones for Ecological Conservation”, the proportion of vehicles with new energy systems is to be increased by up to 80 %, thereby making a decisive contribution to air pollution control.
[7] Data based on vehicle registration figures in China. The data is collected by Market Insight by S&P Global.

these taxis can be used alone or with several people for ride-pooling[8]. In China, a large part of the on-demand traffic is booked via the "DiDi" platform, which does not differentiate between commercial and private taxi companies. From a German perspective, there is almost no difference between classic taxis and new on-demand offers for DiDi users when booking, especially because the offers on the platform hardly differ in price. When ordering, the vehicle model cannot be selected, which is why electric taxis cannot be ordered explicitly. In China there were around 1.39 million conventional taxis in 2020, of which 9.5 % (around 132,000 vehicles) were already electric (Huaon 2021 and Ministry of Transport 2021). According to the 14th Five-Year Plan, NEVs are expected to account for 35 % of the vehicle fleet in the taxi industry by 2025. In the following, this report refers to the commercial taxi fleets, which are officially marked as conventional taxis („巡游出租车") in China and are statistically monitored.

The taxi industry in China is organised through a franchise system. If a company wants to operate a taxi fleet[9], it must first apply with the local government's taxi administration. In addition, government standards and safety requirements must be met. The local taxi administration authority decides whether a business license can be issued on the basis of the regional taxi development plan, traffic planning and analysis of the actual local demand for taxi services. In certain cities where the electrification of taxis is particularly encouraged, business licenses are only issued on condition that the taxi service provider uses purely electrically powered vehicles. Basically, there are no regulations for the choice of the vehicle model for taxi companies. However, only certain EV vehicle models are funded under state and local guidelines, so many local governments use these as a benchmark and mandate specific models. In addition, city administrations often sign purchase agreements with local car manufacturers in order to strengthen the regional economy. The vehicles are sold to the taxi company, which then hands over the vehicles to its drivers for a monthly rent.[10] Electrically powered taxis are explicitly identified by a green number plate and, in some cities, by special characters. In addition, local governments, taking into account factors such as vehicle type (conventional or electric), set specific time intervals for how long fleets may be in operation before a vehicle replacement is required. In 2013, China's Ministry of Commerce, the Na-

[8] While ride-hailing directly connects the origin and destination of a traffic route and is only used by the person with the booking request, ride-pooling can accept different trip requests from multiple passengers on a single trip.
[9] There is no official definition of the size of a fleet of vehicles. However, it is a legal requirement by the Chi-nese government that a taxi company must have at least 20 vehicles.
[10] Source: Conversation with a taxi driver in Beijing on 07.07.2022. In Beijing, taxi drivers normally pay CNY 170 (EUR 24) per day for electric vehicles. However, due to the corona pandemic, the rent has been re-duced to 50-80 CNY (7-11 EUR). The rent for internal combustion taxis is slightly lower. For the conver-sions, an exchange rate of 1 EUR = 7.02 CNY was assumed for the entire report (as of March 21, 2022).

tional Development and Reform Commission, the Ministry of Public Security, and the Ministry of Environmental Protection established mandatory vehicle scrapping standards. According to these regulations, taxis may only be used for eight years after which they have to be replaced (Ministry of Commerce 2013), in Beijing the time interval is shorter and only six years long (BMCoT 2015). Separate rules apply to electric taxis. In Beijing, for example, these must only be replaced every eight years.

According to a study on charging behaviour, electric vehicles in China are often charged when the battery level is at 50 %. This can be traced back to the shift system that is common in China. A taxi is usually operated in two shifts of 12 hours each, with most day shift drivers handing over their vehicle between 5 p.m. and 7 p.m. (Bauer et al. 2021, p. 2). Some drivers also work in 24-hour shifts. The vehicle can thus be used without interruption. Surveys show that a particularly large number of drivers who drive in a two-shift system charge their vehicles two to three hours before the shift change in the afternoon to hand over a fully charged car to the driver on the night shift. This is common in China and applies to combustion taxis as well, which are always handed over to the partner with a full tank. Therefore, the battery often has more than 50 % capacity when charging begins. Although this shortens the loading time, simultaneous loading behaviour causes waiting times at the stations. Shortly before the end of their shift, drivers are often reluctant to accept long journeys, which can also lead to loss of income (Bauer et al. 2021, p. 2). According to the „White Paper on Charging Behavior of Electric Vehicle Users in China 2021“, published by the China Electric Vehicle Charging Infrastructure Promotion Alliance (EVCIPA), 1.1 million public charging stations were in

Vehicle Tracking

Tracking systems are often built into Chinese taxis so companies can identify where their vehicles are and allocate them according to demand. In addition, the GPS data increases the safety of the taxi users. Misuse of passengers can be prevented by constantly tracking the vehicle. In some cases, the installation of these GPS systems is a requirement of local authorities. However, the data generated through the GPS analysis can also be used in another context.

As Yang et al. have shown in the study "Design government incentive schemes for promoting electric taxis in China", the data can be used to determine ideal locations for charging stations and the range re-quirements of a vehicle (Yang et al. 2018, p. 6).

operation nationwide by October 2021, almost 40 % of which were DC fast charging stations. Most taxi drivers prefer charging at public DC columns because of time savings. Around 80 % charge their vehicles in less than an hour and a third completes the charging process in less than 30 minutes. In order to reduce waiting times and avoid a corresponding loss of income, in 90 % of cases the battery is not fully charged and 40 % of taxi drivers charge their vehicle with less than 20 kWh. Taxis are often charged at night between midnight and 6 a.m. when there are fewer customers.

Subsidies

To advance the goals of improving air quality and the electrification of vehicle fleets, the purchase of electric taxis is being strongly promoted in China. In addition to local funding opportunities, either from individual cities or provincial governments, there is a national funding program for the purchase of NEVs. Consumers who want to make use of the funding, need to buy, since 2020, an electric vehicle that must have a range of at least 300 km (ICCT 2020, p. 3). The subsidy decreased by 10 % from 2019 to 2020 from 18,000 CNY (around 2,564 EUR) to 16,200 CNY (around 2,310 EUR) and is expected to continue to fall until 2022 (ICCT 2020, p. 4).[11] However, the concrete funding quotas differ between municipalities, which means that funding can be significantly higher depending on the location. While some cities determine the subsidy dependent on the price of the vehicle or the model, others decide on the basis of the vehicle‘ range. To further assist, many local governments have facilitated access for taxis to public charging points and given them priority charging. In some cities, such as Shanghai, an electricity price guarantee for electric taxis of 0.4 CNY/kWh (equivalent to around 6 cents/kWh) was introduced as a pilot project in 2020 (Shanghai Municipal Development & Reform Commission 2020).

[11] For vehicles with a range of more than 400 km, the subsidy decreased from CNY 25,000 (around EUR 3,560) to CNY 22,500 (around EUR 3,205).

3.2 Case Studies of Taxi Fleet Electrification

Due to the electrification targets for taxi fleets set in the 14th Five-Year Plan, many cities have already defined local targets for the electrification of their respective taxi fleets. Since 2017, the provincial capital of Guangzhou has stipulated that electric taxis must account for 70 % of all new purchases, a rate that is increasing by 5 % each year (The People's Government of Guangzhou Municipality 2017). This should ensure that all taxis are fully electrified by the end of 2023 (Guangzhou Municipal Development and Reform Commission 2021). The provincial capital of Hangzhou has targeted electrifying at least 30 % of all taxis by 2022 and 60 % by 2024 (Transportation Bureau of Hangzhou 2022). The provincial capital Zhengzhou also wants to fully electrify its taxi fleets by 2022, with 90 % of all taxis already being electric by November 2021 (Henan Government 2021). The Chinese cities of Taiyuan and Shenzhen are the only cities in the world that already possess a fully electrified taxi fleet (IEA 2021, p. 19). In the following, the approach and funding guidelines in these two cities and in the capital of China, Beijing, will be examined in more detail.

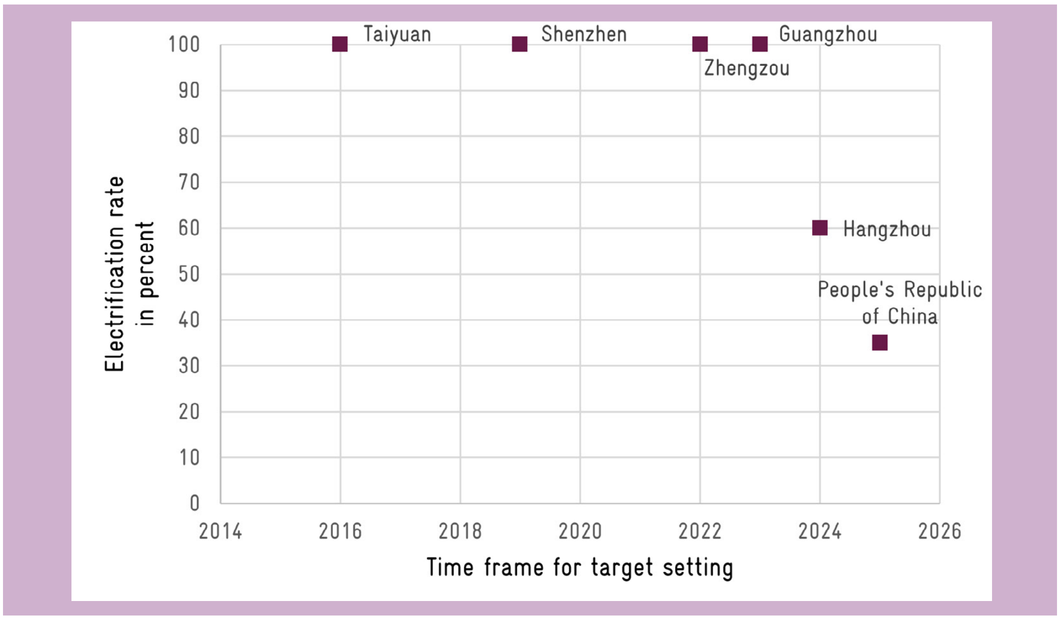

Figure 2: Overview of the electrification targets of selected Chinese metropolises

Taiyuan

In Taiyuan, around 8,300 taxis were electrified within eight months in 2016. As in many other cities in China, the Taiyuan Municipal Government decided on the configuration of the taxi fleet. The local government gives the taxi companies the right to participate in the business activities for a certain period of time. In order to obtain these corresponding licenses, taxi companies must meet certain requirements, such as the use of electrified taxis. The drivers mostly rent the vehicles from their taxi companies, while the city determines which vehicle models can be used through mandatory purchase requirements (Chun 2018). In the case of Taiyuan, the city was obliged to replace the entire fleet due to administrative[12] requirements. The city offered massive subsidies to accompany the electrification. Notably, around two-thirds of the cost for purchasing an electric taxi was funded by subsidies, shared between the city, region and national government at a 2:1:1 ratio.[13] As a result, the purchase price for a BYD E6 vehicle for taxi companies was reduced from around CNY 309,000 (around EUR 44,000) to CNY 89,800 (around EUR 12,728) (IEA 2021, p. 25). The type of internal combustion engine taxis in China differ in design and model depending on the city. For example, SAIC-Volkswagen taxis are mainly used in Shanghai because the company's headquarters are in Shanghai. A typical Chinese taxi with an internal combustion engine costs around CNY 60,000-80,000 (EUR 8,900-11,900) for taxi companies.[14] Hence, owing to the grants from the city of Taiyuan, the purchase price for an electric taxi was similar to that of a combustion vehicle.

Chinese car manufacturer BYD accompanied the transition of Taiyuan's taxi fleets by building its own electric vehicle production plant near the city, as all conventional vehicles were replaced with the same BYD E6 model. The vehicle model has a range of 400 km with a battery capacity of 80 kWh and an average consumption of 20 kWh/100 km (Bauer et al. 2021, p. 2). The BYD E6 is also equipped with an on-board computer that can be used to show which locations have a shortage of taxis, e.g. in busy locations such as train stations or airports where there is a large number of people. The display is also used to show the route and the ticket price to prevent drivers from taking detours or charging surcharges (Science X Network 2019). In addition, more than 2,000 charging stations with an output of 40 kW were set up in the same year, at which vehicles can be fully charged within two hours (Herger 2016). At the end

[12] In Taiyuan, the time interval for the purchase of new taxi fleets stands at eight years.
[13] Original title of the policy: 中国人民政治协商会议太原市委员会. Available from the Taiyuan Local Government website at http://www.tyzx.gov.cn/proposalDetail.html?i=91e92185-b46e-4bfc-824b-984863088574, last checked 21/06/2022.
[14] Conversation with a taxi driver in Beijing on 07/07/2022.

of 2021, the city had a total of 3,405 charging stations, divided between 834 DC and 2,571 AC charging stations (Huayang Group 2022).

Shenzhen

The Chinese city of Shenzhen received international attention when it fully electrified its public bus fleet back in 2017. By 2019, the city's entire fleet of around 22,000 taxis was also replaced by battery electric vehicles, which is leading to emissions savings of 850,000 t CO_2 per year (Shenzhen News 2019). In addition, the city had the world's largest charging station built in cooperation with the car manufacturer BYD and the Chinese energy company Southern Power Grid with a total of 637 fast charging points, which can handle up to 5,000 charging processes per day (Schmidt 2019). In 2021 the city had over 90,000 public charging stations[15]. To create purchase incentives, the city of Shenzhen also exempted all electric taxis from license fees (Hui et al. 2018, p. 24). According to the International Association of Public Transport (UITP 2020, p. 2-3), taxis in Shenzhen cover an average distance of 384 km per day, with 78 % of all taxi companies working in two shifts.

Peking

Beijing's taxi fleet consisted of around 71,500 vehicles at the end of 2019 (Statista 2020) and recorded over 210 million passengers in the taxi industry in 2021 (Statista 2022). Due to the large number of journeys, Beijing has a very high potential for reducing greenhouse gas emissions via taxi traffic. In 2017, the city administration announced for the first time plans to electrify the entire fleet within the following years (Marks 2017). According to the International Standardization Academy, taxi operators expect total costs for this measure to be at CNY 9 billion (around EUR 1.28 billion). The city administration announced that since 2017 every newly purchased and newly registered taxi must be electrically operated (Hsieh et al. 2020, p. 102).[16] In addition, the purchase of electric taxis was subsidised, with the amount of the subsidy depending on the price difference to comparable conventional vehicles: If the difference was up to CNY 50,000 (around EUR 7,120), the subsidy corresponded to the actual difference, otherwise it amounted to a maximum of CNY 50,000 (Hui et al 2018, p. 23). By the end of 2020, subsidies were increased to 73,800 CNY (around 10,513 EUR) to accelerate the purchase of electric taxis (Beijing Municipal Com-

[15] In official data from China, no distinction is made between charging stations and charging points. The number of 90,000 refers to the amount of charging stations in Shenzhen, some of which have one charging point, while others have two.

[16] So far, there are no concrete figures on the number of electrified taxis. In 2020 alone, about 11,000 electric taxis were promoted, according to the Beijing Municipal Government (Beijing Municipal Commission of Transport 2021). In 2019, China Daily (2019) reported the delivery of 800 electric taxis from car manufacturer Beijing Electric Vehicle with a range of 300 km, suitable for battery swapping stations.

mission of Transport 2019).[17] In 2015, before the beginning of the electrification campaign in Beijing, a scrapping premium for the abolition of internal combustion engine taxis of CNY 10,000 (around EUR 1,425) per vehicle was paid if it was less than seven years old (Yang et al. 2018, p. 2).[18] According to plans by the Beijing Department of Transportation, 100 % of all conventional taxis should be electrified by 2025 (The People's Government of Beijing Municipality 2022). To provide the necessary charging infrastructure, Beijing is

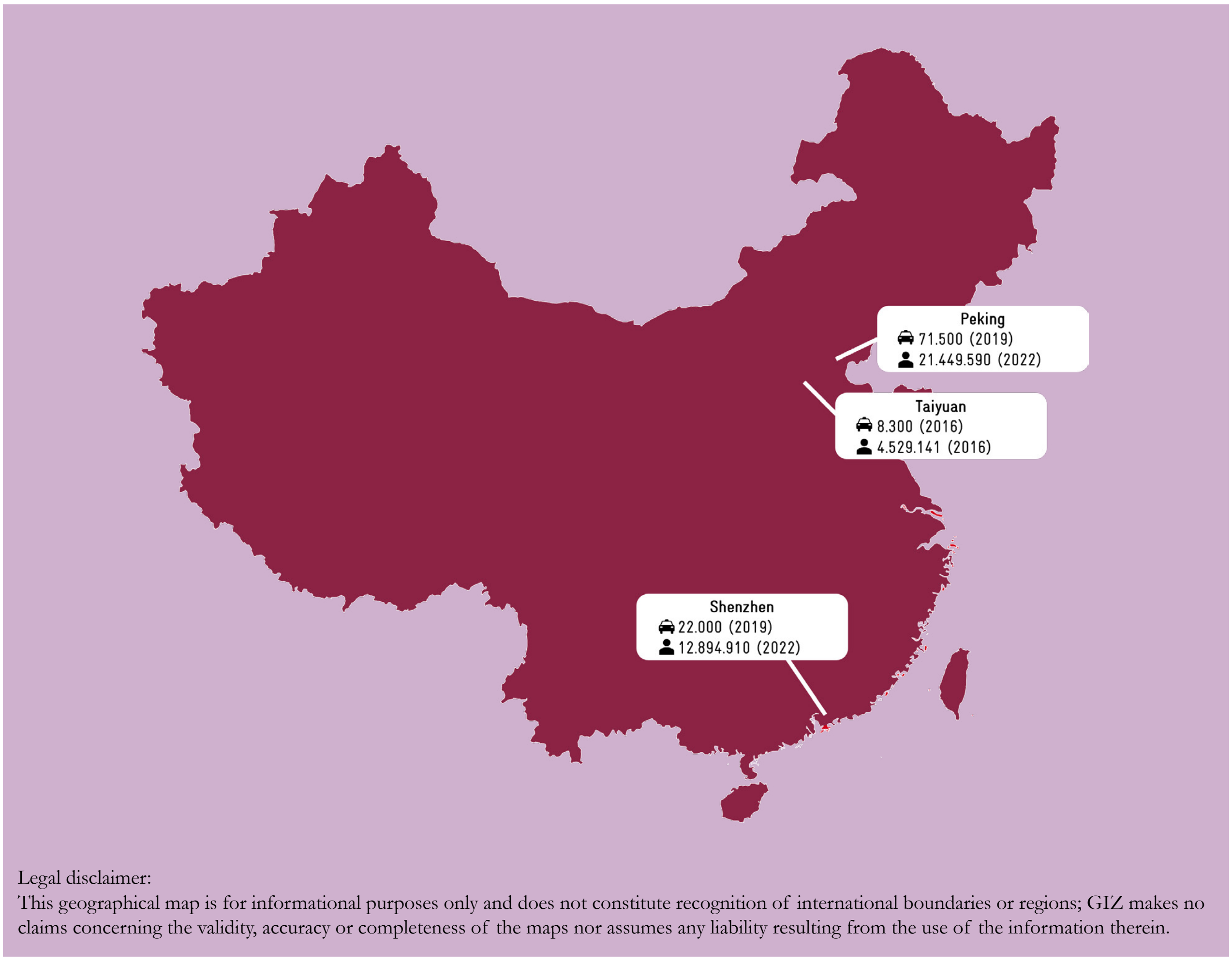

Figure 3: Overview of the size of taxi fleets and population in Taiyuan, Shenzhen and Beijing
Source: Copenhagen Centre on Energy Efficieny (2016); Wendell Cox Consultancy (2022)

[17] According to the Beijing Municipal Commission of Transport (2019), other conditions for receiving subsi-dies were a minimum range of 300 km and a warrant on the battery for 8 years or 600,000 operating kilo-metres.
[18] The coupling of fees was intended to make the use of electric vehicles more attractive, facilitate market entry, and expand the supply of electric taxis. In addition, the time interval for renewing vehicles has been reduced from eight to six years for non-electric vehicles.

aiming for a 3:1 ratio of electric taxis to fast charging stations in urban areas and 5:1 in peripheral areas (Hui et al. 2018, p. 16). With a massive expansion of the charging infrastructure, the city plans to set up over 50,000 additional charging stations by the end of 2022 (Bernard et al. 2021, p. 10), with the number of charging stations being around 256,000 by the end of 2021 (The People' s Government of Beijing Municipality 2022b). As part of the 14th Five-Year Plan, the city administration is also planning to set up 700,000 charging stations for all NEVs by 2025 (The People's Government of Beijing Municipality 2022a). In 2015, the city piloted a service fee for charging electric vehicles, linked to the price of conventional fuel. Consequently, such service fee added by the charging station operator to the price of the electricity could not exceed more than 15 % of the current price of gasoline (Yang et al 2018, p.3). As this regulation has now expired, the service charge is on average 20-25 % of the cost of the electricity price. Together with the parking fees due at certain locations, the electricity and service price make up the total cost of the charging process. Compared to refuelling a combustion engine, in China, charging an electric vehicle only incurs around 20 to 33 % of costs. Despite the strong expansion of the charging infrastructure, taxi drivers in Beijing complain that the duration of a fast-charging process cannot be compared to conventional refuelling. Up to one hour of time is lost each day, mainly due to long queues at the most cost-effective loading points. Bauer et al. (2021, p. 2) also conducted interviews with local taxi drivers in Shenzhen, who criticised that long queues at central charging stations sometimes caused delays of up to three hours a day.

In the future, the city will increasingly make use of the battery swapping technology. With a total of 265 stations, Beijing already has the highest density of battery swapping stations in the world (Yang 2022). Most of the stations are operated by the car manufacturer NIO and the company Aulton New Energy, which focuses on providing battery swapping stations. This technology is particularly attractive for a two-shift system, since the car must no longer be charged before the shift change, and the vehicle can be handed over after a short battery swap. If there are enough stations, the battery swapping technology represents an efficient alternative to wired charging, especially for application in the taxi industry

4 Taxi Industry in Germany

In Germany, the transport sector is responsible for around 20 % of national greenhouse gas emissions (Federal Environment Agency 2021). Throughout the whole European Union, around 72 % of CO_2 emissions in this sector are caused by road traffic, with cars, ahead of heavy-duty vehicles and light-duty vehicles, emitting the lion‘s share of greenhouse gases in road traffic at 61 % (European Parliament 2019). In recent years, fine dust pollution from diesel vehicles in large cities has emerged as a public as well as political problem. Therefore, similar to measures in China, environmental zones have been set up to reduce fine dust pollution. Closing central urban areas to regular car traffic is also a priority for many municipalities. The federal government is aiming to bring ten million electric vehicles on German roads by 2030 (Bundesregierung 2022a). According to Grausam et al. (2015, p. 20), fleet operators are the most important target group when it comes to the electrification of vehicles since the majority of new registrations come from commercial fleets and company cars. In addition, commercial fleets are often used for less time and more intensively, making commercial fleets an important starting point to reduce CO_2 emissions. In this context, the German taxi industry could serve as a role model for the electrification of vehicle fleets. Due to newer on-demand offers (so-called ride-hailing) such as Uber or Bolt-Taxi, the German taxi industry sees itself facing intense competition with a more modern and dynamic adversary.

4.1 Status Quo

In 2022, around 55,000 taxis were driving in Germany (Taxi Deutschland 2022). Figure 4 shows an overview of the number of vehicles per company in Germany. Around 74 % of all 21,000 taxi companies in Germany only own one vehicle. Most insurance companies refer to fleets of three or more vehicles as a fleet (transparent-beraten.de GmbH 2022). In their survey, Niebuhr and Jakobs (2020, p. 458) emphasise that the size of taxi companies often depends on local conditions and that these are often organised in local taxi associations. In Germany, the biggest stakeholders in the taxi industry are the “Bundesverband Taxi und Mietwagen e. V.” and the “Taxi and Rental Car Association Germany e. V.“ der „Bundesverband Taxi und Mietwagen e. V.“ und der „Taxi- und Mietwagenverband Deutschland e. V.“

Information on the average distances covered by a taxi range from 177 km in the day shift and around 168 km in the night shift (Niebuhr and Jakobs 2020, p.462) to 100 to 300 km in single-shift operation or up to 600 km in two-shift operations (Grausam et al 2015, p.158). Extrapolated over the year, taxis cover up to 63,000 km, which is around 6 times as much as an average car. In the German city of Hamburg, around 80 % of all journeys are ordered via phone (Freie und Hansestadt Hamburg 2021a). The Federal Office of Economics and Export Control (BAFA) supports the purchase of new energy vehicles as well as the purchase of used electric and hybrid vehicles with the Promotion of Electrically Powered Vehicles program, which is often also referred to as the Environmental Bonus. For vehicles with a net list price of less than EUR 40,000, the subsidy amounts to EUR 6,000. If the net list price is higher than EUR 40,000, the premium is EUR 5,000 (BAFA n.d.). This bonus can be combined with various support programs.[19]

4.2. Case Studies of Taxi Fleet Electrification

Hamburg: Pilot Project „Zukunftstaxi“

A total of around 2,700 taxis are driving in the northern German city, a number that has decreased drastically in the course of the corona pandemic (Norddeutscher Rundfunk 2022). As part of the „Future Taxi“ project, Hamburg is promoting the purchase of electrically powered taxis through various measures. In a press release, the Hanseatic City (2021a) emphasises that the project will be funded with up to EUR 3 million from the city´s climate fund, since the emission saving potential when converting the entire fleet is estimated at up to 25,000 t of CO_2 per year. In the first stage, companies that purchased emission-free vehicles were supported with up to EUR 10,000 over a period of two years. This phase included 130 electric taxis and 20 barrier-free electric taxis.[20] In the second phase of the project (as of April 2022), additional funding of EUR 5,000 each is available for 170 electrically powered vehicles.[21] Other measures by the city administration and the respective companies included improving the visibility and percep-

[19] A detailed overview of the funding rates as well as the eligible electric vehicles and the exact procedure of the funding process can be found on the BAFA website at https://www.bafa.de/DE/Energie/Energieeffizienz/Elektromobilitaet/Neuen_Antrag_stellen/neuen_antrag_stellen_node.html.

[20] Funding for barrier-free taxis stood at EUR 20,000 for 20 vehicles in the first phase and EUR 10,000 for 30 vehicles in the second phase (Freie und Hansestadt Hamburg 2021b).

[21] The exact processes for concessions and disbursement of subsidies can be found on p. 6 of the report of the Freie und Hansestadt Hamburg (2021).

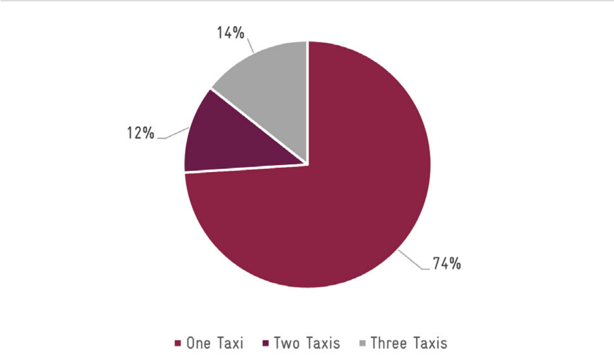

Figure 4: Ratio of single- and multi-car companies, as of December 2016.
Source: Bundesverband Taxi und Mietwagen e. V. (2020, p. 66)

tion of the electric taxis. To send a positive signal to citizens, a special project branding was implemented for electric taxis. The city of Hamburg also advertises these taxis with various environmental seals, which can be awarded to BEVs and contribute to their better perception (Freie und Hansestadt Hamburg 2021, p. 26 and p. 33). For online orders, a function for booking electric taxis directly via the "taxi.eu" app and a specific telephone number have been set up (Freie und Hansestadt Hamburg 2021, p. 26).

In addition, the city invested in the development of a comprehensive charging infrastructure. In direct exchange with the taxi companies, effective positioning of the charging stations was discussed and a total of more than 1,000 publicly accessible charging points in the city area (including 65 fast charging stations) were set up using only renewable energies (Freie und Hansestadt Hamburg 2021, p. 22). The charging stations were equipped with floor sensors to detect incorrect occupancy and to display availability in real-time via an app and on websites (Freie und Hansestadt Hamburg 2021, p. 22). At HAMBURG ENERGIE charging stations, only the charged electricity is billed regardless of the charging speed and taxi companies are waived the monthly basic fee (Freie und Hansestadt Hamburg 2021, p. 22). From the start of the project in 2021 to July 2022, 951 t of CO_2 emissions were saved by 202 electric taxis (Free and Hanseatic City of Hamburg n.d.).

Berlin: Funding Program for Business-Related Electromobility (WELMO)

At the end of 2021, just over 6,000 taxis were driving on the streets of the German capital, with a downward trend, just as in Hamburg (Neumann 2021). The funding program for business-related electromobility (WELMO) was initiated in 2020 by the Berlin Senate Department for Economics, Energy and Business to support the electrification of commercial vehicle fleets. The program is aimed at small and medium-sized companies in Berlin. In addition to an advisory service, the Senate Department provides funding to promote the commercial purchase of electric vehicles such as cars, vans, scooters, or pedelecs, which must be either battery-electric, fuel cell electric, or plug-in hybrids. Since July 2021, electric vehicles designed for passenger transport have only been subsidised for companies or self-employed people that have a valid taxi license. During the implementation of WELMO, the development of public and non-public charging infrastructure is also supported (IBB Business 2022). Since July 2021, the amount of funding for cars has covered around 25 % of the vehicle costs or a maximum of EUR 15,000 per vehicle (IBB Business 2022a). WELMO can be combined with the Environmental Bonus. Depending on the type of vehicle, the purchase of an electric taxi in Berlin can be funded with up to EUR 20,000, depicting a considerable incentive to switch to electric taxis. A total of EUR 15.6 million is available for the funding program for the 2022 and 2023 budgets. According to official information, 3,000 electric vehicles and 400 charging infrastructures in commercial estate, both AC and DC charging stations, have been funded to date (Werwitzke 2021).

4.3 Demands of the Taxi Industry

Taxi companies and associations are important stakeholders and political partners in Germany, without whom the transformation of taxi fleets cannot succeed. Concrete demands of the German taxi industry regarding the electrification of their fleets are presented below.

Survey of Taxi Companies in the Aachen Region

A study by Niebuhr and Jakobs (2020), in which six taxi companies in the Aachen[22] area were surveyed, resulted in the following demands for the electrification of the taxi industry: Firstly, drivers and taxi companies should be better informed about electric taxis and funding options through consultations or industry-specific information[23]. Sample calculations for the „Total Cost of Ownership" (TCO) and specific electricity bills contribute to a better understanding of the electrification of fleets (Niebuhr and Jakobs 2020, pp. 459-460). The public charging infrastructure and in particular fast charging stations would have to be greatly expanded. As a downside of wired charging the following issue was raised: According to the position of the charging station at the taxi line, either at the beginning or at the end of the line, customers may be lost or conflicts with other drivers may occur. Therefore, in addition to specific electric taxi stands, the further development of inductive charging technologies was called for (Niebuhr and Jakobs 2020, pp. 458 and 465). In addition, the local taxi industry should be involved in the charging infrastructure planning process at an early stage to help reduce conflicts in infrastructure usage (Niebuhr and Jakobs 2020, pp. 467-468). The weather conditions in winter are seen as a particular challenge, since the use of heating leads to significantly higher power consumption and cold temperatures put a much greater strain on the battery (Niebuhr and Jakobs 2020, pp. 462-463). Half of those surveyed indicated 400 km as the necessary minimum range for electric vehicles, while two respondents called for a minimum range of 190 km. In addition, a larger selection of models was desired in order to be able to meet different requirements (e.g. inclusion taxi, large-capacity taxi, small models). At the same time, however, financing must be guaranteed, especially for smaller companies (Niebuhr and Jakobs 2020, p. 464). To improve the visibility

[22] Niebuhr and Jakobs (2020) provide a detailed overview of the taxi companies surveyed on p. 461. They emphasise that this is not a representative study of the taxi industry due to the small sample size. They underline further that studies should pay particular attention to local conditions.
[23] On p. 467 of their study, Niebuhr and Jakobs (2020) list numerous potential aspects of an information brochure.

of electric taxis, special ordering systems are to be set up that enable customers to specifically request electric taxis when ordering by telephone or digitally (Niebuhr and Jakobs 2020, p. 458).

Integration of Electromobility in Fleets – Survey of Fleet Operators

In the report „Recommended actions for the integration of electric mobility in fleets for fleet operators", Grausam et al. (2015)[24] surveyed fleet operators who already have electric vehicles. Grausam et al. (2015, pp. 28-30) named high mileage, consistent and plannable driving profiles, a high proportion of city trips, and sufficiently long idle times for charging as decisive factors for the economic use of electric vehicles. In this context, charging technology becomes particularly relevant when the daily mileage exceeds the range. In addition to subsidies and the promotion of charging infrastructure, fleet operators are demanding preferential treatment for electric vehicles, for example through tax reductions or specific parking zones (Grausam et al. 2015, p. 31). The training of drivers and fleet operators is crucial for the sustainable use of vehicles. Moreover, drivers can pass on knowledge to customers and thus promote acceptance (Grausam et al. 2015, p. 166).

Bundesfahrplan eTAXI – Demands of the Bundesverband Taxi und Mietwagen e. V.

In fall 2021, the German Taxi and Hire Car Association (Bundesverband Taxi und Mietwagen e.V.) presented the „Bundesfahrplan eTaxi. Climate Path for Zero-Emission Passenger Transportation", which includes demands and proposals for the electrification of taxi fleets. The plan envisions electrifying 25 % of all taxis by 2025 and 80 % of all taxis by 2030, which could save up to 675,000 t of CO_2 per year, according to the association (Bundesverband Taxi und Mietwagen e.V. 2021, p. 1). The presented triad „promote, demand and connect" describes the building blocks that are necessary for the electrification of fleets from the point of view of the German Taxi and Hire Car Association. The proposals and requirements contained therein are summarised below (Bundesverband Taxi und Mietwagen e.V. 2021, pp. 3-7): Under the heading „promote", a degressive subsidy of EUR 15,000, decreasing over time, is proposed.[25]

[24] In their report on pp. 157-167, Grausam et al. (2015) describe an example of a concrete procedure for the electrification of a taxi fleet, from fleet analysis and definition of goals to insurance, network analyses and user acceptance, based on a fleet of 52 vehicles.

This could provide incentives for taxi drivers to switch to a battery electric or fuel cell vehicle as quickly as possible. A total of EUR 390 million in funding ought to be made available by 2030, which could support the purchase of 40,000 vehicles in total. According to the proposal, around EUR 50 million would have to be made available annually for the electrification of taxis, with 40,000 vehicles representing a large proportion of the taxis operating in Germany. At the same time, the Bundesverband Taxi und Mietwagen e.V. „demands" the early communication of binding specifications, such as entry restrictions and proposes the introduction of a sign „eTAXI" to facilitate the identification of an emission-free vehicle and the establishment of special electric taxi stands. The taxi association also calls for a government electricity price guarantee until 2030 of 30 cents/kWh for AC charging and 50 cents/kWh for DC charging.[26] This is intended to counteract the uncertainty in the development of electricity costs and provide additional incentives for the purchase of electric vehicles. The call for the development of a dense charging infrastructure is mentioned by the association under the keyword „connect", suggesting synergies between public transport and taxi companies, which could share a charging infrastructure. It also proposes the establishment of regional round tables on the electrification of taxi fleets to promote electrification in a dialogue between companies, municipalities, and vehicle manufacturers.

[25] Bundesverband Taxi und Mietwagen e.V. (2021, pp. 4-5) proposes a dynamic degression of one percent compared to the previous month so that the subsidy decreases over time, but at the same time reacts flexi-bly to the number of subsidy applications submitted. The ability to combine this with other funding pro-grams should be maintained (Bundesverband Taxi und Mietwagen e.V. 2021, p. 5).

[26] In addition, the Bundesverband Taxi und Mietwagen e.V. (2021, p. 7) suggests that the difference between the guaranteed electricity price and the actual costs should be returned via a tax relief.

5 Recommendations

The experiences gained from the electrification of taxi fleets in major Chinese cities offer relevant insights into the legislative framework as well as operational requirements on the part of the taxi industry. These learning can be similarly taken into account when planning the electrification of taxi fleets in Germany and beyond.

5.1 Political Recommendations

1. Acceptance: When designing incentives for fleet operators, acceptance must be created to make the purchase of electric taxis attractive. Specific information on the electrification of taxi fleets (funding opportunities, vehicle models, operating concepts, total cost of ownership) can contribute to a better understanding and be supportive of the transformation. The continuous exchange between representatives of the taxi industry, politicians and experts is crucial for a favourable transformation of fleets.

2. Operational costs: Setting a price cap for charging costs over a certain period, as was the case in China, provides taxi drivers with planning security and creates additional incentives.

3. Incentive policies: Drivers and fleet operators should be able to choose from a variety of models to purchase a vehicle that meets their specific needs. Surveys and studies have shown that ranges of at least 300 km are required. In addition, the use of electric taxis by users could be made more attractive by explicitly subsidising the services of drivers using electric taxis through policy measures. This would provide incentives for other taxi drivers to switch to electric vehicles.

4. Charging technologies: When introducing new technologies such as battery swapping or inductive charging, up-front technical standardisation is critical to maintain the competitiveness of different providers and offer users choice and long-term availability/planning certainty. The development of comprehensive charging infrastructure should also be a priority for the government.

5. Push factors: To facilitate the rapid electrification of the taxi industry, the registration of new taxis could be limited to electrically powered vehicles, or other benefits such as a simplified registration procedure for electric taxis.

5.2 Operative Recommendations

1. Real-time data: A platform with real-time data on forecasting and actual usage of charging stations can improve the utilisation of charging infrastructure and help reduce waiting times. Optimal distribution of electric taxis at charging stations through real-time data contributes significantly to the economic viability of charging stations and can help municipalities predict energy needs as well as better coordinate demand through data analysis (Bauer et al. 2021, p.10). The availability of GPS data can also help determine optimal locations for charging stations as well as the necessary range requirements for fleets. Basically, planning charging infrastructure with regard to the accessibility of taxis should take place in constant exchange with fleet operators and taxi companies.

2. Charging behaviour: Vehicles should be charged primarily at night and during break times to minimise loss of income due to the time spent while charging. To ensure a long life of the vehicle battery, both taxi drivers and fleet operators should receive training on how to handle the electric cars and how to optimally charge the battery.

3. Labelling: The set-up of an explicit online function for ordering an electric taxi as well as specific labelling at the taxi stand and on the vehicle itself support the perception of electrified vehicles and can help customers in their decision to choose a vehicle. Separate and conspicuous labelling of electric taxis should be introduced. Consumers´ increased environmental awareness could give them a competitive advantage over internal combustion engine taxis.

6 Conclusion

The electrification of taxi fleets in China is characterised by the rapid conversion of large fleets, supported by massive government subsidies. The political framework conditions, the high subsidy rates and the expansion of the public charging infrastructure favour the switch to electric taxis. Regarding the transferability of the results to the German taxi industry, it must be noted that 74 % of all taxi companies in the Federal Republic are operated by individual companies. Support of the electrification of taxi fleets through financial means can only be carried out by German city states such as Bremen, Hamburg or Berlin, which have sufficient financial resources. In the future, the federal or singular state governments could provide political support for the electrification of taxi fleets. Additional consulting and funding programs for the conversion of taxi fleets, based on the Hamburg or Berlin model, are likely to meet broad consensus. More far-reaching would be a legal regulation that obliges taxi companies to purchase only electric cars as new vehicles. Whilst the respective legal framework would have to be evaluated beforehand, regulation through the taxi concessions would appear as a suitable solution. For this far-reaching measure, however, further progress would first have to be made in expanding the charging infrastructure, especially in rural regions. In regions without sufficient charging options, the potential of battery swapping stations could come into play. The mix of different charging solutions could also bring about improved infrastructure for electric vehicle operation in certain areas. This report looked at the electrification of taxi fleets in major cities in China and Germany. Taking a holistic view of the transport transition, future studies should also take a closer look at the potential and challenges of electric taxis in rural areas and the role of on-demand transportation and ride hailing.

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