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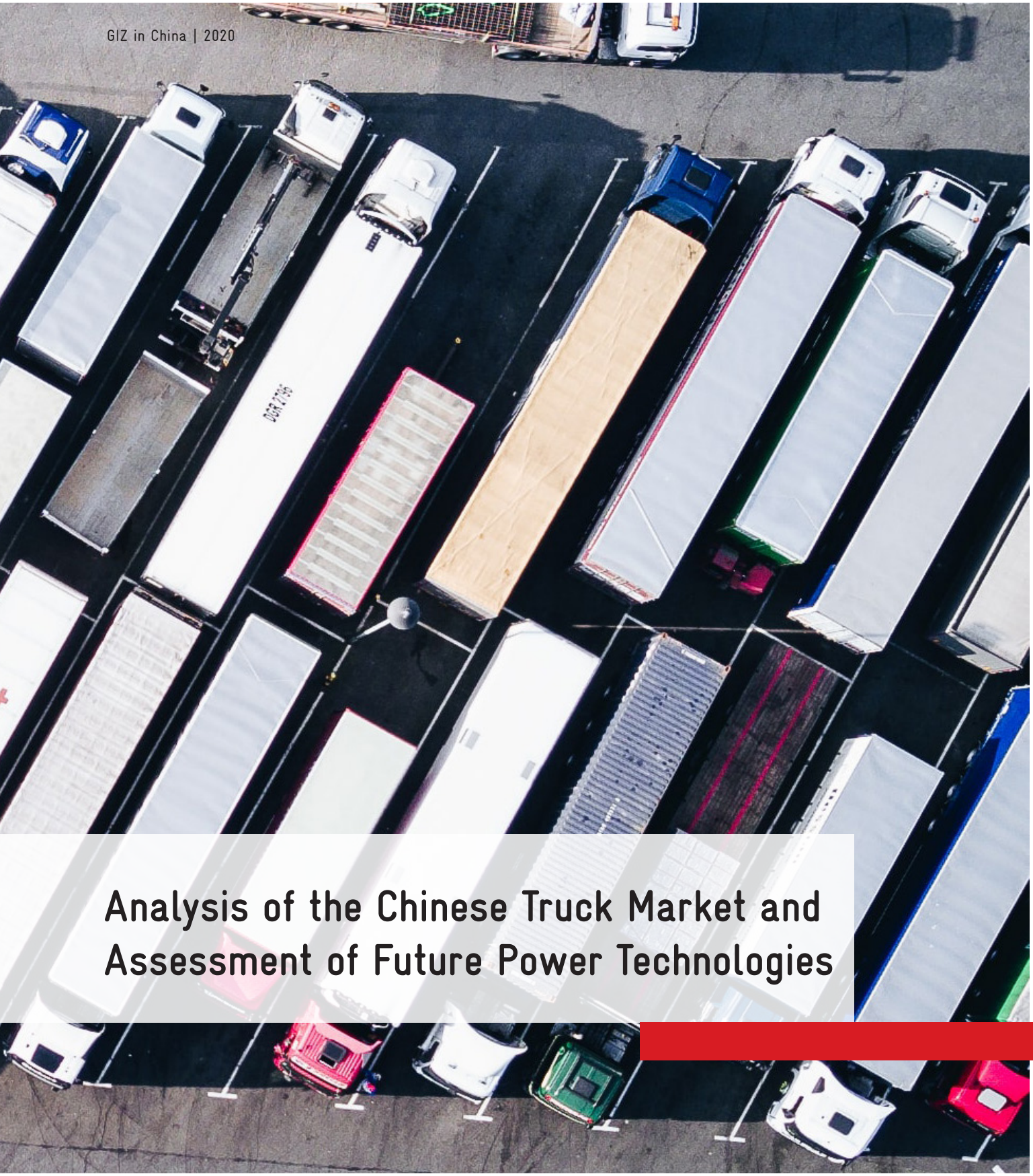

Analysis of the Chinese Truck Market and Assessment of Future Power Technologies

On behalf of

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Mobility and Fuels Strategy (MFS) as a Contribution to the Traffic Transition in China - Pilot project in the Jing-Jin-Ji region

Sino-German Cooperation on Mobility and Fuels Strategy (MFS) as a Contribution to the Mobility and Transport Transition

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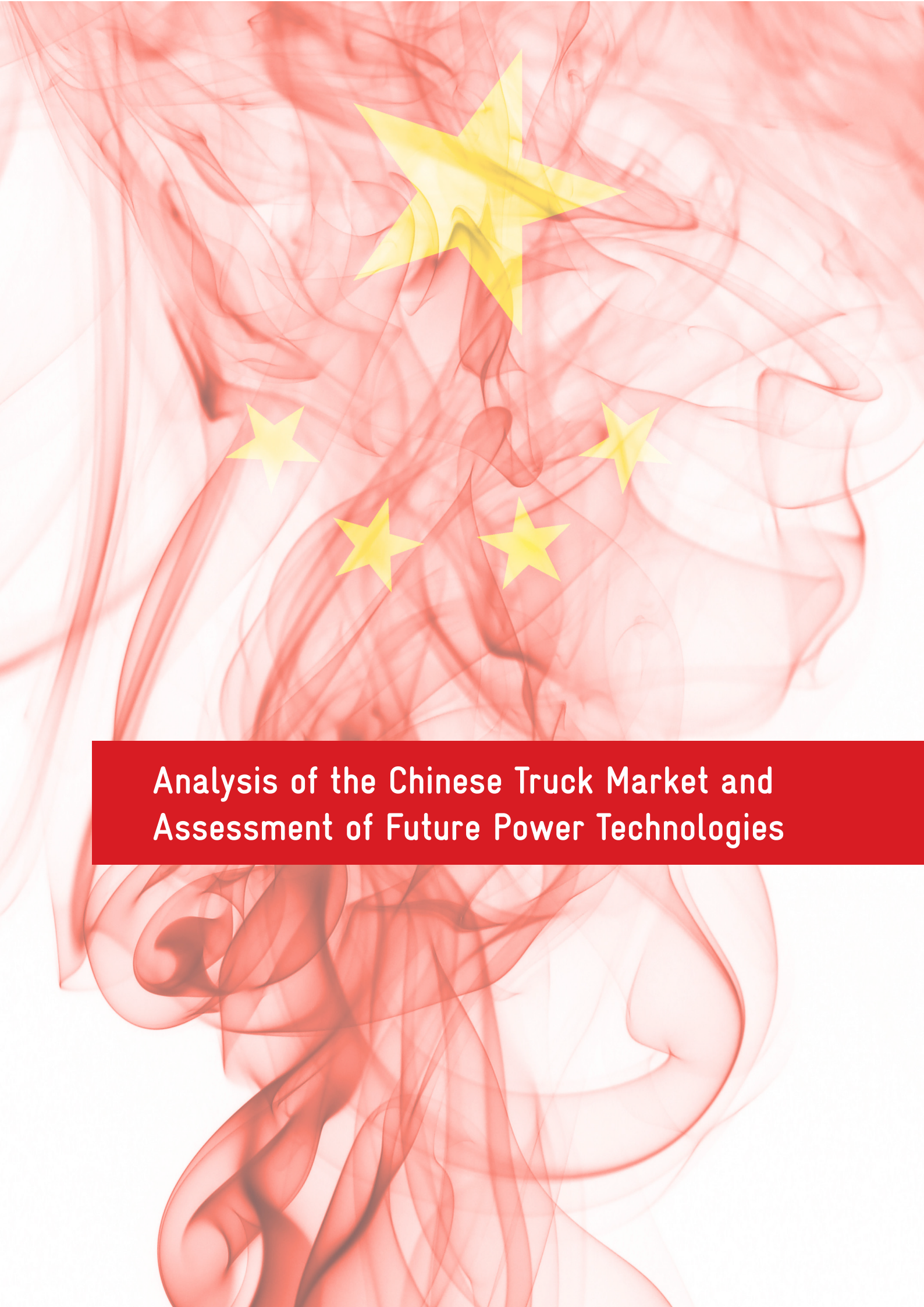

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Abbreviations

BAIC	BAIC Motor Corporation
BEV	Battery Electric Vehicle
BRI	Belt and Road Initiative
CNG	Compressed Natural Gas
CNHTC	China National Heavy Duty Truck Group
CO	Carbon Monoxide
FAW	First Automotive Works
FCEV	Fuel Cell Electric Vehicle
HC	Hydrocarbon
HDV	Heavy-Duty Vehicle
ICV	Intelligent and Connected Vehicle
JAC	Anhui Jianghuai Automobile
Jing-Jin-Ji	Beijing-Tianjin-Hebei
JV	Joint Venture
LNG	Liquified Natural Gas
MEE	Ministry of Ecology and Environment
MoST	Ministry of Science and Technology
MoT	Ministry of Transport
NOx	Nitrogen Oxide
OEM	Original Equipment Manufacturer
PHEV	Plug-in Hybrid Electric Vehicles
PM	Particulate Matter
PM2.5	Particulate Matter with a maximum diameter of 2.5 μm
RMB	Renminbi
SAIC	SAIC Motor
SOx	Oxides of Sulphur
STNE	Shanghai Sinotran New Energy Automobile Operation
TCO	Total Cost of Ownership

1. Introduction

In Chinese cities, the average concentration of PM2.5 – fine particulate matter with a maximum diameter of 2.5 µm – is about 48 micrograms per cubic meter of air (µg/m³). That is more than double the world average of 19 µg/m³ [1]. In particularly highly populated areas such as the Beijing-Tianjin-Hebei region (also known as the Jing-Jin-Ji region), the PM2.5 concentration far exceeds the recommended standard of 10 µg/m³ of the World Health Organization (WHO) [2]. While the reasons for the notoriously poor air quality in China are manifold, road transportation is considered to be one key culprit behind air pollution. In fact, experts estimate this sector, which accounts for more than 75 % of the entire Chinese transport volume, to be the second largest driver of air pollution in China [1].

What merits further attention is the negative impact of commercial vehicles and, more specifically, trucks upon air quality. As demonstrated by Figure 1, while trucks in China account for 11 % of the total vehicle stock in 2017, they release far higher emissions of PM and Nitrogen Oxide (NO_x)[1]. Specifically, 10 % of overall Carbon Monoxide (CO) emissions are caused by trucks, with the share of Hydrocarbon (HC) (19 %), NO_x (57 %) as well as PM (78 %) being even higher. [3]

In light of these findings, the Chinese government is paying increasing attention to the truck sector in its fight to mitigate air pollution. In addition to critical influence in the environmental sphere, China's truck sector is also worth studying due to its special role in technological developments: Since total costs of ownership (TCO) have gained increasing relevance for Chinese truck customers [4], the sector holds great potential for autonomous driving technologies. This is mainly due to the fact that – alongside the cost for fuel – the expenditures for human drivers account for

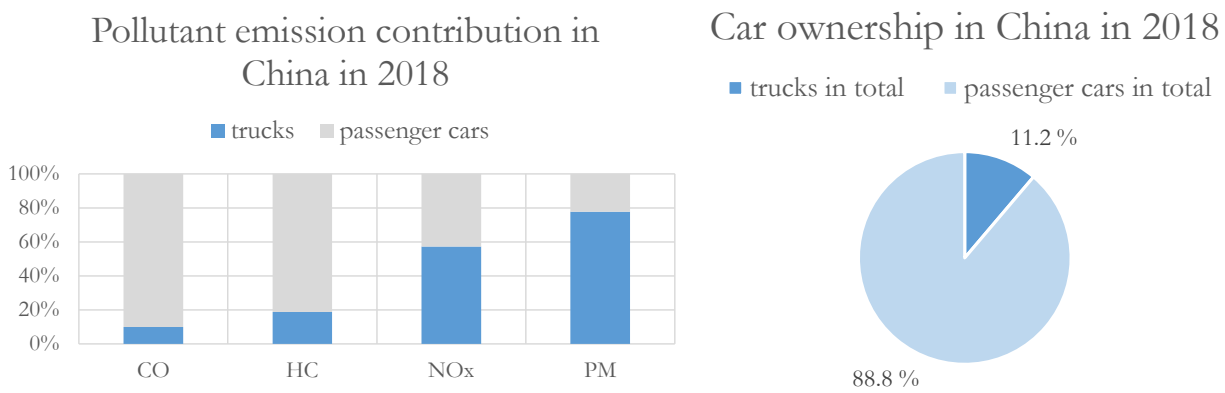

Figure 1: Share of pollution by passenger cars and trucks compared with their total stock in China. Own graphs, based on data derived from China's Ministry of Ecology and Environment (MEE) [3]

[1] In addition to PM2.5 and the bigger PM10 particles, Carbon Monoxide (CO), Hydrocarbon (HC) and Nitrogen Oxide (NO_x) are considered as components of air pollution.

the lion's share of TCO for China's trucks [5]. This share could be significantly reduced with further progress in autonomous driving, especially in regards to specific applications such as inter-city transportation.

Given the central role of the truck industry within China's economy and the country's environmental efforts, this report seeks to provide a comprehensive overview of the truck market in China (first part of the report) and analyze potential future trends in the Chinese truck industry, especially with regard to the use of alternative power resources (second part of the report). The market overview will encompass a survey of the market structure, the key manufacturers as well as the main policy developments and their effect on the market. The outlook on future trends will entail an assessment of various alternative power modes, particularly with regard to the options for different usage scenarios (inner-city distribution, inter-city transportation or specific construction). Finally, the conclusion will provide a critical summary of the research findings and highlight respective policy recommendations.

2. The Chinese Truck Market – Structure, Key Players and Policy Impact

To provide a comprehensive overview of the Chinese truck market, one must first actually define what types of vehicles the term "truck" encompasses. Most importantly, there is no universal definition, especially since trucks themselves are often again classified into further categories. While the European Union (EU) uses the categories of N2 (vehicles weighing more than 3.5 tons) and N3 (vehicles weighing more than 16 tons), the description of light- (3.5-7.5 tons), medium- (7.5-12 tons) and heavy-duty (more than 12 tons)[2] vehicles are commonly used in China. [6] [7]

Since this report particularly focuses on the use of new energy sources, the term "trucks" here will refer to all motor vehicles with (1) at least four wheels, (2) a minimum weight of 3.5 tons which are (3) used for the transportation of goods. This definition allows to capture new developments that typically evolve from niche markets or special applications (e. g. electric-based urban delivery).

2.1. Structure and Important Players

In China, truck sales reached a new peak in 2017, with more than 1.1 million vehicles sold (see Figure 2). In stark contrast, truck sales in Europe were less than half (slightly above 300,000 units) in the same year [8]. Compared to 2016, this represents an increase of more than 50 %, following a clear upward trend from 2015 onwards. This pattern is also likely to continue, with sales again expected to have exceeded one million trucks throughout 2018. [9]

According to HSBC Global Research, this growth can be mainly traced back to new regulations and policies. First, over recent years the Chinese government passed stricter regulations on overloading as well as on emission limits that together led to a higher demand for vehicles [10]. Those new regulations logically make companies use a greater number of vehicles for transporting their freight. As a result, the average size of trucks per company or fleet

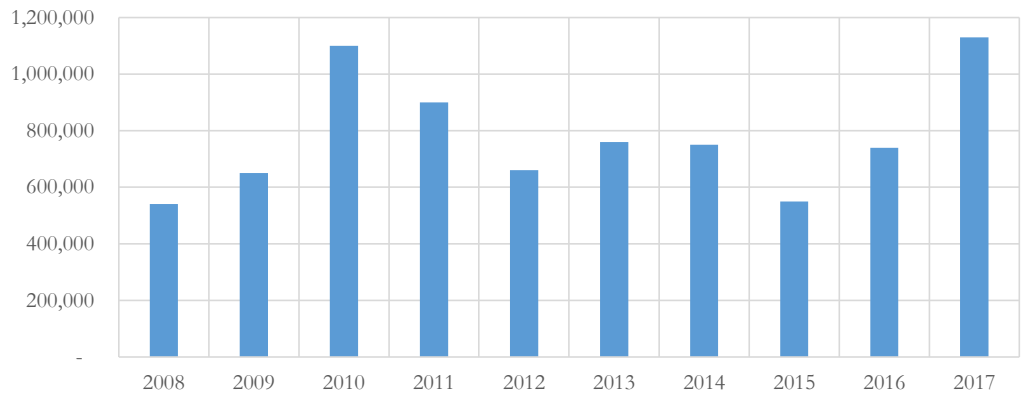

Figure 2: Number of trucks sold in China between 2008 and 2017. Own graph, based on data derived from HSBC Global Research, 2018 [9]

[2] All weights are based on gross vehicle weight that includes the weight of the vehicle itself plus the weight of the passengers and cargo.
[3] The respective years are 2009, 2011, 2012 and 2013.

sprang from two vehicles in 2008 to nearly six vehicles in 2016 and is expected to grow up to seven vehicles in 2019. Further reasons for the industry's growth are both the high demand for construction and urban logistics and also the relatively short life spans of trucks. This span ranges between five and ten years. Hence, the vehicles sold in the peak year of 2010 are starting to be replaced. [10]

When looking more closely at the truck types sold in the Chinese market, one observes an increased share of tractor-trailer combinations (52 %), while the shares of chassis (27 %) – often used for construction purposes – and the combined chassis trucks (21 %) decreased. When comparing this with the data gathered over the past ten years, where the share of sold tractor-trailer combinations was the lowest in several years[3], this development signals a shift towards the logistic sector, since these types of trucks are often used for logistical purposes. [9]

Similar to the European truck market, where more than 86 % of all vehicles were produced by the five largest manufacturers in 2017 (Daimler, MAN, Volvo, Scania and DAF)[4], the structure of the Chinese manufacturers is highly concentrated [11]. More precisely, in China, the five largest truck manufacturers account for 83 % of the total truck market (see Figure 3). The main reasons for the global concentration of the truck industry include the high fixed costs for production facilities, the need for large scale manufacturing to ensure profitability and the requirement of an extensive skilled workforce. [10]

The top five Chinese truck manufacturers include three state-owned companies, that also play a central role in the car sector (ranked top ten in sales numbers), namely: First Automotive Works (FAW), the Dongfeng Motor Corporation and the BAIC Motor Corporation (BAIC), with its subsidiary FOTON.

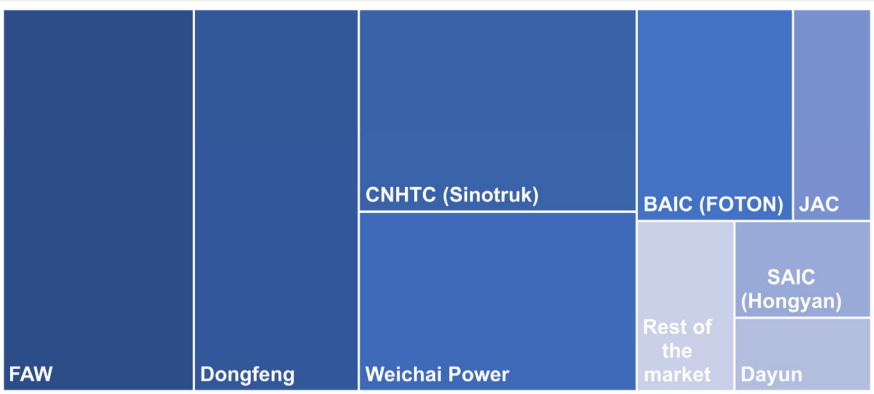

Figure 3: Market share of Chinese truck manufacturers. Own graphic, based on data derived from HSBC Global Research, 2018 [9]

[4] If counting MAN and Scania as one brand (both belong to Volkswagen), the number of manufacturers would be even less.

Figure 4: Overview of the car and truck OEMs in China. Own illustration, based on data from Statista, 2017 [12] and South China Morning Post, 2017 [13]

Furthermore, SAIC Motor (SAIC), with its subsidiary Hongyan, and Anhui Jianghuai Automobile (JAC) are also manufacturing trucks. Both companies also produce passenger cars, highlighting the close link between the car and truck businesses in China (see Figure 4). Exception to this trend is presented by Weichei Power and China National Heavy Duty Truck Group (CNHTC), with its subsidiary Sinotruk, which are the only two Original Equipment Manufacturers (OEMs) that are currently active in the truck business and do not manufacture passenger cars. The firms BYD Automobile and Brilliance Auto China are shown as special cases, since according to sales numbers they do not hold a leading role in neither the car nor truck markets, but are well-known in the business as the worlds largest manufacturer of electric cars, buses, trucks as well as machninery and strategic Joint Venture (JV) partners with BMW respectively[5].

Similar to the passenger car industry, many Chinese OEMs in the truck sector cooperate with foreign companies via Joint Ventures to develop and produce their vehicles. Figure 4 presents the foreign JV partners, which are framed with a blue square and positioned right next to their Chinese partners. As Figure 4 illustrates, with Dongfeng and Volvo, BAIC and Daimler, SAIC and Iveco, JAC and Navistar as well as CNHTC and MAN, five out of the top seven truck manufacturers according to sales figures (see Figure 3) work in cooperation with non-domestic partners. The only exceptions are Weichai Power and FAW, that, thus far, have not entered into partnerships with foreign companies in the truck industry [13] [14].

When analyzing the Chinese truck market, one also needs to consider the export capability of Chinese firms. In 2017, around 200,000 trucks were exported from China – an increase of 10 % compared with 2016 [15]. In comparison to

[5] First automotive joint venture that is no longer relying on the 50 % rule for foreign companies and therefore allows shares in a Joint Venture with more than 50 % (BMW 75 %).

the overall sales statistics, these relatively small numbers show that China's OEMs rely heavily on domestic demand. In terms of industry players, CNHTC, with its subsidiary Sinotruk, is China's leading truck export company. In 2017, the company had a market share of overseas sales of 13 %, whereof central Asian countries account for the largest share. [9]

In previous years, Chinese truck exports have proven to be highly volatile with a relatively small overall growth rate of 2 % since 2009. [16] This is mainly due to the fact that – given China's weakness in highly motorized engines – the country mainly exports smaller trucks to regions such as Latin America, Russia, the Middle East and North Africa. Since countries in these regions crucially depend on oil earnings, the demand for Chinese trucks varies according to the fluctuations of the global oil price. However, under China's Belt and Road Initiative (BRI) – a global strategic infrastructure project initiated by the Chinese government in 2015 – Chinese trucks have recently gained improved market access to Australia, New Zealand, Russia, Kazakhstan, Singapore and other relatively developed countries. Therefore, Chinese truck companies are currently expanding their production capacity overseas and aim to raise their export numbers. For instance, Weichai Power has set up a spare part centers in Algeria, Dongfeng and CNHTC operate assembly lines in both Iran and Morocco. [16]

2.2. Role of Current Policies

As demonstrated by the example of the BRI, government policies play a crucial role in shaping the developments of China's truck market. This chapter will, therefore, grant an overview of the most important regulatory instruments for diesel trucks. Policies targeting the development of alternative power sources for trucks will be discussed in the next section.

Similar to the EU and the United States, China uses national standards to control and reduce emissions, such as NO_x or Oxides of Sulphur (SO_x). In January 2017, the latest national standard, China V, came into effect. In comparison to the former China IV standards, China V mainly strives to limit sulfur content in fuel to 10 parts per million – one fifth of the China IV's 50 ppm requirement. [9] According to an announcement by the MEE in June 2018, the latest emission standard, China VI, will be implemented between 2019 and 2021 for all heavy-duty vehicles[6]. This new piece of regulation – that is said to be more stringent than the Euro VI emission standard – aims to reduce the NO_x emissions by more than 77 % and PM emissions by more than 67 % compared with the previous regulation China V [17]. In a next step (China VIb), China plans to reduce emissions even further by 2030 (see Figure 5). Hence, this move is expected to cut annual PM2.5 emissions by 5 % in China. [18]

[6] Heavy-duty vehicles refer to buses as well as trucks.

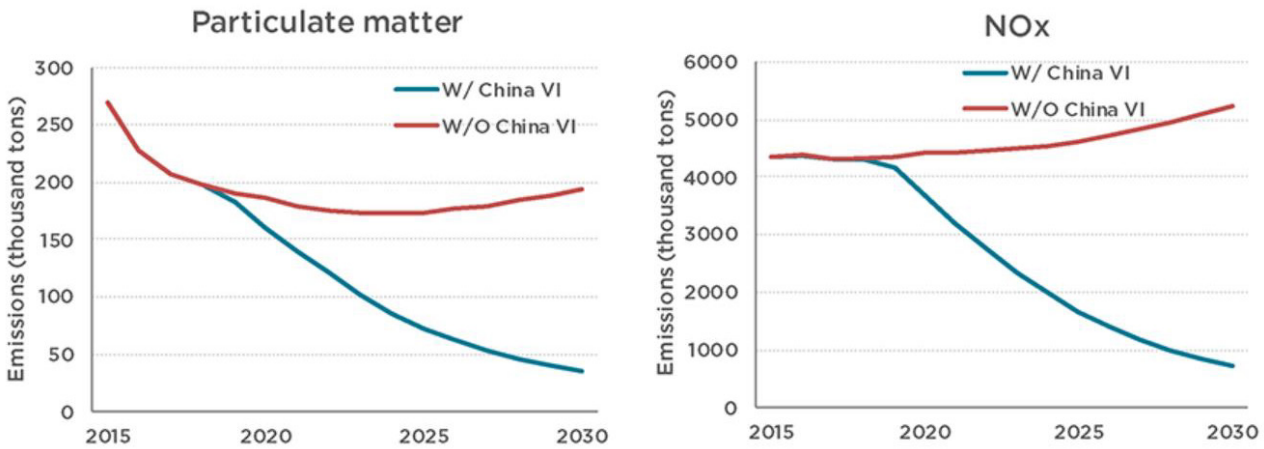

Figure 5: China VI – Proposed mid- and long-term emission reductions.
Climate & Clean Air Coalition, 2018 [18]

In addition to new regulations concerning emission standards, different levels of the Chinese government (local, municipal, national) use various instruments to regulate the production and use of trucks. Important and recent examples are outlined below:

1. By 2020, China plans to remove one million diesel trucks, which fall below the national standard China III[7] within the Jing-Jin-Ji region. This measure was announced in July 2018 by the Ministry of Transport (MoT) and the State Council. The apparent goal is to shift cargo from road to rail transportation as well as to enhance environmental well-being, specifically in regard to urban roads. [19]

2. In June 2018, several specific targets for 2020 were set by the State Council with the goal of protecting the environment and mitigating air pollution. In combination with cleaner ports and an increased share of railway transportation, the truck sector is supposed to play a crucial role in reaching targets regarding pollution reduction: Improvement in these three fields are expected to decrease the amount of cities that fail to meet PM2.5 standards by 18 % and to reach 80 % more days with good air quality in cities. However, similar to various other announcements, specific details on how to implement such measures have not been offered. [20]

3. In 2017, the Tianjin Port as well as several other ports in the province of Shandong banned diesel trucks from transporting coal. [21] Due to the fact that port areas also account for a high share of air pollution, these regions are of particular political interest when it comes to new regulation from the Chinese government.

[7] China III was implemented in 2008.

4. In order to comply with port regulations and manage diesel truck bans in winter times, many Chinese provinces are increasingly focusing on railway transportation. For instance, the responsible transportation office of the province of Hebei[8] in August 2018 announced its decision to shift deliveries of coal and steel to rail transportation instead of relying on trucks. The goal is to shift all major deliveries of such goods to rail transport by 2020. [22]

Although one would expect these policies to reduce the demand for trucks, historical data shows that, paradoxically, new regulations actually have often strengthened the demand for trucks. [9] In general, new regulations often complicate the use of older vehicles while also generating several advantages for vehicles using new technology. Therefore, it is often the case that increased investments in new vehicles are made when new policies are implemented. For instance, it is expected that due to the upcoming national standards China VI for heavy-duty vehicles, the relatively high sales figures for trucks from 2017 will continue to also be stable in the upcoming years.

Lastly, in light of increasing restrictions for diesel engines, the sales numbers of trucks relying on new power sources like Liquefied Natural Gas (LNG) or Compressed Natural Gas (CNG), electric powered engines like in Battery Electric Vehicles (BEV) or Fuel Cell Electric Vehicles (FCEV), can be expected to further increase.

[8] The province Hebei is part of the highly populated Jing-Jin-Ji region.

3. Alternative Power Sources and their Role in the Chinese Market

As previously mentioned, one million trucks in the Jing-Jin-Ji region that do not fulfill the National III Standard, will be decommissioned by 2020 and will be largely replaced by new or clean energy vehicles. Therefore, this raises the question on how these new developments in the truck sector will look like.

Importantly, when analyzing the options for alternative power sources in the truck sector, one has to bear in mind the sector's specific characteristics:

1. Since the annual driven mileage of trucks is five to seven times higher[9] [23] than that of regular cars, the maintenance costs are often more important than the initial sales price. Therefore, changes regarding the ongoing costs have a higher impact on the buyer's decision.

2. Furthermore, the reliability of vehicles is of profound importance in the truck business as inoperative vehicles often lead to high costs and less flexibility for firms.

3. Freight transportation via trucks commonly adheres to planned and fixed routes, time pressure and – depending on a country's legal framework – regulated driving schedules.

4. Truck-based transportation companies typically expect a high capacity efficiency, which in turn requires minimum driving ranges in order to avoid nonproductive recharg-ing or fueling time [23].

3.1. Natural Gas Applications – Liquefied and Compressed

China is the world's main source of increased demand for natural gas, being responsible for one third of the global demand growth in 2017. While natural gas is used as an energy source in many different sectors and industries, transportation so far holds a minor role (8,3 %) [24]. However, over the last years, natural gas has become the most commonly used alternative energy source to diesel, especially in China's road transport sector. In 2017, China's OEMs produced 96,000 trucks that were powered by LNG, which represents a share of nearly 10 % in the Chinese truck sector. In comparison to 2016, when merely a total of 19,600 LNG trucks [25] were produced, this constitutes a strong increase in demand for this power source and highlights the strong need for alternatives to traditional diesel engines.

LNG is produced by cooling down the primary gas, which mainly consists of methane, to -162 °C where it gets liquefied. Therefore, the density can be increased 600-fold in comparison to the standard conditions of the gas [26]. The alternative compressed version (CNG) is another option to increase the energy density of gas, whereby the primary gas is compressed with a maximum of 250 bar [26], and therefore provides an increased energy density. However, neither can reach the energy density of diesel. While the energy density of

[9] Data is based on the German truck use.

LNG compared to diesel is about 58 %, the energy density of CNG is half compared to LNG, which further increases the demand of storage to reach an acceptable driving distance for trucks [27]. Given this disadvantage, CNG has lagged behind in China's recent development compared with LNG.

One of the main advantages of LNG is its price and therefore the operating costs compared with diesel vehicles. The costs of diesel at Chinese service stations are estimated 10-30 % higher than the costs of gas and therefore, the higher purchase prices[10] of LNG trucks can be compensated in the best case after one year of operation. [28] This advantage is widely seen as central driver for the increasing demand of LNG vehicles in China over the last years. In light of the increasingly stringent regulations regarding diesel (e. g. China VI) and a further expected rise in prices, the price advantage of LNG is likely to grow even further in the coming years. Such an event might, in turn, induce a further growth of LNG demand. In addition, new regulations such as China VI will also lead to the tightening of the emission standards for NO_x as well as PM. Since, similar to CO_2 emissions, gas engines are less polluting, the usability of LNG is further strengthened with such stricter emission standards. Figure 6 compares LNG trucks with diesel trucks based on the sector key requirements mentioned above (1-4).

In general, the key Chinese truck manufacturers are active in deploying LNG technologies. China's leading manufacturers of LNG trucks are FAW and Weichai Power, with nearly 20,000 produced vehicles in 2017 each. Together, they accounted for over 40 % of the Chinese production in the same year. CNHTC (14.1 %) and Dongfeng (13.2 %) have lost market shares compared with 2016 when shares were more equally distributed with Dongfeng in a leading position (4,200 vehicles) [29]. FAW and Weichai Power will therefore most likely be the main beneficiaries of an upcoming increase in LNG sales.

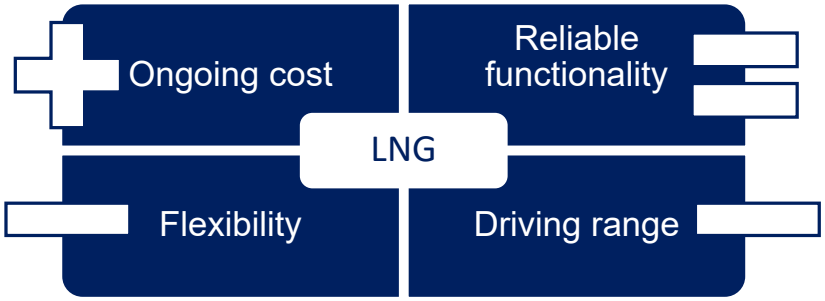

Figure 6: LNG comparison (+ / = / -) with diesel trucks on the sector's key requirements (1-4). Own graph, based on previous analyses

[10] The purchase price of LNG trucks around 6,000 EUR higher, depending on the specific model.

Overall, the LNG truck market is less concentrated compared with the overall truck market, indicating that natural gas is widely seen as an important upcoming alternative to diesel. Furthermore, the purchase of LNG trucks is supported by government promotions up to 10,000 RMB (Renminbi, around 1,300 EUR) and additional local or municipal subsidies of up to 20,000 RMB (around 2,600 EUR) [30] combined with direct subsidies for LNG fueling.

3.2. Electric Powered Trucks – An Analysis of Several Options

Especially in the Chinese passenger car sector, electric powered vehicles have grown more important over the last years, with China as leading market for electric vehicles worldwide. As previously highlighted, the reduction of emissions from trucks is of particular interest, especially in urban areas. In such urban environments, there are several applications, like trash collection [31], which rely on relatively short driving ranges, predictable driving routes and mainly daytime use, making them more applicable for electric powered engines.

When analyzing the market of electric powered trucks[11], one has to distinguish between several technical solutions: On the one hand, there is the option of infrastructure-bound power supply. Figure 7 below visualizes the three respective technical options of overhead contact line, contact rail and contactless inductive charging.

All of these variants require an adequate infrastructure. To make them more flexible, trucks could also be equipped with an additional diesel or electric engine to ensure short-term power supply for infrastructure gaps.

The more commonly known way of power provision is through lithium-ion batteries. Due to the high energy consumption of heavier trucks in particular, the limited driving range combined with the weight of the vehicle is the main challenge for this technology. To put this in perspective, providing a driving range of 200 to 300 km for a truck with a gross vehicle weight of 18 tons, requires a total battery weight of 2 to 3 tons [32]. This challenge manifests itself even further if a certain scenario, for instance inter-city transport, requires longer driving ranges or if the energy consumpti-

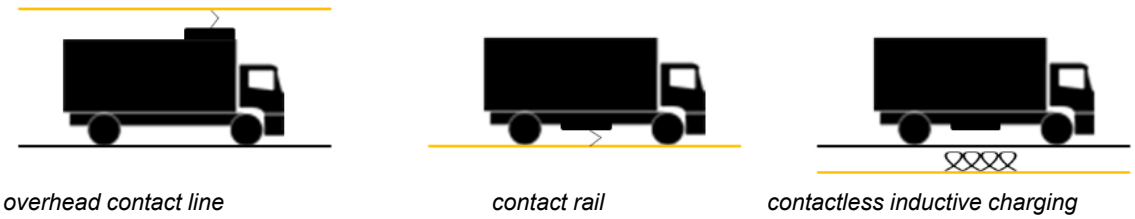

Figure 7: Overview of infrastructure charging options during operation. Wietschel, et al., 2017

[11] As the fuel cell technology is of particular relevance for this report, it will be analyzed in detail in the next section, although it is officially classified as electric power.

on rises due to higher gross weights.

There are several options to tackle these challenges. First, the development of solid-state batteries is an innovation that aims to improve driving ranges as well as the safety level of lithium-ion batteries. With the use of solid electrolytes instead of liquid ones, those batteries have the potential to provide a two- to threefold higher energy density and therefore longer driving ranges. However, this has been a highly controversial topic, especially in China. In particular, manufacturing these types of batteries at a large scale and at an attractive price, has not yet been accomplished [33]. Therefore, this development needs to be observed, but so far, its potential is difficult to assess.

Another option to compensate the limited driving range is the use of Plug-in Hybrid Electric Vehicles (PHEVs), which rely on an additional diesel engine. Since this technology requires the use of two power trains, it however increases weights and costs [32] and is therefore not very common in the truck sector. On the positive side, electric powered vehicles in general provide a far more efficient use of energy since the electric engine reaches an efficiency factor of up to 95 %, while a combustion engine only reaches between 30 % and 40 % [32]. Figure 8 compares BEV/PHEV trucks with diesel trucks based on the sector key requirements mentioned above (1-4).

Additionally, electric engines do not directly contribute to emissions, but since the necessary energy supply, for now, mainly relies on fossil fuels, this technology should neither be considered entirely clean.

While the ongoing costs of electric powered trucks in general are lower compared with those of trucks running on diesel, especially with the often applied financial support for charging, the main barrier for electric powered trucks appears to be the limited driving range and the consequential lack of flexibility. In addition, the reliability of lithium-ion batteries is also a critical issue depending on different OEMs.

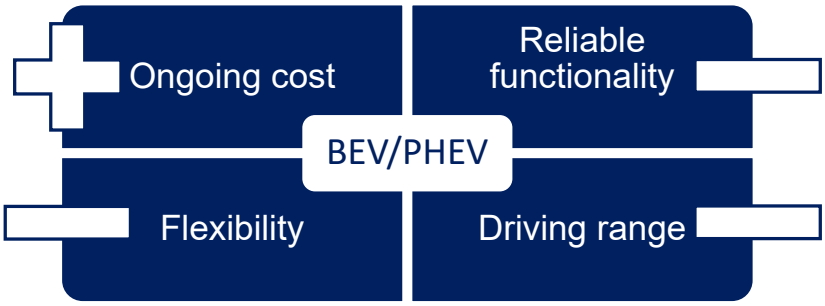

Figure 8: BEV/PHEV comparison (+ / = / -) with diesel trucks on the sector's key requirements (1-4). Own graph, based on previous analyses

In the first six months of 2018, China produced around 50,000 commercial vehicles that are powered by electric motors. This equates to the entire total commercial sales of the last year [34] [35]. However, most of those vehicles either are buses or belong to the category of light commercial vehicles serving for last mile distribution purposes (e. g. vans). Only a negligible share[12] of trucks produced in China that are in line with this report's definition on trucks are electric-powered.

While several companies such as Dongfeng, FAW or Dayun are currently working on solutions for electric powered trucks and investing in research and development, BYD is the only OEM that is already selling electrified models on the market. The firm's tractor-trailer combination BYD Q1 has entered the market and its lithium-ion based power train enables a driving range up to 210 km with full loads. Due to the vehicle's maximum speed of 95 km/h and its relatively strong engine with more than 350 kW [36], it is also suitable for longer-distance transport. In contrast to BYD's serial development, Dongfeng's electric dump truck prototype is mainly developed for construction sites and short distance transportation. Accordingly, the electric range is between 150 and 200 km [36]. Another prototype was developed by Dayun, yet the vehicle's net weight reaches 14 tons with its batteries accounting for almost half of the total weight. The fact that the truck is not able to provide more than 120 km of driving range [36] illustrates the main barrier regarding the demand of those trucks.

The Chinese government is promoting electric powered vehicles in general and tries to strategically strengthen its industry through Five-Year Plans and the initiative "Made in China 2025" – a long-term plan to upgrade ten key industrial sectors in China, with electric vehicles being one of them. [37] Purchase incentives, charging facilities as well as technology upgrades particularly on battery quality are simultaneously promoted. However, while the Chinese market for electric-powered passenger vehicles experienced a steep growth over the past years, battery electric trucks are at their initial stage. Besides BYD, Chinese manufacturers are currently focusing on research and development activities.

3.3. Fuel Cell Trucks – Hydrogen as Promising Option

Besides the widespread trend towards BEVs and PHEVs in the sectors of passenger cars, buses and light commercial vehicles, the technology of hydrogen powered fuel cells continuously gains more importance, especially for cargo transport.

As of November 2018, the sales of hydrogen powered vehicles in China reached around

[12] Estimates assume around 2 % of the overall market (360BYYLZ, 2018) [35].

1,700 units, of which trucks accounted for 61 % [38] while passenger cars held a less significant share with the SAIC ROEWE 950 being the only available model in the sector of cars. Similar to the year 2017 [39], the two main manufacturers in this field are Dongfeng and Youngman Auto.

Fuel Cell Electric Vehicles (FCEVs) generally also belong to the category of New Energy Vehicles (NEVs). However, instead of relying on a large battery as power source, FCEVs are based on electricity generated by fuel cells. These cells generate the required energy through the chemical reaction between oxygen and hydrogen with water being a side product after the process. The main challenge here is the ongoing necessity of hydrogen that needs to be fueled in a compressed but gaseous form.

One of the main advantages of the technology lies in the short refueling time[13] especially compared with battery-based cars, due to the fact that hydrogen is fueled in a gaseous form. Another benefit is the high efficiency of fuel cells that currently ranges around 60 % with experts expecting further potentials for improvement [23]. Particularly trucks with high yearly mileages, such as tractor-trailer combinations for long-distance cargo transport, have the potential to strongly decrease the ongoing TCO if the production of hydrogen can be realized in an economical way. However, this simultaneously brings us to one of the technology's central problems: To prevent CO_2 emissions – the main driver for the use of hydrogen – it is necessary to produce hydrogen from renewable energies. This production process is currently lacking a competitive level of energy efficiency and, therefore, raises a central task for further research. Although even heavier[14] hydrogen-powered trucks reach a far higher driving range compared with BEVs, the limited range of 300 to 400 km with equal fueling capacity [23] limits the flexibility. An increase of the pressure for hydrogen storage from 350 to 700 bar is one of several solutions to improve driving ranges and the energy density of the technology. In general, it can be said

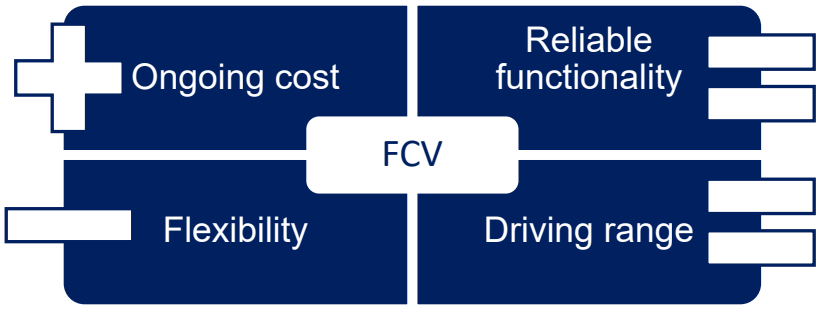

Figure 9: FCEV comparison (+ / = / -) with diesel trucks on the sector's key requirements (1-4). Own graph, based on previous analyses

[13] Refueling processes take three to five minutes with to reach a driving range of maximum 400 km, as latest demonstration vehicles in Shanghai show (fcvechina, 2019) [40].
[14] Vehicles with more than 12 tons gross vehicle weight.

that due to the premature stage of technical development, combined with high costs for enabling an appropriate infrastructure, the technology relies on the economics of scale improvements.

Figure 9 compares FCEV trucks with diesel trucks based on the sector key requirements mentioned above (1-4).

While China is aiming to continuously reduce its subsidies on BEVs [41] over the next years, financial support for hydrogen-based vehicles remains unchanged [23] – a development that emphasizes the expected potential of this technology combined with a lack of knowledge, especially in research. Besides the United States, Germany and Japan, China is already seizing a leading role in research and development activities in the sector of fuel cell trucks: Concerning the amount of scientific publications as well as the amount of declared patents, China's worldwide role strongly increased over the last years. [23] According to Wan Gang, former Minister of the Ministry of Science and Technology (MoST), the truck industry is particularly supposed to be one of the key target sectors for research and development in the upcoming future. Due to the special requirements in this sector, such as long driving ranges and fast refueling to maximize service time, Wan Wang sees important potential to compensate the shortcomings of BEVs. [42]

However, China faces several serious challenges concerning the technologies' deployment. The country's missing gas pipeline infrastructure will require truck transportation of the compressed hydrogen, limited hydrogen production methods are restraining sufficient and efficient supply and high capital investments for the construction of hydrogen fueling stations depict a crucial barrier for setting a base for widespread commercial use.

In order to overcome such challenges, it is expected that China will also rely on overseas support for scaling-up and commercializing hydrogen technologies. Several foreign manufacturers have already been attracted by China's noteworthy market potential in the fuel cell technology.

One of the key actors regarding foreign investments in the field of hydrogen is the Canadian fuel cell pioneer Ballard, which has participated in Chinese hybrid battery/fuel cell platforms for heavy-duty transport (buses, trucks and light rail). The company signed several cooperation agreements with Chinese enterprises to deploy their fuel cell technology in various projects in the bus as well as the truck industry. Currently they are introducing a fleet of 500 trucks in Shanghai, mainly for inner-city deliveries. [43] U.S. Hybrid Corp., the California-based developer of electric powertrains for commercial vehicles, is another North American specialist for hydrogen-based

powertrains starting to invest into the Chinese market. The company is co-developing fuel cell trucks with Dongfeng [44]. Moreover, the French company Air Liquide, a specialist in the field of industrial gases, has recently invested 10 million EUR in a cooperation with the Chinese start-up Shanghai Sinotran New Energy Automobile Operation Co., Ltd. (STNE) with the goal to run a fleet of up to 7,500 trucks and to operate a network of around 25 hydrogen refueling stations by 2020 in China [45]. These increasing activities of key western companies in the hydrogen sector furthermore illustrates the growing importance of the technology gains.

The developments in the FCEV sector have been impacted by recent incentive policies. The very first step was China's participation in the UN Development Program and Global Environment Facility, whereby several pilot demonstration zones like Beijing and Shanghai were established in order to commercialize hydrogen technology. As the fuel cell industry matures, China has adopted more concrete policies on fuel cells and hydrogen. In China's 13th Five-Year Plan (2016-2020) as well as in the strategic plan "Made in China 2025", hydrogen power plays an important role in the development of strategic emerging industries. For example, fuel cell technology is a central target for technological breakthroughs as well as further industrial promotion in order to ensure leading industrial innovations in this field. Therefore, the Energy Technology Revolution Innovation Action Plan (2016-2030) was published to provide a detailed overview of the long-term targets for both passenger cars and commercial vehicles as well as the amount of hydrogen refueling stations. [46] In addition, to this set of long-term targets, the Chinese government offers substantial financial support for purchasing fuel cell vehicles, ranging from 200,000 RMB (around 26,000 EUR) for passenger cars to 500,000 RMB (around 65,000 EUR) for large trucks and buses [23]. The dimensions of these numbers, which apply to the first strategic period (2016-2020), lead to the following conclusions: On the one hand, fuel cell vehicles are presently uneconomic. On the other hand, the government tries to firmly promote the application of the technology among domestic industries.

Currently, most of the existing fuel cell vehicles are used in various pilot projects all over the country: These pilots seem to be clustered in provinces such as Guangdong, Hebei, Hubei and Jiangsu and, to a lesser extent, in Beijing and Shanghai. Significant events – such as the Winter Olympic Games in 2022 – seem to have a positive effect on hydrogen development in some cities.

Year	Refueling stations	Vehicle stock
2020	Over 100 stations	5,000 FCEVs in demonstration (60% commercial vehicles, 40% passenger cars)
2025	Over 300 stations	50,000 FCEVs in service (20% commercial vehicles, 80% passenger cars)
2030	Over 1,000 stations (more than 50 % of hydrogen production from renewable resources)	Over 1,000,000 FCVs in service

Figure 10: Overview of long-term targets for FCEVs in China. International Energy Agency, 2018 [47]

The city of Zhangjiakou in the province of Hebei is a well-known example for this effect: As important location for the Winter Olympic Games 2022 and selected by President Xi Jinping to be a pilot city for energy and transportation, Zhangjiakou is holding a leading role in the development of hydrogen infrastructure. The city accounts for the most prominent pilots where hydrogen appears to be a potential solution for wind curtailment. Furthermore, the city of Wuhan in the province of Hubei is another key player in developing its fuel cell vehicle manufacturing industry. Rugao, in the province of Jiangsu, is another city with ambitious plans to become China's first hydrogen demonstration city.

Overall, these projects and the current technical circumstances show that, on the one hand, hydrogen-powered fuel cells are at a very early stage of commercial deployment with some key challenges to overcome. On the other hand, Chinese decision makers expect the technology to hold an important role, especially in the sector of cargo transport, to mitigate pollution and climate change. The demand for FCEVs will not only rely on its own technical development and research achievements, but also on the rating of other competitive power sources. The future weighting of CO_2 emissions is especially decisive for the development of fuel cells. Indeed, while fuel cell technologies seemingly offer noteworthy advantages concerning refueling time and driving range compared with BEVs, it cannot be assumed that FCEV technologies are competitive compared to LNG and diesel, before CO_2 emissions are not taken into account. However, the need to cut CO_2 emissions becomes ever more urgent, one can expect that fuel cell technologies will suit wider applications, especially for longer distance transport.

4. Conclusion and Policy Recommendations

The aim of this report is to provide an overview of the Chinese truck market and to analyze the role and the future potential of alternative power sources for this sector. From the first part of the report, the following key takeaways can be deduced:

- More than **1.1 million trucks** were **sold in the Chinese market in 2017**. This shows a steep growth since 2015 and amounts to a sales volume that is close to **fourfold that of the total European truck market.**
- The central sources of growth stem from government regulations on overloading and emissions.
- Due to their **disproportionate effect (57 % NO_x and 78 % PM)** on emissions in relation to the total stock of vehicles (11 %), trucks are of **special political interest** when it comes to the mitigation of air pollution problems.
- In recent years, the political attention can be seen in **several truck specific regulations** and policies such as the upcoming ban of one million high polluting trucks in the Jing-Jin-Ji region.
- The introduction of China VI, which is widely viewed as even more stringent than Euro VI, sets **ambitious targets (NO_x reduction of 77 % and PM reduction of 67 %)** for the reduction of emissions caused by heavy-duty commercial vehicles.
- Similar to the European market, the Chinese truck market is highly concentrated with the largest **five companies accounting for 83 %** of total production volume.
- Many Chinese OEMs are active both in the truck sector as well as the passenger car sector, indicating a **close interconnection** between the two industries.
- While a large share of Chinese truck manufacturers cooperate with western OEMs, the **export capability** of the sector is **weak, with a share of merely 13 %** being exported. However, political initiatives such as the BRI aim to increase Chinese export figures.

With regards to the future potential of alternative power sources, the following key results need to be considered:

- Ongoing costs, reliability, flexibility and driving ranges can be **considered as central deter-minants** for the acceptance of possible future technologies.
- While electric powered trucks (BEVs, PHEVs and FCEVs) are at an **early stage of commercial deployment**, LNG has already **gained importance** over the recent years.
- At present, **LNG-based powertrains** are the **main alternative** to diesel trucks, especially due to their l**ower emissions, the com-**

petitive pricing of natural gas as well as the **acceptable driving ranges.**

- **Limited driving ranges** and **long battery charging times** are the main barriers for battery-powered solutions in the truck sector.
- **BYD is the only Chinese OEM** offering battery-based trucks in the market (in China and international). While the NEV technology can partly be applied for urban short-distance applications such as buses or delivery vans in a **promising way,** particularly the **reduced driving range** limits the technology's potential for the truck sector.
- Policy and financial support from the government **currently exert a strong focus** on the promotion of **hydrogen** fuel cell technology.
- In comparison to battery-powered trucks, the main advantages here can be seen in **reduced fueling times** and **higher driving ranges**. At the same time, the **limited efficiency** of hydrogen production and the **costly infrastructure** so far hinder the technology's breakthrough.
- Overall, the development of alternative power solutions is **heavily reliant on how stakeholders prioritize transport emission reductions.** None of the available technologies are currently competitive to diesel technologies when it comes to fulfilling the key requirements in the truck sector.

To support the political path towards emission reduction, several proposals for further investigations can be inferred from the results of this report. Firstly, the main barrier for the widespread acceptance of alternative power sources – the limited driving range of BEVs and FCEVs – requires support such as investments in research and development. Only through an increase in energy density, for example through new battery generations, low-emission technologies can become competitive. Secondly, well-defined pilot areas need to be established in order to develop specific concepts that combine the use of several technologies for definable applications. Finally, it is essential to conduct research on the feasibility of the coexistence and co-development of several energy sources to combine and complement each of the technologies' advantages. The central question is whether these technological adaptions can be achieved without losing a necessary amount of scaling effects in the truck industry so that the economic viability of the industry can be ensured.

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