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Electrical Bus Mobility in the EU and China: Technological, Ecological and Economic Policy Perspectives

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Summary

The analysis provides a hybrid techno-economic perspective on EU and China e-bus development dynamics. China is a leading global electric bus user – particularly in certain provinces. In Europe, the European Commission has started an electric bus initiative and several EU member countries have tried to achieve progress with regard to their own municipal e-bus fleets. While the economic analysis shows that e-bus innovation and diffusion dynamics can be influenced by government procurement policy, it is also obvious that certain pricing schemes in e-bus (mixed) municipal mobility networks are not successfully promoting clean e-bus expansion. A key issue is that various grant schemes depress the prices for used e-buses which in turn creates additional risk for e-bus leasing arrangements. Industrial policy aspects as well innovation policy face challenges in the e-bus context. China's regional e-bus approaches have shown considerable success and part of China's patent dynamics supports e-bus expansion perspectives. From a technological perspective, there are several alternative modes of e-bus mobility whose technological and economic advantages have to be explored in the context of the characteristics of local and regional bus routes. A very important technological element of e-mobility concerns technical aspects of battery charging – for example, cycle lifetime, power density, charging time and safety. The price dynamics of battery packs is rather high and should stimulate the expansion of e-bus mobility in Europe and China. One key problem faced by Europe and Asia is the challenge of common technical standards. As regards Germany's and the UK's position as a potential lead markets for e-bus mobility – or a similar positioning of a network of EU cities – much depends on adequate new policy initiatives. The emissions reductions which could be achieved by transitioning to 100% e-bus mobility in the EU would amount to an estimated 1.3% cut in terms of emissions of the transport sector (without aviation).

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1. Introduction

Bus transportation is indeed a key element of local transportation and in many cities in OECD countries and China it stands for a growing share of public transportation. The traditional large bus fleets used by big and small cities are mostly diesel powered and thus are problematic with respect to CO_2 and NOx emissions. Electric bus transportation could replace traditional buses, however high upfront costs and many practical and political questions are raised in this context. In the EU, the European Commission has put new pressure on Germany and some other EU countries to improve the local emission situation in several cities – and here e-bus mobility could be a crucial concept. At the same time, it is obvious that certain Chinese provinces, benefitting from subsidization via regional and national funds, have made progress in reducing greenhouse gases through pilot programs involving regional certificate trading systems, the trading of emission certificates has intensified, particularly in China as it moves towards a single national trading system (WELFENS/YU/HANRAHAN/GENG, 2017).

The overall number of buses in municipal fleets globally is about 3 million units and in EU countries the replacement cycles are about 8-10 years which means a rather slow natural replacement cycle of municipal bus fleets. If special government incentives shorten the reinvestment cycle, there is a risk that the price of traditional buses would fall strongly which has a negative effect on the buses appearing as assets on the balance sheets of bus operators, including municipal units. With special government incentives for electrical buses, one could generate considerable benefits as electrical buses have three advantages over diesel buses:

- The greenhouse gas emission level per passenger-kilometer is lower – and this is lower the higher the share of renewable electricity in the respective country is;
- there are lower noise emission levels which means that electric buses could cover a wider traveling radius in cities than diesel buses which in turn raises the market volume for electrical buses worldwide;
- the willingness to pay of users of electrical buses should be higher than for diesel buses since users know about the advantage of (1). From this perspective, it would be useful not to have a flat annual price – such as, for example, in Vienna and in some German cities introduced in 2018. Rather, pricing structures should positively reflect the percentage to which renewable energy is used in the municipal bus fleet. Computerized pricing should allow both to integrate this aspect into pricing as well as a scheme for peak times and off-peak times.

However, a certain disadvantage of e-buses using renewable energy is the high cost of intermittent electricity production in periods of volatile availability of solar and wind energy. It is not fully clear whether additional e-buses as users of electricity grids could help dealing with the stabilization of the electricity system.

As regards medium-term electric bus perspectives, the assumption is that traditional routing and transportation modes will be maintained. It is conceivable in the long run that autonomous electrical bus transportation, using many small buses for providing transportation services, will be established.

The EU has started a major electrical bus initiative in 2016, China's mainly regionally focused e-bus initiatives – quite successful in some provinces - have started largely in 2015.

However, even in China the percentage of e-buses employed in major cities is rather small in the overall stock of buses for public transportation. A regards the EU28, the share of e-buses/hybrid buses in total municipal buses in the EU in 2017 was just 1.6% (BLOOMBERG, 2018). Trolleybuses would have to be added to these figures; such buses play a traditional role in some US cities but also in Europe – including Eastern Europe/former Soviet Union countries in particular. Trolleybuses could be upgraded by adding modern batteries so that the range of service would be beyond the traditional network with pantographs; while recharging battery stations built at the terminus of the respective line (or at each bus stop in certain parts of the city) could reinforce the flexibility of such trolleybuses. The Bloomberg study argues that in large cities it is easier to achieve parity in the total cost of ownership for e-buses compared to diesel buses: In larger cities, buses travel at least 220 km a day which gives a relative cost advantage compared to medium or smaller cities where the bus typically runs shorter daily cycles. Initial investment for e-buses is relatively high while the operating costs are lower than for diesel power buses. From this perspective, China - with many large cities - should have a natural advantage for operating e-buses compared to the EU or the US.

The following analysis looks at a rather restricted number of electric buses which could replace conventional municipal buses – the limited number of technically feasible options will be highlighted in section 2 which also covers other key technical aspects of municipal bus mobility; this includes technical perspectives on the whole value-added chain which in turn points to important aspects of value-added network development which might be of interest for an adequate industrial policy that wants to help jumpstarting electric municipal bus fleets. Section 3 will look at economic market perspectives and at ecological aspects of municipal bus operation. Section 4 is about markets in the EU and section 5 about selected aspects of China’s electrical bus mobility while section 6 makes comparisons between the EU and China. The final section offers some conclusions and suggestions for future research.

2. Technical Challenges, Chances and Perspectives

Beside the economic differences compared to conventional buses, the successful distribution of electric buses depends on the mastery of technical challenges. The technical requirements regarding electric buses lead to necessary changes, amongst others, in terms of the powertrains, energy management as well as electricity grids. Based on the latter point, the transformation from conventional buses to electrical buses could be complex for some cities. However, in the case of a thoughtful planning of the transformation process and the consideration of gained experience of other cities, the integration of electric buses into the local public transport system is feasible, as has already been shown by different projects, such as the EU project Zero Emission Urban Bus Systems (ZeEUS, 2016).

2.1 Technical Introduction about Alternative Bus Technologies

The majority of automotive public transport systems consist of buses powered by traditional diesel combustion engines. The disadvantages of this technology – damaging to the climate and noise emissions – are well known. Thus, both municipalities and transport companies use electric buses in order to avoid emissions and to archive climate protection goals (FRAUNHOFER, 2015). Many German cities have a significant interest in alternative transport systems. Until September 2018, 608 buses with an alternative propulsion system (full electric, hybrid, hydrogen fuel cell, etc.) were already registered in Germany. Most of them (422) use a hybrid technology and only 177 of the buses are full electric vehicles without a combustion engine. Compared to the total bus stock in Germany (40,000), the share of alternative buses is only 1.52% (PWC, 2018). The authors of the PWC study emphasize that German cities plan to order 3,243 full electric buses, see Figure 15 in the appendix. This prediction is based on data from September 2018, thus many open tenders are not included. In OMNIBUSSPIEGEL (2018), the authors present the vehicle stock of electrical buses in Germany in May 2018. Compared to data of PWC (2018) the vehicle stock is 189.

On the one hand, it can be emphasized that there is an increasing trend. On the other hand, the sales volume of electric buses in Germany is very low compared to Asian countries, particularly China (FRAUNHOFER, 2015).

Potential operators of electric buses have the option of choosing between different electric bus technologies such as battery electric bus, trolley bus and so on (for an overview of available technologies, see Table 1). The bus operators and municipalities need to consider, among other things, the current circumstances in the decision process. For example, almost all cities which have integrated battery trolleybuses in their transportation system have gained experience with trolley infrastructure, i.e. wiring, in the past. Hence, an existing infrastructure for trams or trolleybuses is a great advantage for the integration of battery trolleybuses (see chapter 2.4), but is not a precondition. In addition, European cities like Eberswalde (Germany), Solingen (Germany) or Szeged (Hungary) use battery trolleybuses to increase the flexibility and operating range of their existing trolley network (ZeEUS, 2016).

Table 1: Overview of Electrical Bus Technologies

Technology	Energy storage	Charging technology	
Battery electric buses	Battery	Conductive, inductive, pantograph	Overnight, at bus stops, at depot
Plug-in hybrid electric buses	Battery	Conductive	Overnight, at bus stops, at depot
Trolley buses	Battery, diesel tank	Pantograph, external fueling	Overnight, at bus stops, at depot
Battery trolley buses	Battery	Conductive, inductive, pantograph	In motion, at bus depot, overnight
Electric buses with range extender	Battery, diesel tank	Conductive, inductive, pantograph	Overnight, at bus stops
Fuel cell electric buses	Fuel cell	External fueling	At depot
Ultracapacitor electric buses	Ultracapacitor	Conductive	At bus stops, at depot

Source: Own representation

2.2 Daily Operating Range and Time

The daily operating range and time of the buses depend on, amongst other things, the size of the public transport network, the number of buses in the bus fleet, the frequency of the buses, and the applied propulsion and charging technology. Conventional buses with a combustion engine are able to drive 600-900 km with a full fuel tank (CIVITAS, 2013) and the refueling process takes only a few minutes. The maximum range of the battery electric buses considered in the ZeEUS project (ZeEUS, 2016) goes up to 340 km, which was achieved by the BYD 10.8m under standardized on-road test cycles (SORT). The new BYD 18m electric bus has a 547 kWh battery and a range of 440 km under real driving conditions (ELECTREK, 2017). This rate of technological development leads to possible operating ranges which are sufficient for most public transport networks.

Table 2: Classification of cities in the context of electric buses

	Daily operating range[1]	**Annual operating range**
Small cities	82.19 km	30,000 km
Medium cities	164.38 km	60,000 km
Large cities	219.18 km	80,000 km

´Source: Own representation of data in Bloomberg (2018); ZeEUS (2016)

Table 2 shows the classification of cities which was done by BLOOMBERG (2018). According to this definition, the annual operating range is between 30,000 km and 80,000 km. Divided into the daily operating range, the electric vehicle must be able to drive 82.19 km to 219.18 km per day. In addition, the authors of BLOOMBERG (2018) mention that the daily operating range can go up to 300 km per day. Hence, the range of the above mentioned buses of BYD are extensive enough to comply with the necessary daily operating ranges in all cities.

2.3 Energy Storages

The battery technology is one of the key factors for the successful wide scale adoption of electric vehicles. For example, the energy and power density (Wh/kg, W/kg) as well as the battery price (€/kWh) are important parameters. In addition, there are some more properties which are of interest to municipalities and bus operators (see Figure 1).

Figure 1: Current state of the art and clarification of the technical needs

	Capital cost	Safety	Cycle lifetime	Energy density	Power density	Charging Time	Reliability
Full electric vehicles	-	○	+	○	+	-	-
Electrical buses	-	+	+	○	+	+	○

○ partially satisfactory + satisfactory - great need

Source: Own representation based on ARTHUR (2018)

[1] Result of annual operating range divided by 365 days.

As shown in Figure 1, the capital costs are very high and need to be reduced by expanding battery production and achieving economies of scale. Many companies from different industry sectors are investing in battery production. The battery market is a dynamic and growing market. ARTHUR (2018) identify a total investment volume of 13.7 billion USD in the last years. This trend is reflected by the forecast of the IEA (2018) for 2030. The production capacity of Li-ion factories is between 0.5 and 8 GWh/a. In 2030, the production capacity could reach the threshold of 35 GWh/a. Besides Tesla, with a planned production capacity of 35 GWh for 2018, further big players include BYD and CATL from China with a current production capacity of 8 GWh/a and 7 GWh/a, respectively. According to DBS (2018), CATL is the market leader in the production of batteries for electric vehicles in terms of sales volume in 2017. The FRAUNHOFER (2017) report forecasts a battery production of 700 GWh for 2025. These data clarify the rapid expansion of the battery production based on growing demand. The growing sales volume of electric buses is one example that is responsible for this trend. The worldwide battery demand for electric buses was 3.5 GWh in 2014 and 12.5 GWh in 2017 (BLOOMBERG, 2018). In a scenario of FRAUNHOFER (2018) for 2025, approximately 76% of the overall worldwide demand for batteries is based on electric vehicles. Electric buses have a share of 4% in this scenario (see Table 3). These values underline the great need of an expending production capacity of lithium-ion batteries.

Table 3: Forecasted demand for batteries for 2025 sorted by different applications based on Fraunhofer (2017)

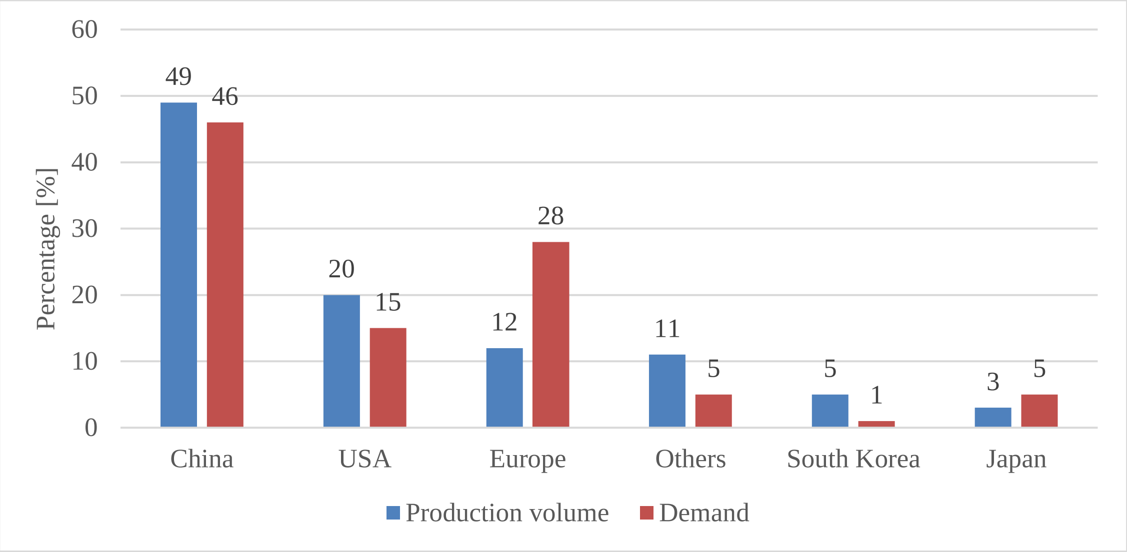
Application	Percentage
BEV, PHEV, HEV	42%
Trucks	8%
Electric buses	4%
Energy storage systems (EES)	9%
Others[2]	63%

Source: Own representation of data available in FRAUNHOFER (2017)

In the aforementioned scenario, China has the greatest demand and production volumes of lithium-ion batteries in 2025 (see Figure 2). In addition, Figure 2 underlines the dominant role of China with regard to the future development of electric vehicles and their components. The financial support and the introduction of favorable political mechanisms on the part of the Chinese government (see chapter 4) leads to a faster and greater distribution of electric vehicles compared to other countries.

[2] The category "others" includes e.g. bicycles, motorcycles, lift trucks and 3C (consumer, computer, communication), whereby 3C has a share of 15%.

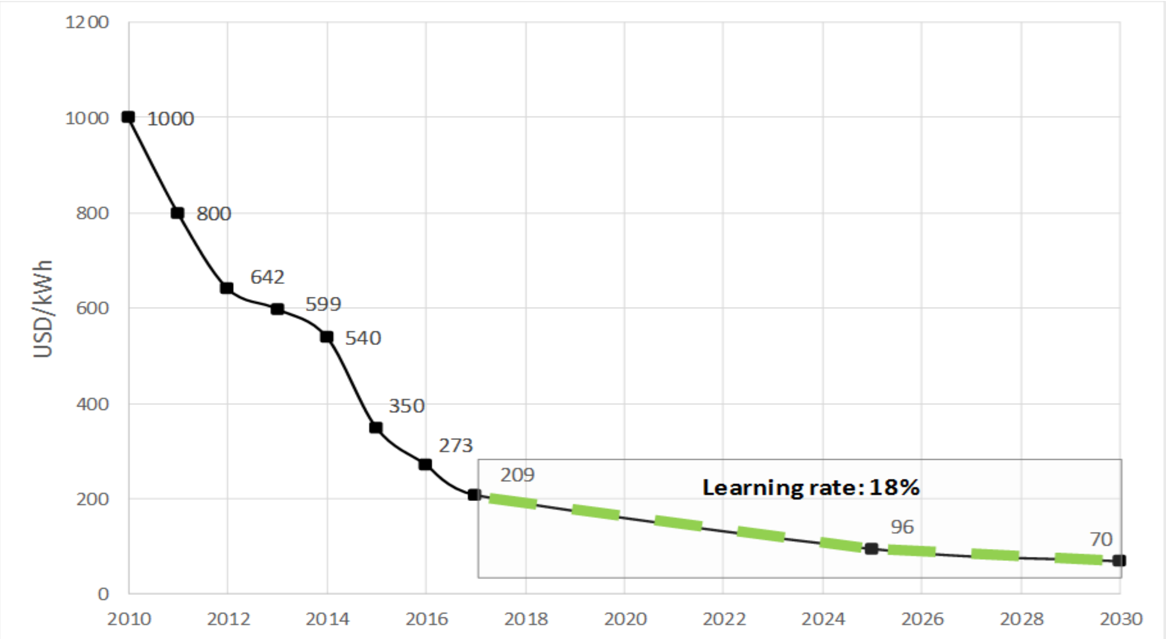
Figure 2: Comparison of production volume and demand of Lithium-ion batteries



Source: Author's representation of data available in FRAUNHOFER (2017)

The growing production rate leads to a decreasing price per kWh for battery packs. In 2010, the battery price per kWh was 1,000 USD while in 2017, the price for lithium-ion battery packs is close to the threshold of 200 USD/kWh (see Figure 3). In addition, the cell price for lithium-ion batteries was approximately 147 USD/kWh (BLOOMBERG, 2018). Furthermore, BLOOMBERG (2018) forecasts developments in relation to future battery pack prices. The authors calculate a price of 96 USD/kWh for 2025 and 70 USD/kWh for 2030. The forecast, shown in Figure 3, is based on the assumption that the future learning rate will be the same as during the period 2010-2017 (18%).

Figure 3: Price development for lithium-ion battery packs



Source: Own representation of data available in BLOOMBERG (2018)

FRAUNHOFER (2017) predicts battery prices of 60-100 €/kWh for cylindrical cells for the period between 2020 and 2030. Furthermore, the price for pouch cells (e.g. CATL) could fall below the threshold of 100 €/kWh in the period between 2020 and 2030.

Nowadays the price of pouch cells is between 200-300 €/kWh. Regarding battery packs for electric buses, large pouch cells have the advantage that the number of electric connections can be reduced compared to cylindrical cells (BLOOMBERG, 2018). The future development of the annual production volume (economies of scale) and the degree of innovation of the production processes, as well as of the material processing, are the key factors for a decreasing battery price. Lower battery prices means lower acquisition costs. Thus, the falling prices are a great advantage for municipalities and transport companies regarding the amortization of their electric buses. The following example makes these economic aspects clear.

The IEA (2018) provides a detailed comparison of the total cost of the ownership gap between diesel buses and electric buses. The authors conclude that electric buses with an annual operating range of 40,000-50,000 km can compete with buses with an internal combustion engine (ICE). The precondition for this case is a high diesel price of 1.4 USD/L, electricity price of 0.13 USD/kWh, and a battery price of 260 USD/kWh. Furthermore, the authors highlight that the high sales volumes of electric buses in China is mainly due to subsidies and regulations and not based on economic benefit, because the price for diesel in China is low compared to the international diesel price (IEA, 2018). This result can be underlined by GPP (2018): In Summer 2018, the average diesel price was 1.10 USD/L in China and 1.59 USD worldwide. Hence, besides the annual operating range, the battery price is a key factor regarding to the amortization period of an electrical bus.

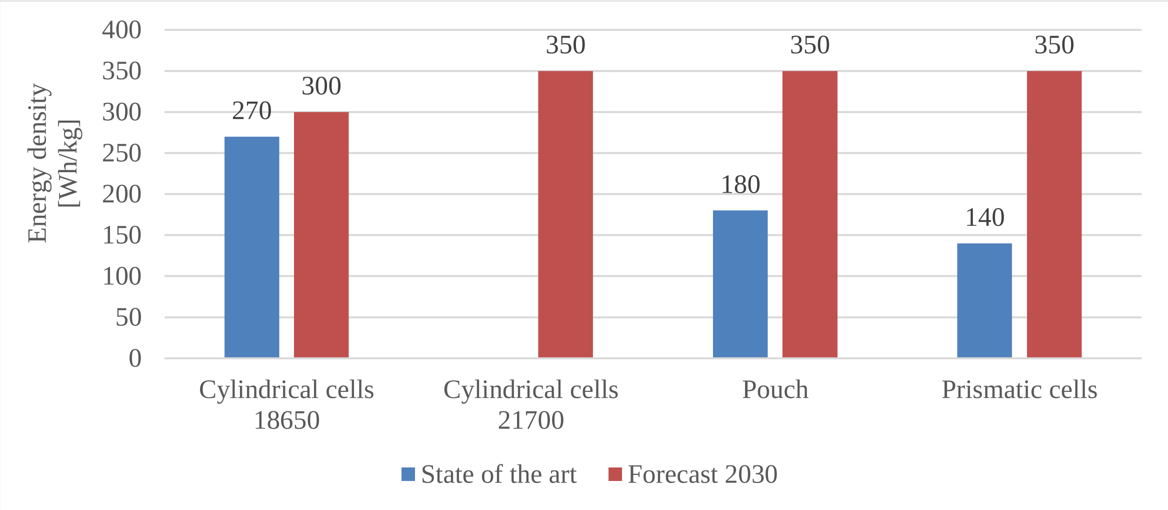
The batteries required for electric buses differ from other electric vehicles. Electric buses need batteries with a long cycle lifetime depending on higher operating ranges and the number of charging processes. In Germany, electric buses have an annual operating range of 50,000 km. In practice, this annual range could lead to up to 1,200 charging processes per year ROTHGANG (2015). Lithium iron phosphate batteries (LFP) and lithium titanate batteries (LTO) meet these requirements and provide high cycle lifetimes (BLOOMBERG, 2018; ROTHGANG, 2015). A further advantage of LFP and LTO batteries is the possibility of charging with high currents, which means shorter charging times (IEA, 2018). Further important requirements relate to the energy and power density of batteries. The high energy density of lithium-ion batteries id mainly based on the chemical composition of the cathodes, especially on the large amount of cobalt. Nevertheless, some battery manufacturers shift their production processes from batteries with cobalt (e.g. NCA: Lithium nickel cobalt aluminum oxide) to batteries with cobalt-free cathodes (e.g. LFP, LTO). The increasing demand for large-scale applications, such as energy storage systems and electric buses, is one reason for this development (EU, 2018). LFP and LTO are able to offer a high cycle life and high power density, which are the necessary requirements for electric buses (BLOOMBERG, 2018).

The IEA (2018) find that the energy density of lithium-ion batteries could be increased by the reduction of cobalt at the cathode and, for example, by the simultaneous decrease of nickel. The addition of silicon and silica at the anode (graphite) is a further promising chemical modification that has the potential to increase the energy density. According to

IEA (2018) and ARTHUR (2018) this could lead to a 40-50% higher energy density compared to the state of the art and could be the realized in the period 2025-2030. In the literature, this battery technology is called “next generation lithium-ion”.

Energy density needs to be enhanced for electric vehicles as well as electric buses. The analysis of FRAUNHOFER (2017), presented in Figure 4, clarifies the predicted gravimetric energy density of different Lithium-ion batteries. The current state of the art of cylindrical cells of the type 18650 has the highest energy density (270 Wh/kg). In 2030, cylindrical cells of the type 21700, pouch cells, and prismatic cells could reach an energy density of 350 Wh/kg. In other words, the energy densities of the different battery types come closer to each other. The estimations of IEA (2018) and ARTHUR (2018) for future energy densities of Lithium-ion batteries support the forecast of FRAUNHOFER (2017). Therefore, one important requirement of batteries for electric buses will be achieved in the next years.

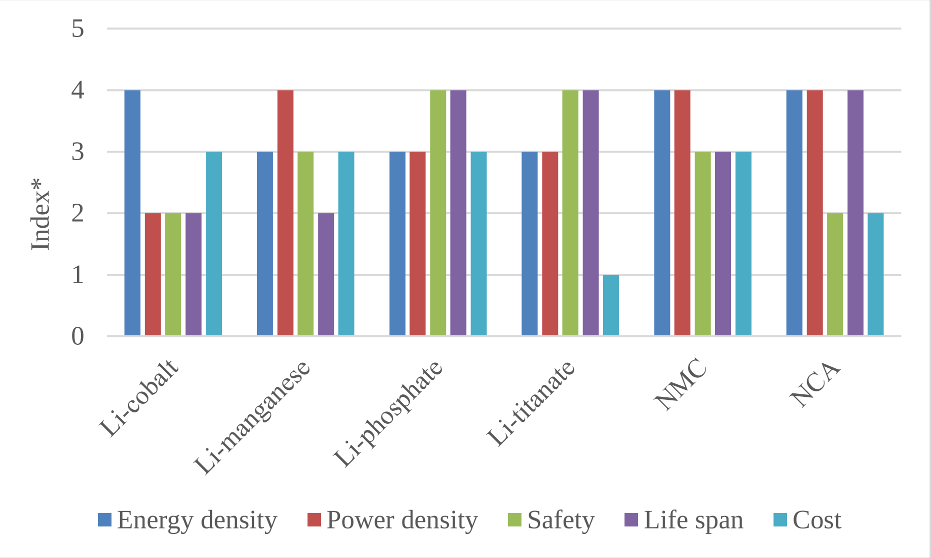
Figure 4: Forecast of the gravimetric energy density of Lithium-ion batteries



Source: Own representation based on FRAUNHOFER (2017)

Compared to electric passenger cars and long distance buses, for electric city buses the power density is more important than the energy density (ARTHUR, 2018). As shown in Figure 5, the power density of LFP and LTO gets the index value of 4. Additionally, the life span (index: 4) and the safety (index: 4) of these battery types is high as well. The safety needs for electric buses is greater than for electric passenger cars. The damage caused by thermal runaway or any other technical or chemical error involving an electric bus could be greater based on the higher capacity of the bus batteries (ARTHUR, 2018). The three mentioned characteristics (power density, safety, life span) of LFP and LTO leads to a wide distribution of them inside the electric bus sector. This finding is supported by our own analysis of the EU project ZeEUS. 55 of the 73 electric buses analyzed in the ZeEUS project use LFP or LTO batteries (ZeEUS, 2016).

Figure 5: Assessment of the performance of different types of lithium-ion batteries



*Source: Own representation based on HANNAN (2018); Note: *Index: 5 = high; 0 = low*

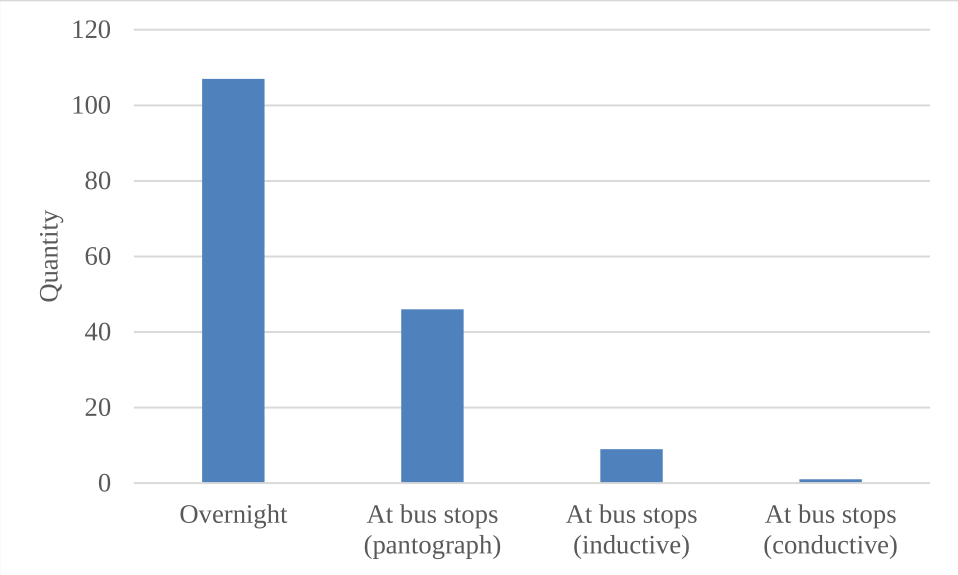
The great need of improved battery technologies have led to many patent applications in the last years (ARTHUR, 2018). For more information regarding this topic, see Figure 16 in the appendix. This figure delivers data of different patent applications, sorted by technologies (e.g. liquid electrolyte, separator, and recycling), in 2015.

2.4 Charging Systems and Requirements for the Power Grid

The focus of this paper is an analysis of the spread of electric buses in China and the EU. Nevertheless, further Asian countries, like India, are also targeting the integration of electric buses in their public transport system. Air pollution levels in India are some of the worst worldwide. Hence, the Indian government aims to increase the share of electric vehicles of the total Indian vehicle fleet to reduce air pollution which is caused by vehicles with an internal combustion engines. The government has provided financial support in the amount of 370 million USD for the purchase of electric buses via the political program "Fast Adoption and Manufacturing of Electric Vehicles (FAME)". One great challenge, amongst others, is the expansion of the charging infrastructure for electric buses. With a total investment of 4.5 million USD in the period of 2015 to 2017, the government has tried to promote a faster rollout of charging stations around the country (DBS, 2018). The development of charging possibilities for electric buses is indispensable for the realization of smart and sustainable local transportation networks in the cities worldwide as you can see in the following example.

Table 1 already introduced different charging technologies and strategies, such as conductive charging (pantograph, plug-in) and inductive charging (wireless power transmission, WPT). In Germany, the majority (107) of the analyzed 189 electric buses are charged overnight, see Figure 6. This charging method has the advantage that the bus operators only need to install the necessary charging system at the bus depot.

Figure 6: Overview of used charging technologies in Germany



Source: Own representation based on PWC (2018)

In contrast to this advantage, the buses have batteries with a greater capacity to realize sufficient ranges. Thus, the vehicle mass and energy demand is higher. This based on the following physical model in (1), which describes the calculation of the total vehicle drive force (F_{total}).

$$F_{total} = cw \cdot A_{SF} \cdot \frac{\rho_{air}}{2} \cdot v_x^2 + f_t \cdot m_{total} \cdot g \cdot \cos\alpha + m_{total} \cdot g \cdot \sin\alpha + \left(e_i \cdot m_{empty} + m_{total}\right) \cdot a_x \qquad (1)$$

As you can see, three of the four presented driving resistances of (1) are dependent on the empty vehicle mass (m_{empty}) and total vehicle weight (m_{total}). The description of the further parameters of (1) are shown in Table 6 in the appendix. The first term of (1) represents the air resistance, the second term the rolling resistance, the third term the climbing resistance, and the fourth term the acceleration resistance. The air resistance is independent of the vehicle mass and dominates at higher velocities. For example, at velocities above approximately 70-80 km/h, the air resistance of passenger cars is the dominating parameter (FECHTNER, 2018). In urban settings and on highways 92% and 30%, respectively, of the driving resistance are depending on the current vehicle mass (FRIEDRICH, 2017). This physical correlation results from the computation of the total energy demand of vehicles (E_{total}), as shown in (2), whereby F_{reg} represents the forces regarding regenerative breaking.

$$E_{total} = \int_{start}^{end} \left(F_{total} \cdot v_x\right) \cdot dt + \int_{start}^{end} \left(F_{reg} \cdot v_x\right) \cdot dt \qquad (2)$$

Therefore, the air resistance has a cubic influence (v^3) on E_{total}. In this paper, the focus is on electric buses in the context of urban transportation. For example, the speed limit is 50 km/h in German cities. Regarding to the described physical model, see (1), the battery weight has a significant influence on the energy demand of electric city buses.

One chance to handle this challenge is the increase of the energy and power density of the batteries (see chapter 2.3). A further opportunity is the integration of fast or ultra-fast charging systems, which enables shorter charging processes using charging power of 300-400 kW. In STEEN (2017), they use a charging system with a maximum charging power of

300 kW. The charging system, which makes a conductive charging process by a pantograph possible, is integrated at every end stop. The majority of the analyzed buses in Gothenburg (Sweden) get charged by an electrical power between 100 kW for hybrid buses (charging time: 3 min) and 240 kW for fully electric buses (charging time: 2 min). Furthermore, the authors of STEEN (2017) analyzed the implementation of energy storages to reduce energy demand from the grid. The usage of energy storage systems could be a promising approach to handle the increasing load demand that is caused by the rapidly growing spread of EVs and their load behavior respectively. The charging characteristics of the electric vehicles differ in their usage, driving behavior, energy consumption (e.g. vehicle mass changes, driving behavior) and further parameters. In addition, the volatile load demands of electric vehicles are very difficult to predict. Hence, energy storage systems can be used for the energy supply of electric vehicles at peak hours (SHUKLA, 2018; STEEN, 2017). In summary, it can be recommended that municipalities and transport companies can use technological solutions, like energy storages, to reduce the energy demand from the grid. The necessary technical requirements depend on the existing infrastructure (transformers, rectifiers etc.) at the bus depots, bus stations or any other charging possibility.

On the other hand, the reduction of the lifetime of the batteries is one of the disadvantages of ultra-fast charging. Furthermore, the technological requirements of the battery design also increase in order to withstand the higher currents and voltages. The enlargement of the electrodes is one of the electrochemical changes which are needed compared to charging systems with a lower power supply (e.g. 3.7 kW) (IEA, 2018). In the context of electric buses, the new developments and drafts of the two charging standards CCS and CHAdeMO, respectively, are promising technological advances. According to IEA (2018), this means charging powers of 400 kW. In comparison to these charging powers, Tesla´s superchargers are able to charge the vehicles of Tesla with a power of 120 kW. The so-called OppCharge standard made charging powers of 150-400 kW possible by energy transfer via pantographs. The next level of OppCharge is a charging process using a charging power of 600 kW and is currently under development (IEA, 2018).

Conductive charging using pantographs is a widespread charging solution in Europe and the United States of America (BLOOMBERG, 2018). A further charging technology is WPT. On the one hand, the static WPT offers the realization of a great number of charging points along the route, such as at bus stops (similar to the pantographs). Additionally, the dynamic WPT makes a continuous charging in motion feasible. On the other hand, this charging method is very expensive compared to the conductive solution caused by the complex integration of the primary coils under the road surface. According to BLOOMBERG (2018), current WPT for electric buses have charging powers of up to 200 kW. The next generation of WPT of the manufacturer WAVE are able to deliver charging powers up to 250 kW (METRO, 2017), which leads to shorter charging times. For more information regarding WPT see, e.g., AHMAD (2018).

3. Economic Market Perspectives and Ecological Aspects

3.1 Traditional Local Transportation Economics

Demand functions and supply functions of metropolitan bus/metro transportation have been analyzed for many cities in Europe, North America and Asia. DARGAY/HANLY (2002) study bus fares and per capita bus patronage for the UK. Useful meta-analyses are, for example, by NIJKAMP/PEPPING (1998), KREMERS ET AL. (2002) and HOLMGREN (2007) which focus on price elasticities of demand for urban transportation where car ownership is one of the determinants. GRAHAM ET AL. (2009) give estimates for the effects of fares, quality and income for a large sample of cities, namely 22 international urban metros. ENRIQUE FERNANDEZ ET AL. (2005, 2008) have presented studies where demand responsiveness is linked to transportation supply design. This suggests that quality improvement in municipal transportation could raise the willingness to pay by e-bus users provided that the e-bus transportation generally brings an improvement in the quality of the service; for example, in terms of the frequency of bus services or security of transportation.

The traditional municipal bus transportation issues have been covered in the literature and empirical estimation of demand curves and supply curves for EU countries have helped to better understand local bus transportation markets (ALBALATE/BEL, 2010). The authors have tested for cities in OECD countries and in Asia - within a modern empirical approach - both demand equations and supply equations and could identify relevant variables on both sides of the market. This implicitly allows estimating an equilibrium price.

The only problem with the authors' approach is that they have not differentiated with respect to diesel buses versus buses operated by renewable electricity; clearly, there have been significant advances in technology in the field of e-bus production and services only after 2010 where e-bus concepts naturally benefit from declining battery cell prices.

As regards the supply side dynamics, patents in electrical mobility play a key role and here China, along with the EU, the US plus Japan and the Republic of Korea, is really a key player at the global level. China's market is rather big with large cities experiencing emission problems from diesel buses on the one hand and many regional governments which are willing to support production of innovative e-buses and e-bus mobility on the other hand. E-buses could be a double positive externality, namely to the extent that the electricity used is generated from renewable energy sources. Reducing emissions means that negative externalities are reduced, at the same time it is clear that the government's promotion of renewable electricity in general and of innovative green engine solutions for buses in particular stand for less emissions and hence also for a positive externality.

3.2 Innovation Aspects, Industrial Policy, Efficiency, Networks

As regards innovation dynamics, one may point out that some of the world's largest bus producers are laggards in offering e-buses which implies that in 2018 there was rather modest competition in e-bus markets in the EU. With more suppliers entering the market in OECD countries, the mark-up in the e-bus market will reduce which in turn should help to stimulate the diffusion process. To some extent, one may assume that the global e-bus markets are quickly expanding in the medium and long run and thus the e-bus markets should be characterized by enhanced international competition. However, given the global rise of protectionism – particularly in the US – there could be considerable hesitancy to begin or expand e-bus production on the basis of widely-spanned international production networks. Moreover, securing access to critical natural resources, such as those used in the production of batteries for example, could also be a strategic point. Finally, using economies of scale should play some role in the e-bus business once a critical number of cities have decided to switch to e-bus mobility concepts.

Bus production has certain technological and economic characteristics which are crucial for the expansion of electrical bus mobility over time:

- In the production of buses, there are static and dynamic economies of scale so that standardization and the joint development of city e-bus mobility is crucial for Europe, China/Asia and the US.
- A key question concerns interoperability which means the ability of e-bus type A to be substituted fully by e-bus type B – here the type of battery used and the development and sharing of joint standards are crucial. If there are different suppliers which for example use (automatic) battery swapping of different types and incompatible across producers and bus models, respectively, the degree of competition is restrained and therefore the price elasticity of demand will be rather low which in turn implies rather high bus prices when bought or leased by cities.
- There is the specific question of whether or not e-buses can be combined with green electricity use. Users – say those with a monthly ticket – might be willing to pay more for a green e-bus ticket than for other bus tickets. Introducing green e-buses thus should be accompanied by a special marketing and pricing campaign. Once all buses in a city are already run using green electricity, it would not be easy to introduce a higher price for e-bus transportation so that a rapid introduction of all buses as e-buses would be a doubtful concept (e.g. Wiesbaden in Germany in 2018)

As regards the procurement of e-buses, the networked procurement of several cities/regions/countries could be considered as a useful strategy. It is clear that even if there is networked procurement of e-buses to some extent, one should maintain sufficient competition among e-bus producers and e-bus mobility service providers. Given the fact that e-bus networks could be linked to a faster roll-out of mobile broadband internet, there is even a certain overlap of e-bus expansion and modern digital communication.

Networks of cities in certain countries or across countries could join forces for a project on the joint public procurement of e-buses – but competition rules would have to be taken into account. The key question for governments in Europe, China and other countries is to what extent international standardization could help to jumpstart municipal e-bus transportation; part of the standardization process could stem from the industry itself. Standardization could help to exploit economies of scale. Beyond this, one could organize a benchmarking of e-bus transportation services where differentiation across the size of cities and types of bundled transportation (e.g. e-bus & metro) could be useful.

3.3 Lead Market Perspectives

It is clear that government – in a combination of national policy initiatives and local government activities (plus sometimes regional bus activities) – could play a strategic role in e-bus procurement. There is a certain trade-off since sufficient competition is desirable with a focus on Schumpeterian innovation dynamics. At the same time, it is clear that networked public procurement could help to reduce the overall offer price of e-bus producers. It seems that China and some Western EU countries have tried to assume the role of a lead market. Those countries which stand for a lead market must have demanders that are willing to test the new innovative mobility concepts. In high-income countries in the OECD area and in China, one would hope to find such transport service providers.

In bus procurement, leasing traditionally plays a key role. A key problem with respect to the leasing of buses is the residual value at the end of the first ownership period. The smaller the e-bus markets in Europe, Asia and North America are, the lower the residual value at the end of the normal leasing period will be. Private bus fleet operators might be willing to buy used e-buses, but also cities in developing countries could be interested in buying used e-buses. Development aid policy approaches of OECD countries and of China should naturally consider some of the associated aspects early on and indeed could then encourage investment in renewable electricity in developing countries.

Policymakers in Europe will generally play a key role both at the level of the EU – for example, with options to promote e-bus mobility via cohesion funds or special investment projects (possibly involving the European Investment Bank (EIB) and the European Bank for Reconstruction and Development (EBRD)). In the EU, the European Commission and the Committee of the Regions play a key role in the growth of e-bus mobility. The EU's Clean Bus Deployment initiative of 2016 emphasizes three pillars (EUROPEAN COMMISSION, 2016):

1. *A public declaration endorsing a common ambition of cities and manufacturers to accelerate roll-out of clean buses.*
2. *Creating a deployment platform where public authorities, public transport operators, manufacturers and financial organisations can come together with the aim to:*
    - *better exchange information,*
    - *better organize relevant actors and create coalitions,*
    - *leverage potential investment action*
    - *issue recommendations on specific policy topics*
3. *Creation of an expert group bringing together actors from the demand and supply side. This expert group will benefit from consolidated expertise on technological, financial and organisational issues.*

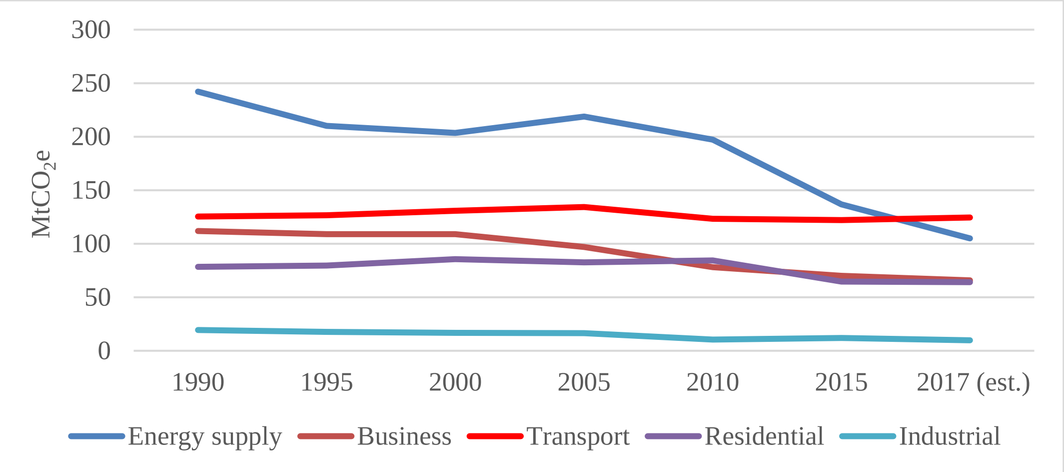
It is obvious that the electrical bus market dynamics are a fairly new and innovative transport policy element. Standardization in e-bus production and operation could be a useful element of modern electric bus diffusion. Patent dynamics in the EU and China in relevant fields of renewable energy and green e-bus mobility are interesting to analyze.

3.4 Lead Market Dynamics in the United Kingdom

Despite the EU's activities at a supranational level, most of the decisions and actions needed to meet national targets at member state level need to be taken and implemented by national policymakers. Greenhouse gas emissions from the transportation sector in the United Kingdom have proved resilient to government efforts to reduce them. However, as recent figures from the Office of National Statistics released by the Department for Business, Energy and Industrial Strategy (DBEIS) show, despite substantial decreases in greenhouse gas emissions by energy producers (stemming from a move away from coal-powered energy plants), and a raising level of energy efficiency awareness and behaviors in firms and homes., i.e. the business and residential sectors, respectively, the emissions of the transport sector remain stubbornly stable accounting for over a third of all CO_2 emissions in 2017 (see Figure 7).

While the growing share of energy efficient and low emission vehicles is acknowledged, the DBEIS explains the lack of reducing GHG emissions in the transport sector by claiming an increase in vehicle kilometers travelled, particularly in private cars (DBEIS, 2018b). However, it is also important to note that the domestic transport sector, while excluding international aviation and shipping, includes domestic aviation and shipping – and domestic aviation in particular has increased substantially in the UK in the decades since 1990 with the growth of budget airlines offering travelers in the UK an affordable alternative to rail journeys or long-distance bus trips.

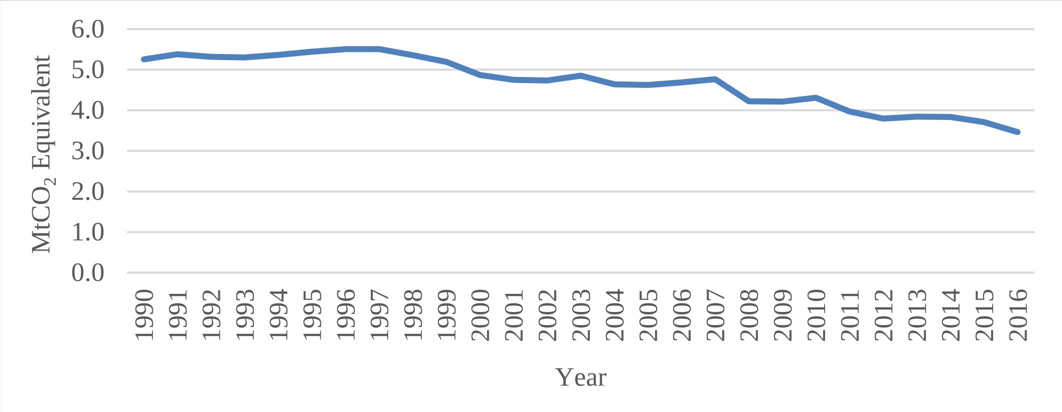
Figure 7: UK Annual Greenhouse Gas Emissions from Selected Sectors, 1990-2017



Source: Own representation amended from DBEIS (2018b), 2017 UK Greenhouse Gas Emissions Provision Figures; Note Transport excludes international aviation and international shipping

Nevertheless, the estimated GHG emissions of buses in the United Kingdom has indeed fallen significantly since 1990, from 5.3 million tonnes of CO_2 equivalent that year, to an estimated 3.5 million tonnes of CO_2 equivalent in 2016 (see Figure 8). In 2016, it was estimated that almost 4,000 Low Carbon Emission Buses (meaning 30% less well-to-wheel GHGs compared to Euro III diesel buses), which include e-buses, plug-in hybrids, hydrogen fuel cell vehicles, were already reducing GHG emissions by 55,000 tonnes annually (LCVP, 2016). With circa 160,000 buses and coaches licenses in the United Kingdom (DEPT. OF TRANSPORT, 2018), achieving the same reduction across the entire fleet could lead to a reduction in GHG emissions of 2.2 million tonnes (55,000/4,000*160000) or circa 60% of the total GHG emissions of buses in the UK.

Figure 8: Estimated Annual Emissions of Greenhouse Gases of Buses in the United Kingdom, 1990-2016



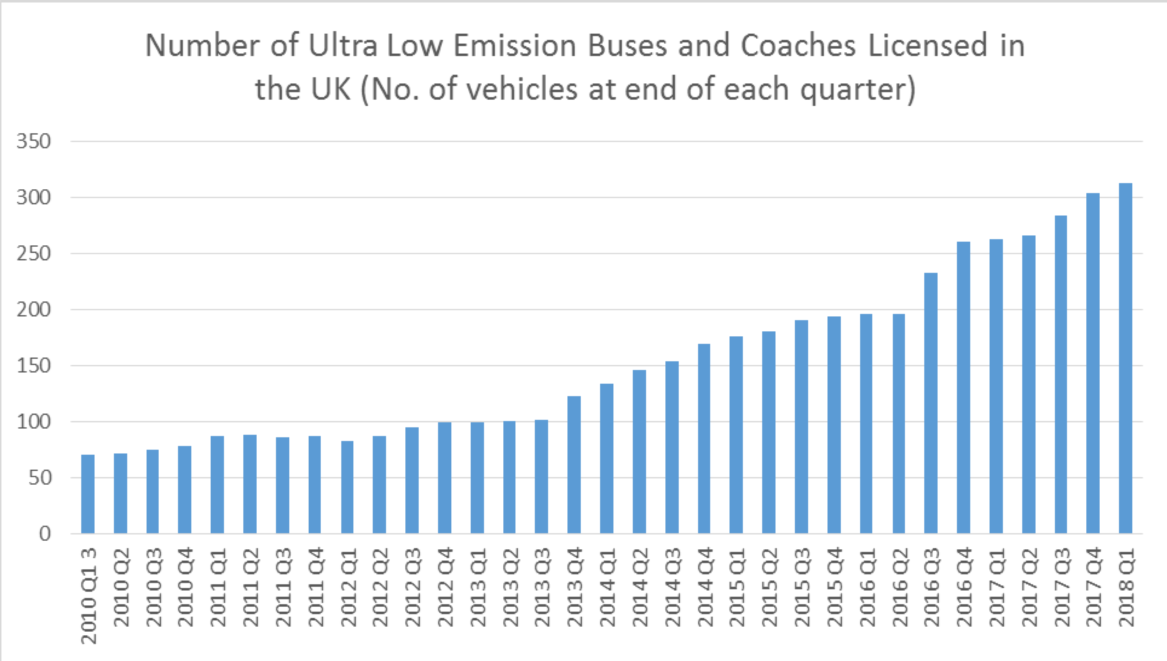
Source: Own representation amended from DBEIS (2018a), 2016 UK Greenhouse Gas Emissions: Final Figures (Data tables)

In the United Kingdom, the Climate Change Act of 2008 resulted in the then most advanced climate change legislation in the world (FRANKHAUSER/KENNEDY/SKEA, 2009). The authors also argue that the long-term decarbonization of the transportation sector will ultimately require a switch away from fossil fuel-based combustion engines to electric vehicles, biofuels (p. 107). Electric buses have an important and multifaceted role to play not only in terms of greenhouse gas emissions but also in regard to noise pollution and other harmful gas emissions. To this end, the United Kingdom has been to the forefront of supporting electric vehicle adoption – both in terms of private vehicles and public transport. The ultimate goal of the British government is that by 2050, the vehicle fleet across the UK, including that of the public transportation sector (here buses) will primarily be made up of Ultra-Low Emission Vehicles (ULEVs) (OLEV, 2013). It has been estimated that the well-to-wheel GHG emissions of an electric bus charged using the UK's electricity grid are over 60% lower than a tradition diesel bus (LCVP, 2016, p. 10) lending support to the rough estimate GHG emission reductions calculated above. However if all buses in the UK were electric buses, 850 Megawatts of power would be needed – the equivalent of a nuclear reactor or two-coal fired turbines (LCVP, 2016, p. 15). An increasing share of renewable energy in the UK's energy mix would reduce the impact of GHG emissions caused by additional power generation required to power the electric bus fleet.

A major step in the UK's journey towards electric buses was taken in early 2014, when Milton Keynes Council introduced a small fleet of induction-powered electric buses to one of the council’s busiest routes (covering a distance of 15 miles – ca. 24 km – and 51 stops) in what was to be the world’s most demanding route to be serviced by electric buses at the time (ARUP, 2014). A major project was undertaken to examine this pilot project, in particular to survey the performance of the buses in practice and actual operation – given the topography of the route, differing traffic demands, differing driver behaviors etc. The findings of this study indicated that real life performance of the buses in the Milton Keynes project was indeed comfortable within what could be expected due to theoretical predictions in terms of efficiency (KONTOU/MILES, 2015). As with any innovation a significant level of risk was associated with the move to electric buses. To solve the issue of all parties being unwilling to assume the risk, thus leading to a failure to implement the innovative technologies, an innovative business model was employed. A special purpose vehicle (SPV) or ‘enabling company’ was formed by the Japanese conglomerate Mitsui and Arup, a UK-based global engineering company. The enabling company assumed the “risk” involved in developing the buses and the charging infrastructure – leasing the buses and use of the infrastructure to the operator at a pre-agreed price – thus shielding the operator from any economic loss should the buses not perform as expected and removing the risk for the operator (MILES/POTTER, 2014). The Milton Keynes project is due to last until 2019 to allow medium-term analysis of the life cycle of the batteries and infrastructure.

The Green Bus Fund was established in 2009, providing public money to support the acquisition of low emission, low carbon buses across England. Under the Green Bus Fund, the purchase of over 1,200 buses was supported, however less than 60 of these were electric buses – the rest being hybrid fossil fuel or biomethane vehicles. The result of these efforts saw the UK reach top spot in Europe as of 2016 with the largest share (18%) in terms of Europe’s fleet of electric buses (including battery powered, plug-in hybrids and trolleybuses) – by comparison Germany, the Netherlands, Switzerland and Poland have around 10% each (ZeEUS, 2016). The number of ultra low emission buses and coaches licensed in the UK since 2010 can be seen in Figure 9. The Green Bus Fund has been replaced by the Low Emission Bus Scheme, announced in 2014, which will provide grant funding for vehicles and associated infrastructure costs up to financial year 2020/21 across England and Wales (OLEV, 2018). In Scotland, a Scottish Green Bus Fund was established alongside the Green Bus Fund and is in its eighth cycle in 2018 supporting the roll-out of low emission buses (LEBs) across Scotland (TRANSPORT SCOTLAND, 2018).

Figure 9: Number of Ultra-Low Emission Buses and Coaches Licensed in the UK



Source: Own representation of data from Department of Transport, Vehicle Licensing Statistics, Ultra low emission vehicles (ULEVs) 1 licensed at the end of quarter by bodytype, including regional breakdown for the latest quarter, United Kingdom from 2010 Q1, Table VEH0130

Electric bus uptake in the UK has been helped by the presence of a number of manufacturers in the UK itself. By September 2016, some twenty bus models produced by eight different manufacturers in the UK were regarded as being Low Carbon Emission Buses with 41% of new buses being produced meeting this target (LCVP, 2016). The dominant producer in the electric bus market in the UK is Optare, while other firms include Irizar and Volvo. Meanwhile, Sino-British partnerships have been developed – connecting the leading e-bus market globally, with the leading European e-bus market. In particular, Alexander Dennis Limited is manufacturing electric buses with its Chinese partner BYD and most recently, the Chinese firm Yutong has partnered with the British Pelican Engineering Group (MIGNJIE, 2018) to produce electric buses in the UK.

With almost 5 billion passenger journeys being made in the UK by bus in 2016/17 (59% of all public transport journeys (DEPARTMENT OF TRANSPORT, 2017)) the market for electric buses could remain robust, particularly with urbanization increasing. While as a sign of the UK’s emergence as a global leader in the field, the UK will host the world’s first Zero Emission Vehicle summit in Birmingham in September 2018. The event is intended to bring together policymakers and industry experts from around world to tackle carbon emissions and to explore ways to improve air quality.

3.5 Perspectives at a European Union Level

With an estimated stock of motor coaches, buses and trolley buses of just under 900,000 in 2016/17 across the European Union (EUROSTAT, 2019; ACEA, 2017), the reductions in terms of emissions which could be achieved if the entire fleet was replaced by electric vehicles is significant.

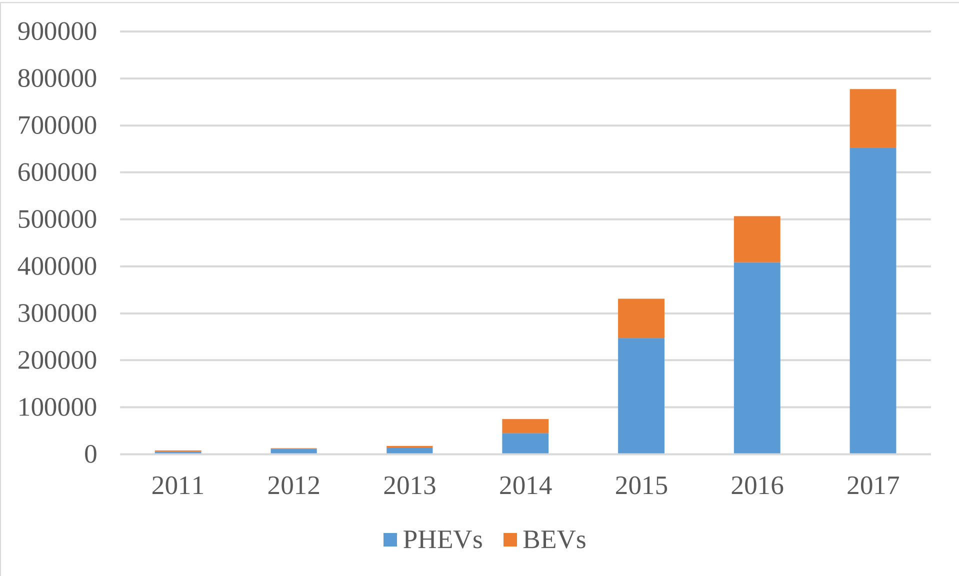
- Assuming a share of non-traditional combustion engine buses of approximately 2% - including electric and other low-emission vehicles – this leaves approximately 882,000 units in Europe which, if replaced by electric buses, could result – in a rough approximation based on UK figures - in a reduction of greenhouse gas emissions of over 12 million tonnes of CO2 equivalent.
- With the EU’s transport sector, excluding international aviation, responsible for an estimated 931 million tonnes of CO2 equivalent in 2016 (EEA, 2018), the reductions would amount to an estimated 1.3% cut in terms of emissions of the transport sector.

4. China as a Lead Market for Electrical Buses

4.1 Background and Development of Electrical Buses in China

The Chinese government uses the term new energy vehicles (NEVs) to include battery-powered electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). The stock of new energy vehicles in China is the world's largest, with cumulative sales of more than 1.7 million units up to December 2017 (see Figure 10).

Figure 10: Sales of New Energy Vehicles (NEVs) in China by Year (2011-2017)

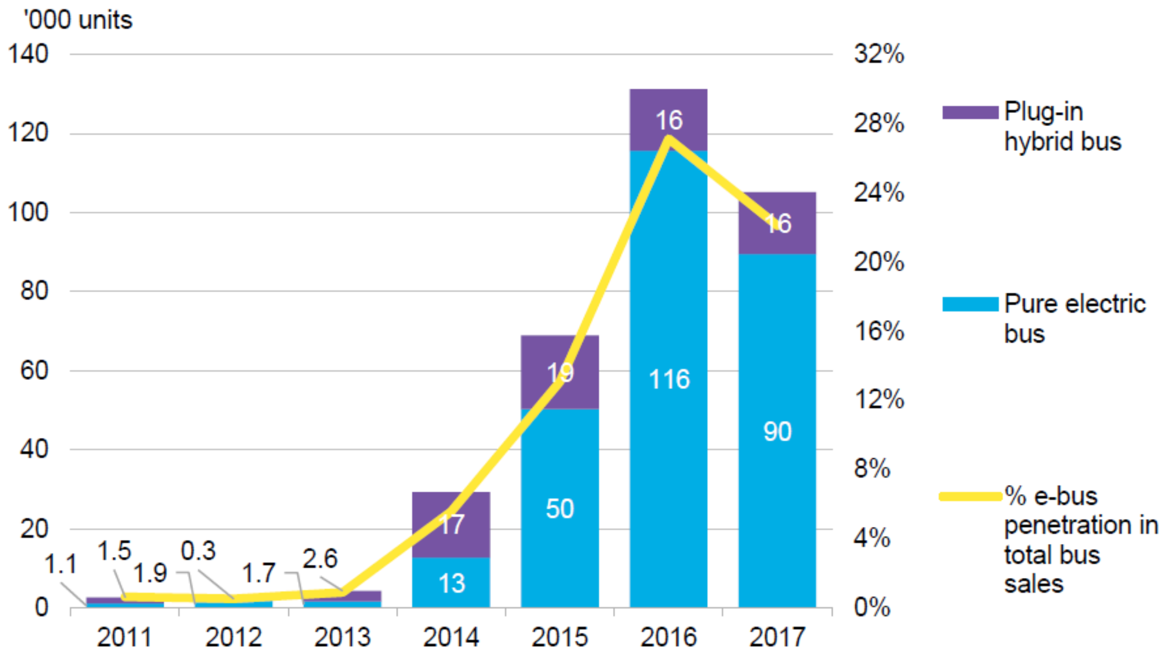


Source: evwind.es (2011), China Cars21.com (2012), chinadaily.com.cn (2013), Association of Automobile Manufacturers (2014&2015), d1ev.com (2016), autonewschina.com (2017)

Due to the pressure of increasing air pollution and the central government’s goal, China became the largest producer and user of electric buses and is also the world’s largest electric bus market. According to the State Council’s guidance which was issued in 2012, the priority development of public transportation, taxis and urban transportation are the main avenues for the promotion and application of electrical buses. The Chinese electrical bus stock grew nearly sixfold between 2014 and 2015. The plug-in buses stock reached 343,500 units in 2016, doubling the 2015 stock. The goal set by the Ministry of Transport (MoT) in 2015 is to promote the application of new energy vehicles by increasing the stock of NEVs by 300,000 vehicles in the entire bus industry by 2020; among them, 200,000 electrical buses and 100,000 logistics vehicles for rental and urban distribution. According to the statistics of the MoT, in 2016, the promotion of electrical buses increased and showed substantial growth. In 2016, 80,000 electrical buses were added and replaced, accounting for 86% of the total new replacements in the year. As of December 2016, China ranked as the world's largest plug-in electric bus market.

The city of Shenzhen is leading the modernization and electrification effort in China with hundreds of electric buses already in operation in 2016. Shenzhen achieved the goal of having a 100% electrical bus fleet in 2017.

Figure 11: China's Electric Bus Sales and Electric Bus Sales as Share of Total Bus Sales



Source: Bloomberg New Energy Finance, 2018

4.2 Central and Local Policies for Electrical Buses

As early as 2014, the General Office of the State Council issued the "Guiding Opinions on Accelerating the Promotion and Application of New Energy Vehicles" (translated from《关于加快新能源汽车推广应用的指导意见》). New energy vehicles, including electrical buses, were gradually developed under the promotion of national policy support and technological advancement in the industry.

In 2015, the Ministry of Transport issued the “Implementation Opinions on Accelerating the Promotion and Application of New Energy Vehicles in the Transportation Industry” (translated from 《关于加快推进新能源汽车在交通运输行业推广应用的实施意见》and hereinafter referred to as “Implementation Opinions”). The “Implementation Opinions” are significant in terms of providing guidance regarding the general requirements, main tasks, and safeguard measures relating to the promotion and application of new energy vehicles. In the same year, the Ministry of Transport, the Ministry of Finance, the Ministry of Industry and Information Technology jointly issued the “Measures for the Promotion and Application of New Energy Buses (Trial)” (translated from 《新能源公交车推广应用考核办法（试行）》) to strengthen the promotion of electrical buses and the effectiveness of local new energy vehicles. On the one hand, this is in order to maintain policy continuity, i.e. to continue to promote the healthy development of the new energy automobile industry; on the other hand, to further accelerate the promotion and application of new energy vehicles in the public transportation sector, and to promote energy-saving emission reduction and structural adjustment of the bus industry. Also in 2015, the central government has set a five-year-target for all provinces and regions in China regarding the share of electrical buses. For the key areas of air pollution control and crucial provinces and cities, including Beijing, Shanghai, Tianjin, Hebei, Shanxi, Jiangsu, Zhejiang, Shandong, Guangdong, and Hainan, the proportion of new energy buses added and replaced in 2015-2019 should be reach 40%, 50%, 60%, 70% and 80%, respectively. Among the newly added and replaced buses in the central provinces and Fujian Province from 2015 to 2019, the proportion of new energy buses should reach 25%, 35%, 45%, 55% and 65%, respectively. The central provinces include Anhui, Jiangxi, Henan, Hubei and Hunan. Among the newly added and replaced buses in other provinces from 2015 to 2019, the proportion of new energy buses should reach 10%, 15%, 20%, 25% and 30%, respectively.

Along with the central government's policy of promoting electrical buses, local governments have also introduced various relevant policies, proposed different promotion plans and subsidy policies according to local conditions, the length of the electric bus, vehicle type, mileage and other relevant factors, and have developed a number of implementation projects. For example, in 2017, the Shanghai municipal government offered a one-time fixed subsidy in addition to existing state subsidies for electrical buses according to the bus length. For pure electric buses over 10 meters in length, this subsidy was 350,000 yuan, the subsidy for pure electric buses of 8-10 meters in length is 280,000 yuan, and the subsidy for pure electric buses of 6-8 meters is 210,000 yuan. In 2017, Shenzhen municipal government has also implemented a series of subsidies according to the electrical bus type and length as the following table (Table 4) shows:

Table 4: Subsidies for Electric Buses in Shenzhen, 2017

Bus type (mileage≥30km/year)	Bus length(L) (meter)		
	6≤L<8	8≤L<10	L≥10
Pure electrical	40,000 Yuan/Unit/Year	60,000 Yuan/Unit/Year	80,000 Yuan/Unit/Year
Plug-in hybrid	20,000 Yuan/Unit/Year	30,000 Yuan/Unit/Year	40,000 Yuan/Unit/Year
Fuel cell	60,000 Yuan/Unit/Year		
Non-plug-in hybrid	20,000 Yuan/Unit/Year		

Source: *https://www.d1ev.com/news/zhengce/60073*

In Wuhan, there are more than 8,000 buses, of which more than 2,400 are clean energy vehicles, and 1,007 are pure electric buses. Environmentally-friendly vehicles account for more than 40% of the total number of buses. According to the local plan, by 2020 new energy vehicles will account for 65% of Wuhan's public transport vehicles, of which more than 3,000 shall be pure electric buses, accounting for 40% of the total number of public transport buses. By 2022, all diesel buses in Wuhan will be eliminated.

The biggest electrical bus deployments are also currently taking place in China. Table 2 shows some selected e-bus municipal fleet projects, delivered or announced in selected Chinese pilot cities. In June 2018, at the regular press conference held by the Ministry of Transport, the MoT announced that the use of electrical buses will be promoted nationwide. By the end of 2020, 100% of the buses from municipalities in the key areas, the provincial capitals, and the cities in the plan will be replaced with electrical buses.

Chinese researchers have estimated that for the whole 13th Five-year Plan, electrical buses will save 5.93 million tonnes of standard coal and reduce carbon emission by 12.5 million tonnes (ZHAO ET AL., 2016).

Table 5: Selected E-Bus Municipal Fleet Projects Delivered or Announced in Selected Chinese Pilot Cities

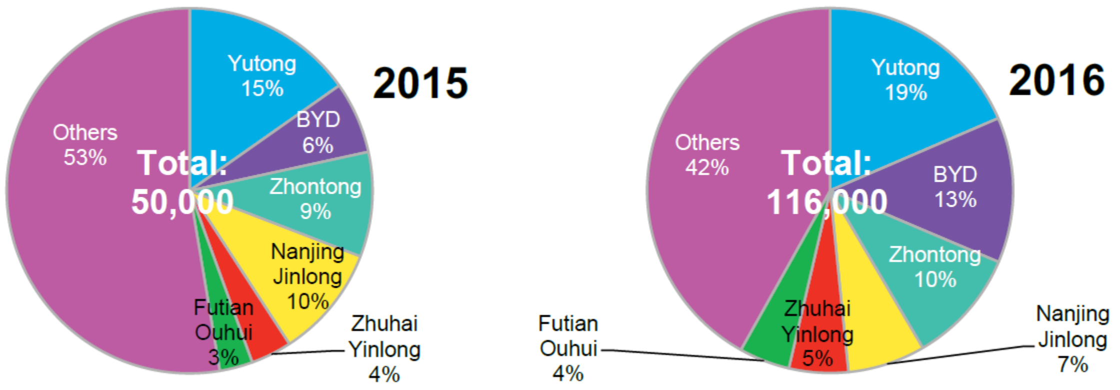
City/transit agency	Country	Number of e-buses	Delivered by	Manufacturer (model)	Additional information on fleet size, prices and targets	Status
Shenzhen	China	1,000 3,600 16,500[4]	2012 2016 2017	BYD BYD	The city of Shenzhen fully electrified all of its buses (around 16,500 buses).	Delivered Delivered Delivered
Shangqiu	China	635 100	11.2016 Not disclosed	Yutong Yutong	With nearly 1,000 electric buses in operation, the city's entire bus fleet is now electric. Additional 100 e-buses to be bought from Yutong to be used on newly added routes.	Delivered Announced
Qingdao	China	347	Not disclosed	Zhongtong	Total value of the contract is 410 million yuan ($65 million). In 2017 the number of electric buses in the city was roughly 600 units, or over 40% of the city's total bus fleet.	Announced
Beijing	China	50 56 1,320 10,000[5]	07.2017 09.2017 09.2017 2020	 Zhongtong BAIC Foton	Beijing has a target of having 10,000 e-buses on the road by 2020	Delivered Delivered Delivered Announced

Source: Bloomberg New Energy Finance, 2018

4.3 Chinese E-Bus Producers and Internationalization

The rise of electric buses has broken the traditional Chinese bus industry structure and ushered in a major adjustment. Yutong, Zhongtong, BYD and other enterprises have become the most representative electric bus manufacturers in China.

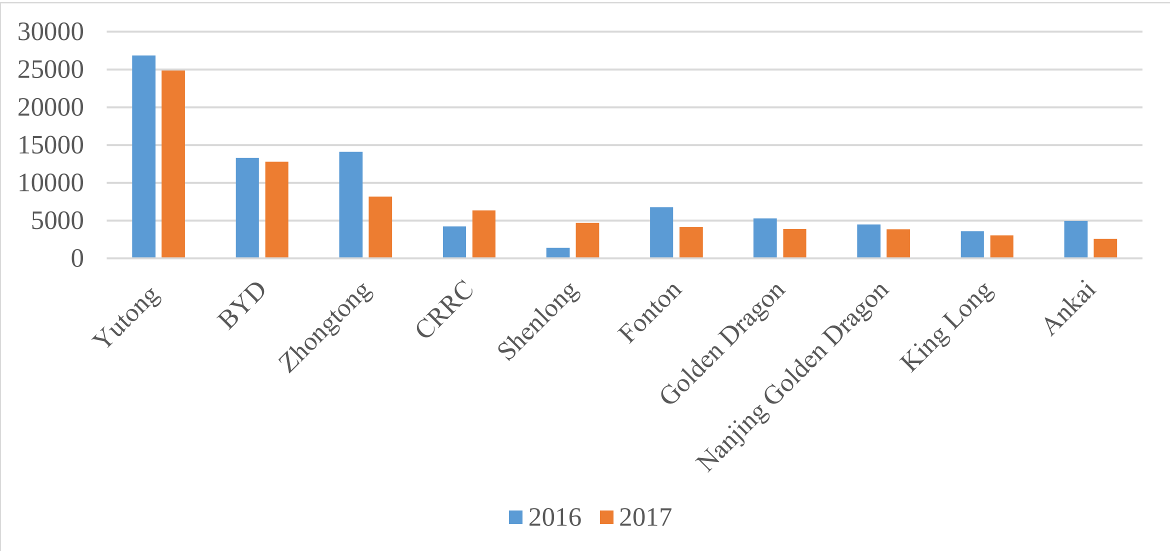
Figure 12: China's Pure Electric Bus Producers, 2015 and 2016



Source: Bloomberg New Energy Finance, 2018

The data of the Qianzhan Industry Research Institute also shows that in the past two years Yutong Bus, BYD and Zhongtong Bus have secured the top three positions in the new energy bus industry (see Figure 13). The sales volume of Yutong Bus's electrical bus is stable at more than 20,000 vehicles, BYD is stable at more than 10,000 vehicles, and Zhongtong Bus is more variable at around 10,000 vehicles. At the same time, the sales of the top three producers has accounted for more than half of the entire market, reaching 52.79%.

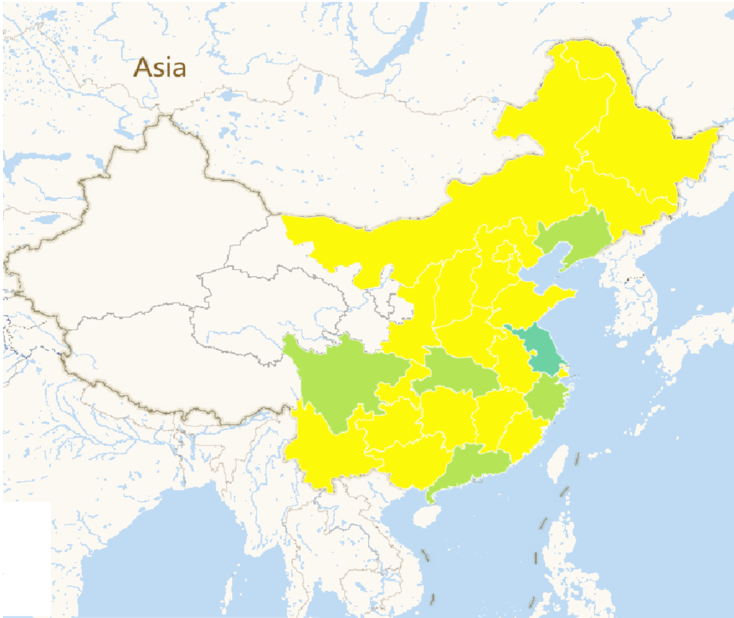
Figure 13: Sales Volumes of the Top Ten Electric Bus Producers in China, 2016 and 2017



Source: Qianzhan Industry Research Institute
https://baijiahao.baidu.com/s?id=1608319375188125819&wfr=spider&for=pc

China's electric bus procurement catalogue covers 114 bus companies. According to China's geographical distribution (see Figure 14) there are 47 in East China, accounting for 41.23%; 18 in Southwest China, accounting for 15.79%; and 13 in Central China, accounting for 11.40%; There are 11 enterprises in the three regions of South China, North China and Northeast China; the distribution in the Northwest is the lowest, and there are only 3 enterprises in Shaanxi Province.

Figure 14: Geographic Distribution of Electric Buses in China



Source: Map is created by authors based on the website:
http://www.evpartner.com/news/65/detail-35772.html

In 2009, Golden Dragon sold the first Chinese self-owned hybrid bus to Singapore. Since then, many Chinese bus manufacturing companies such as Yutong and BYD have also opened up new markets for electrical buses. As the world's largest electric car manufacturer, the BYD K9 series has been commissioned in London, Paris, Bremen, Bonn, Madrid, Barcelona, Salzburg, Warsaw, Amsterdam, Brussels and Budapest; the K9 series also entered the American market in the United States, Canada, Brazil, Uruguay, Chile, Mexico and other countries, and has even been put into production in South America. BYD also operates more than 100 electric buses in London, England. Yutong's exports to Europe are still at a demonstration stage. In 2015, at the World Climate Conference held in Paris, Yutong Pure Electric Bus was displayed and promoted as the only non-European brand vehicle; in the previous 2015 BusWorld Brussels, Yutong released a pure electric bus for the European market which has been trial-operated in European cities such as Paris.

5. Policy Conclusions and Further Research

A key issue in the EU and China is the standardization of electrical buses and the development of innovative e-bus services. As regards the EU, it should not be difficult to come up with a similar standardization initiative as has successfully been developed, for example, in the framework of GSM mobile telephony. This leaves open the issue as to what extent the EU and Asia could agree on joint standards in e-bus mobility.

The main driver of innovation in a market economy is, of course, the competition process. This certainly also holds for the EU and e-bus mobility in a long-term perspective. This, however, does not exclude that the initial stage of the life cycle could be supported by local and national as well as EU policy initiatives:

- At the local level, it would be natural to encourage the formation of city networks which would set up EU-wide tenders for buying various types of e-buses and the required associated local infrastructure. Networks must be limited with respect to the number of cities included to as to make sure that there is competition in the EU market; this does not exclude that some networks could be encompass cities from different (neighboring) EU countries.
- At the national level (in Germany also at the state level), there is the challenge of R&D subsidization, namely the need to internalize positive external effects.
- As many aspects of e-bus services are linked to digital technologies (e.g. the automatic counting of passengers, sending information and data within the fleet of buses in a network, predictive analytics related to optimal maintenance schedules etc.), one should carefully consider to what extent existing national or supranational ICT modernization initiatives could be extended to get a link to innovative e-bus projects). This leaves open the question as to what extent national R&D / ICT promotion could be combined with supranational EU initiatives.
- It seems adequate to organize an EU-ASEAN e-bus forum, possibly with a particular emphasis on China and ASEAN countries – China more because of supply side aspects and ASEAN because of potential demand side aspects. Existing technological cooperation of EU countries with Japan and Korea should also be exploited.

Industrial policy aspects could play a role in government e-bus initiatives where an emphasis on having control over a broader value-added chain could be a new element in a global trade situation in which US protectionism under the Trump Administration creates problems vis-à-vis international confidence among policymakers and international investors alike. The better the quality of e-bus services offered by cities or municipal transportation providers, the higher will be the willingness to pay provided that a high share of electricity used is renewable energy and that users get clear information about this. Nurturing willingness to pay is possible with respect to e-bus mobility and a higher price for such services will stimulate the switch to e-bus services.

A key question of future research is how the expansion of e-bus production is linked to e-bus services growth and which type of government promotion of e-bus innovation is adequate. In the case of the EU, this is both a question for the EU policy layer and a question for individual EU countries. Battery cell production is a broader issue that indeed is related to electricity mobility in general. Aspects of hybrid bus operation are part of a transition model for e-bus mobility. The roofs of buses could be painted white to contribute to a positive Albedo effect – the latter means the reflection of the sun by white colored surfaces; if all vehicles and roofs of houses had a bright color this could offset the melting of the ice in Polar Regions in the context of global warming.

As regards optimizing local traffic routes for e-buses, adequate simulation studies are necessary (e.g. approaches used by FhG-ISI, Karlsruhe). It would also be very important to set up an e-bus mobility database with respect to technical characteristics, experiences with different types of e-bus mobility and reports on new combinations of e-bus mobility and digital services innovations (here, the EIIW and EES could have an active role in the future). The ecological, logistical and economic opportunities of e-bus mobility require further research which could generate considerable benefits for the economy and the society at large.

Among the key policy challenges that should be considered more broadly in future research are

- How could those cities/towns ordering e-buses which cause less noise pollution than traditional buses benefit – this negative externality of traditional buses implies lower real estate and land prices in cities and towns; an adequate modest local tax on real estate income could reflect the internalization of negative external noise effects and thus help to incentivize more e-bus investment in Europe, Asia, North America and worldwide.
- To the extent that e-bus mobility in general allows or facilitates the provision of new services – including tourist services – one should develop a new concept of e-Bus Big Data (EBBD); some form of revenue sharing in e-bus networks (those could be regional, national or international) should also be considered. Adequate R&D promotion and innovative regional pilot projects could be quite useful, but the definition of digital property rights remains a key challenge in Europe and worldwide; without such property rights, the incentive to invest adequately in data security and to create broad big data user networks (and to overcome political resistance against such projects) will remain rather modest. Liability rules of digital service providers would thus also become more relevant which in turn gives crucial incentives for an efficient digital market economy. Moreover, digital liability insurance packages would expand.
- One should not overlook flexible transition solutions that, for some transportation ranges, could include gas-powered bus or truck transportation. Indeed, many technical solutions developed for e-buses and low emission buses could have positive spillover effects into the truck transportation sector. Taking this into perspective, the expected long run benefits of e-bus innovation projects certainly go beyond the bus transportation sector alone.

Thus, e-bus mobility expansion could generate large local, regional, national and international benefits; therefore it should be part and parcel of the UN's Sustainable Development Goals and the associated agenda for global modernization.

Appendix 1: From European Commission website (transportation and mobility)

The following text is a quote from the EU website (https://ec.europa.eu/transport/themes/urban/cleanbus_en):

“Background

Clean (alternatively fuelled) buses in urban areas can offer considerable advantages. Reductions in emissions of greenhouse gases, air pollutants and noise bring about considerable public health benefits. Moreover, moving on quietly and smoothly means greater passenger comfort and new opportunities for routes, making public transport more attractive.

However, the potential of these innovative technologies is far from being really utilized in the EU, owing also to still wide-spread concerns about technological reliability and high costs, particularly of battery-electric and fuel-cell electric buses (Roughly 8 percent of the bus fleet is renewed every year following a typical 8-10 year cycle life for (diesel) buses. Diesel buses continue to represent the largest part of the urban bus fleet. The 3iBS survey noted that in 2013 roughly 10 per cent accounted for biodiesel, 7 per cent for CNG, 1.2 per cent for electricity, 0.6 per cent for biogas and 2.3 per cent for other fuels. In 2016, this picture – with some upward adjustments – is still largely correct http://www.uitp.org/sites/default/files/cck-focus-papers-files/UITP_Posi). The business case for natural gas and other hybrid solutions is already well-established, but demand needs to grow. Recent announcements of leading public transport authorities indicate a much stronger push for alternatively fuelled buses over the next years (For example, the Dutch provinces committed to only buy zero-emission buses from 2025 onwards. Cities of Athens, Paris and Madrid plan to remove diesel vehicles by 2025, as well as the government of Norway. Other cities and regions have announced plans to stop purchasing conventionally fuelled buses, including Copenhagen (in place since 2014), London (announced for 2018), Berlin (announced for 2020) or Oslo (announced for 2020)).

At this point, however, many important implementation issues remain to be resolved, including legal, organisational, technical and financial. Any decision to invest large-scale into alternatively fuelled bus technology needs to be based on a sound, well-understood business model that leaves all involved partners with sufficient confidence into its financing model and its funding strategy seen from a total cost of ownership perspective.

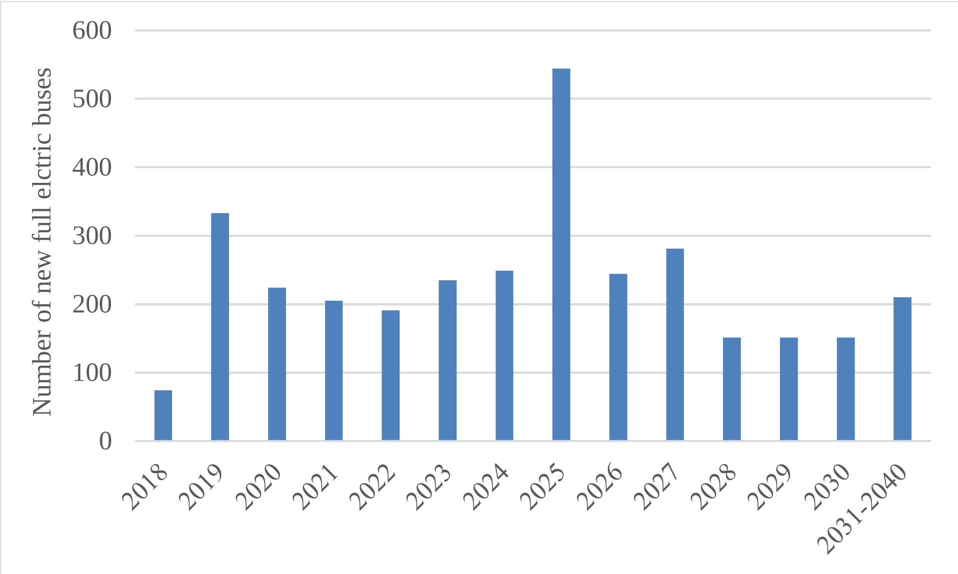
Moreover, there needs to be trust into the ability of the market to deliver products at larger scale and fitting specific local requirements. In addition, public and private stakeholders raised the issue of better coherence of different policy and financial levers.

For the above-stated reasons the European Commission and the Committee of the Regions are facilitating the creation of a dedicated initiative for clean (alternatively fuelled) buses.

The work on the Clean Bus Deployment Initiative started in 2016 when the Commission hosted a meeting with manufacturers, cities, transport operators, etc. in order to understand what the barriers are that need to be tackled in order to have more Clean buses into European cities. Since then several meetings have taken place, which have resulted in the 3-pillar based approach. The launch of the Clean Bus Deployment Initiative took place in Brussels on the 13th of July, during the plenary of the Committee of the Regions."

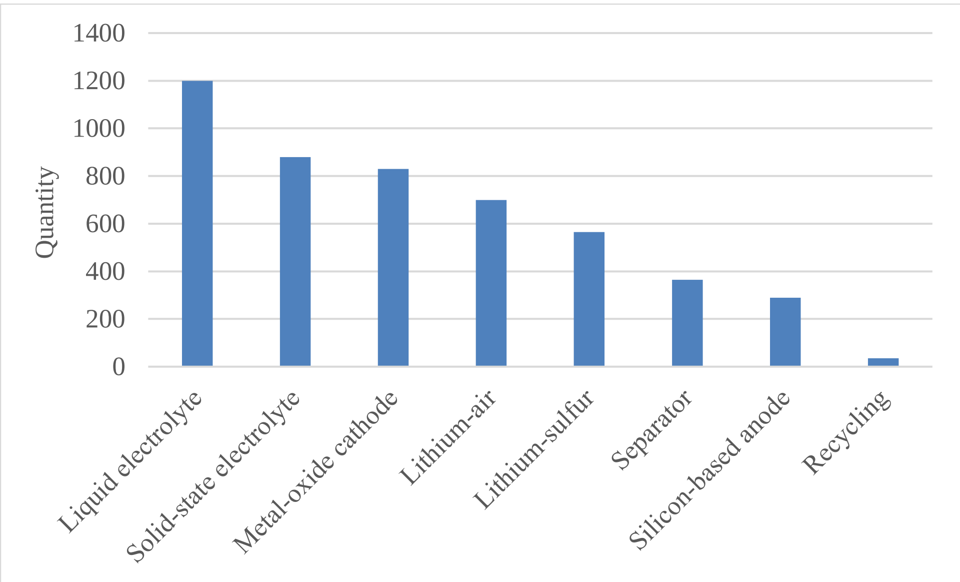
Appendix 2: Additional information

Figure 15: Forecast of new full electric buses in Germany



Source: Own representation based on PWC (2018).

Figure 16: Patent applications in 2015 regarding battery technologies



Source: Own representation based on ARTHUR (2018).

Table 6: Description of Abbreviations Used in Equations 1 and 2

Abbreviation	Description
A_{SF}	frontal area
a_x	acceleration
cw	drag coefficient
e_i	mass factor
f_t	rolling friction
g	gravitation
α	gradient angle
ρ_{air}	air density

Source: Own representation

References

ACEA (2017), European Automobile Manufacturers Association, Fact Sheet Buses https://www.acea.be/uploads/publications/factsheet_buses.pdf

AHMAD, A.; ALAM, M.S.; CHABAAN, R. (AHMAD, 2018), A Comprehensive Review of Wireless Charging Technologies for Electric Vehicles, *IEEE TRANSACTIONS ON TRANSPORTATION ELECTRIFICATION*, 4(1).

ALBALATE, D.; BEL, G. (2010), What shapes local public transportation in Europe? Economics, mobility, institutions, and geography, *Transportation Research*, Vol. 46, pp. 775-790.

ARUP (2014), World's most demanding electric bus route launched in Milton Keynes, press release 9 January 2014, available at https://www.arup.com/news-and-events/worlds-most-demanding-electric-bus-route-launched-in-milton-keynes

ARTHUR D. LITTLE (2018), Future of batteries: Winner takes all? May 2018.

BLOOMBERG (2018), Electric Buses in Cities – Driving Towards Cleaner Air and Lower CO_2, Bloomberg New Energy Finance, March 29 https://data.bloomberglp.com/bnef/sites/14/2018/05/Electric-Buses-in-Cities-Report-BNEF-C40-Citi.pdf

CIVITAS (2013), Smart choices for cities: Clean buses for your city.

DARGAY, J.; HANLY, M. (2002), The Demand for Local Bus Services in England, *Journal of Transport Economics and Policy*, Vol. 36(1), pp. 73-91.

DBEIS (2018a), 2016 UK Greenhouse Gas Emissions Final Figures: Data Tables, dated 6 February 2018 (accessed 31.08.2018) https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-2016

DBEIS (2018b), 2017 UK Greenhouse Gas Emissions Provisional Figures, Department for Business, Energy and Industrial Strategy, Statistical Release, dated 29 March 2018 (accessed 19.08.18)

DBS BANK (DBS, 2018), China Leads the Way: Asia Leapfrogging in Electric Vehicles, *DBS Asian Insights, Sector Briefing* (64).

DEPARTMENT OF TRANSPORT (2017), Transport Statistics Great Britain 2017, 2017 Edition, November 2017.

DEPARTMENT OF TRANSPORT (2018), Buses and Coaches, Statistical Data Set (VEH06), last updated 12 April 2018 (accessed 31.08.2018) https://www.gov.uk/government/statistical-data-sets/veh06-licensed-buses-and-coaches#licensed-vehicles

ELECTREK (2017), BYD delivers first massive 60-ft all-electric bus in the US: 275 miles range on 547 kWh battery pack, last updated 4 May 2017 (accessed 31.01.2019) https://electrek.co/2017/05/04/byd-all-electric-bus/.

ENRIQUE FERNANDEZ, J.; DE CEA CHICANO, J.; DE GRANGE, L. (2005), Production costs, congestion, scope and scale economies in urban bus transportation corridors, Transportation Research Part A: Policy and Practice, Vol. 39(5), pp. 383-403.

ENRIQUE FERNANDEZ, J.; DE CEA CHICANO, J.; MALBRAN, R.H. (2008), Demand responsive urban public transport system design: Methodology and application, Transportation Research Part A: Policy and Practice, Vol. 42(7), pp. 951-972.

EUROPEAN COMMISSION (2016), European Clean Bus deployment Initiative, European Commission, Mobility and Transport, available at https://ec.europa.eu/transport/themes/urban/cleanbus_en

EUROPEAN COMMISSION (EU, 2018), Towards the battery of the future, *Future brief* (20).

EUROPEAN ENERGY AGENCY (2018), Greenhouse gas emissions from transport, last updated 22 November 2018, https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-11, last accessed 25 March 2019

EUROSTAT (2019), Motor coaches, buses and trolley buses, by type of vehicle, database road_eqs_busveh (accessed 25.03.2019)

FECHTNER, H.; SCHMÜLLING, B. (2018), Technical Analysis of Electric Buses, University of Wuppertal.

FECHTNER, H.; SCHMUELLING, B. (2018), Improved range prediction of electric vehicles by a smart tire pressure monitoring system. IEEE Conference on Technologies for Sustainability 2018, Long Beach, USA.

FRANKHAUSER, S.; KENNEDY, D.; SKEA, J. (2009), The UK's carbon targets for 2020 and the role of the Committee on Climate Change, in Building a low-carbon future: The politics of climate change, Giddens, A. et al. (Eds.), Policy Network.

FRAUNHOFER CENTER FOR INTERNATIONAL MANAGEMENT AND KNOWLEDGE ECONOMY (FRAUNHOFER, 2015), Techview Report: Electric Buses.

FRAUNHOFER INSTITUTE FOR SYSTEMS AND INNOVATION (FRAUNHOFER, 2017), Energiespeicher-Roadmap: Hochenergie-Batterien 2030+ und Perspektiven zukünftiger Batterietechnologien.

FRIEDRICH, H.E. (2017), Leichtbau in der Fahrzeugtechnik, Springer Vieweg, Stuttgart, Germany.

GlobalPetrolPirces (GPP, 2018), China Gasoline prices, https://www.globalpetrolprices.com/China/gasoline_prices/, (October 1, 2018)

GRAHAM, D.; CROTTE, A.; ANDERSON, R. (2009), A dynamic analysis of urban metro demand. Transportation Research Part E, vol. 45, pp. 787–794.

HANNAN, A.H.; HOQUE, M.M.; YUSOF, Y.; KER, P.J. (HANNAN, 2018), State-of-the-Art and Energy Management System of Lithium-Ion Batteries in Electric Vehicle - Applications: Issues and Recommendations, *IEEE Access* (6).

HOLMGREN, J. (2007), Meta-analysis of public transport demand, Transportation Research Part A: Policy and Practice, vol. 41(10), pp. 1021-1035.

INTERNATIONAL ENERGY AGENCY (IEA, 2018), Global EV Outlook 2018.

KONTOU, A.; MILES, J. (2015), Electric buses: lessons to be learnt from the Milton Keynes demonstration project, *Procedia Engineering* 118, pp. 1137 – 1144.

KREMERS, H.; NIJKAMP, P.; RIETVELD, P. (2002), A meta-analysis of price elasticities of transport demand in a general equilibrium framework, *Economic Modelling*, Vol. 19(3), pp. 463-485.

LCVP (2016), A Green Bus For Every Journey, Case studies showing the range of low emission bus technologies in use throughout the UK, Low Carbon Vehicle Partnership, https://greenerjourneys.com/wp-content/uploads/2016/11/LowCVP-A-Green-Bus-for-Every-Journey-FINAL.pdf

MILES, J.; POTTER, S. (2014), Developing a viable electric bus service: The Milton Keynes demonstration project, Research in Transportation Economics, Vol. 48, pp. 357-363.

MINGJIE, W. (2018), China-UK electric bus unveiled, China Daily Europe, online edition 02.02.2018 http://www.chinadaily.com.cn/a/201802/02/WS5a74560da3106e7dcc13a7bd.html

MINISTRY of TRANSPORT of the PEOPLE's REPUBLIC of CHINA (2015), Measures for the Promotion and Application of New Energy Buses (Trial) (<<新能源公交车推广应用考核办法（试行）>>, 交运发〔2015]164号), http://zizhan.mot.gov.cn/zfxxgk/bnssj/dlyss/201511/t20151110_1924495.html

NIJKAMP, P.; PEPPING, G. (1998), Meta-analysis for explaining the variance in public transport demand elasticities in Europe, Journal of Transportation and Statistics, 1(1), pp. 1-14.

OLEV (2013), Driving the Future Today: A strategy for ultra low emission vehicles in the UK, Office for Low Emission Vehicles, September 2013.

OLEV (2018), Ultra-Law Emission Bus Scheme, Guidance for Participants, Office for Low Emission Vehicles March 2018 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/694955/uleb-scheme-participant-guidance.pdf

OMNIBUSSPIEGEL (2018), Elektrobus-Einsatz in Deutschland, *Omnibusspiegel*, 18(5), May 2018.

PRICEWATERHOUSECOOPERS (PWC, 2018), E-Bus-Radar: Die Zukunft des öffentlichen Nahverkehrs.

ROTHGANG, S.; ROGGE, M.; BECKER, J.; SAUER, D. U (ROTHGANG, 2015), Battery Design for Successful Electrification in Public Transport, *Energies 2015* (8).

THE STATE COUNCIL of the PEOPLE's REPUBLIC of CHINA (2014), Guiding Opinions on Accelerating the Promotion and Application of New Energy Vehicles (<<国务院办公厅关于加快新能源汽车推广应用的指导意见>>, 国办发〔2014]35号). http://www.gov.cn/zhengce/content/2014-07/21/content_8936.htm

THE STATE COUNCIL of the PEOPLE's REPUBLIC of CHINA (2015), Implementation Opinions on Accelerating the Promotion and Application of New Energy Vehicles in the Transportation Industry (<<交通运输部关于加快推进新能源汽车在交通运输行业推广应用的实施意见>>, 交运发〔2015]34号), http://www.gov.cn/gongbao/content/2015/content_2883248.htm

TRANSPORT SCOTLAND (2018), Scottish Green Bus Fund, https://www.transport.gov.scot/public-transport/buses/scottish-green-bus-fund/

WELFENS, P.J.J.; YU, N.; HANRAHAN, D.; GENG, Y. (2017), The ETS in China and Europe: dynamics, policy options and global sustainability perspectives, *International Economics and Economic Policy*, 14(3), pp. 517-535 https://doi.org/10.1007/s10368-017-0392-4

ZeEUS (2016), ZeEUS eBus Report – An overview of electric buses in Europe, December 2016 http://zeeus.eu/uploads/publications/documents/zeeus-ebus-report-internet.pdf

ZHAO, L.; LIU, W.; LI, B.; ZHANG, M. (2016), Evaluation on Energy-Saving and Emission-Reduction Results of New Energy Buses Based on Policy Guidance, Transactions of Beijing Institute of Technology, 36(2), original in Chinese. http://journal.bit.edu.cn/zr/ch/reader/create_pdf.aspx?file_no=2016S223&year_id=2016&quarter_id=S2&falg=1

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