MOBILITY AND TRANSPORT CONNECTIVITY SERIES

ELECTRIFICATION OF PUBLIC TRANSPORT

A Case Study of the Shenzhen Bus Group

WORLD BANK GROUP

SHENZHEN BUS

UCDAVIS
CHINA CENTER FOR ENERGY AND TRANSPORTATION
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Table of Contents

Figures

Tables

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Abbreviations

Abbreviation	Full Name
AC	Alternating Current
BEB	Battery Electric Bus
BEV	Battery Electric Vehicle
BYD	Build Your Dream Company Limited
CAN	Control Area Network
CAP	Criteria Air Pollution
CATARC	China Automotive Technology and Research Center Company
DB	Diesel Bus
DC	Direct Current
EAP	Employee Assistance Program
EBC	Eastern Bus Company
EEA	European Environment Agency
EU	European Union
EV	Electric Vehicle
FCV	Fuel-cell Vehicle
GHG	Greenhouse Gas
HEV	Hybrid Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
IPCC	The Intergovernmental Panel on Climate Change
ITC	Intelligent Transportation Center
ITS	Intelligent Traffic System
LPG	Liquefied Petroleum Gas
MIIT	Ministry of Industry and Information Technology
MOF	Ministry of Finance
MOST	Ministry of Science and Technology
NDRC	National Development and Reform Commission
NEV	New Energy Vehicle
NJGD	Nanjing Golden Dragon Bus Company Limited
OEM	Original Equipment Manufacturer
PGC	Potevio Group Corporation
PHEV	Plug-in Hybrid Electric Vehicle
SZBG	Shenzhen Bus Group
SMTC	Shenzhen Municipal Transport Commission
SDRC	Shenzhen Development and Reform Commission
SNEVLG	Shenzhen Energy Saving and New Energy Vehicles Demonstration and Promotion Leading Group
SOC	State of Charge
SOE	State-Owned Enterprise
STC	Shenzhen Transportation Commission
SWT	Shenzhen Winline Technology
TCO	Total Cost of Ownership
UITP	Union Internationale des Transports Publics
WZL	Wuzhoulong Company Limited
WBC	Western Bus Company

Foreword

Actions to combat climate change and its impacts are on the urgent agenda of all countries. The transport sector, which accounts for around one-fifth of global carbon dioxide emissions, has always been the focus of decarbonization. Despite the changes caused by the COVID-19 pandemic, when the world went through the largest-ever decline in global emissions due to economic and social shutdowns, the transport sector remains accountable for nearly seven gigatons of carbon emissions in 2020. Furthermore, the rapid redound of fast-growing transport demand, led by the recovery of economic activity, in the coming decades, is expected to generate a large increase in transport emissions if no interventions are taken.

Luckily, transport sector is already going through major transformations to offset its carbon emissions, in which technological innovations play a key role. An example is the electric vehicles, which offer a viable option in reducing emissions from road transport as the world shifts towards a low-carbon grid. In the past decade, China has adopted various policy and stimulus measures to promote new-energy vehicles. So far, the stock of electric vehicles in China has reached 4.92 million, accounting for 47.3 percent of the global stock.

Besides the technology improvement, prioritizing public transport over private motorization is critical to decarbonize transport. Investment in high-quality and low-emission public transport also improves equity, by providing accessibility for all individuals especially the ones that cannot afford a private vehicle as well as positive safety impact. While public transport users are responsible for the lowest emissions on a per capita basis amongst motorized modes, they suffer higher levels of air pollution. Electrifying public transport is therefore a development priority, particularly for developing countries. China has achieved large-scale electrification of urban buses, possessing 98% of the global electric bus inventory. A star example is Shenzhen, which became the first city globally to have fully electrified its bus fleet in 2017, and then its taxis two years later. The Shenzhen case offers not only the operational feasibility of electrification of public transport, but also the experience of utilizing the electrification to improve operation and service provision.

Though distinct from other countries in socioeconomic context, China's experiences could be beneficial to the emerging economies, who are in search of practical solutions for sustainable development. Among the numerous reports already published on electric buses, this report is a rare find that contains the details of the technical, policy, infrastructure, and capacity requirements for making a large-scale electrification transition for bus and taxi operators. I am sure the readers would appreciate the abundant information on the challenges, measures, rationales, lessons, and financial and environmental impacts with real-life data from Shenzhen Bus Group as well as practical key steps for urban bus fleet electrification.

Binyam Reja
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Executive Summary

China is the only economy worldwide that has implemented large-scale electrification of city buses, accounting for 98 percent of the global electric bus stock and 95 percent of the global stock of dedicated bus chargers (IEA 2020). This rapid technology transition was driven by strong policies supporting local governments with experimental innovations and lessons from pilot projects that were scaled across the country. As early adopters with the operational experience of a whole lifecycle of electric buses, Chinese cities can offer valuable knowledge and lessons to the rest of the world in the technology, policy, infrastructure, and capacity requirements for making the electrification transition. This case study on the electrification of buses and taxis is part of a larger effort by the World Bank Transport Global Practice to share China's experience in rolling out electric mobility to the international community so that other governments can make more informed decisions, avoid potential risks, save resources, and connect to experts in the field and build capacity.

The City of Shenzhen has China's, and the world's, first and largest fully electric bus and taxi fleets. Shenzhen began adopting electric buses in 2009, under a national electric vehicle demonstration program that challenged ten cities across China to deploy at least 1,000 electric vehicles (EVs) for three years. In 2017, Shenzhen became the first city in the world that fully electrified its urban transit fleet of 16,359 electric buses. In addition, Shenzhen is also approaching the goal of fully electrifying its taxi fleet of 21,609 taxis—99 percent electrified at the end of 2019 with 21,485 electric taxis. Private cars, garbage trucks, and other heavy-duty vehicles are transitioning toward electrification as well.

The Shenzhen Bus Group Company Ltd. (SZBG), one of the three major bus operators in Shenzhen, was the first public transport operator in China and the world to electrify its entire fleet. SZBG operates nearly 6000 electric buses running one third of the city's bus routes, carrying 40 percent of bus passenger trips of Shenzhen. The SZBG electrified its whole bus fleet from 2009 to 2017 in three phases: a demonstration stage in 2009–2011, followed by small pilots from 2012–2015, and large-scale electrification from 2016–2017. This was certainly not a transition without its challenges: how the SZBG dealt with them and what the financial and environmental impacts are, could provide important lessons for public transport operators around the world embarking on a similar path.

The authors would like to note that Shenzhen is a unique case for electrification, even in China. Shenzhen has a mild and warm climate and relatively flat topography, where electric vehicles tend to perform in a more reliable way than in cold or hilly areas. More importantly, Shenzhen is one of the most affluent cities in China—a young megapolis rising after China's economic reform and opening up, with overall high-quality infrastructure—street network, power grid, utilities—and an almost complete supply chain locally from battery production and vehicle manufacturing to battery recycling companies and research and development institutions, most notably housing the headquarters of the automobile manufacturing giant Build Your Dream Company Limited (BYD). Furthermore, Shenzhen municipal government is financially and institutionally capable—while it can afford very generous fiscal subsidies, the government has been famous for its policy innovation and ambition, given Shenzhen's Special Economic Zone status. Despite its unique advantages that most other cities might not have, this case study on the electrification of buses and taxis of the SZBG still provides other cities and bus operating companies with a series of useful lessons, especially on the practical implementation details as well as a valuable accounting of the financial and environmental impacts of the electrification using real-life data.

Collaborating Closely with Public and Private Stakeholders

The transition to electrification requires coordination and policy synergy across different levels of governments as well as different departments within the governments. Private players especially in vehicle manufacturing, charging, and new technology are also critical. The ultimate users of the service are passengers, who should not be neglected. Shenzhen's success in electrifying its entire bus fleet in a short period of time was a joint effort by private and public entities.

Shenzhen has established the Shenzhen Energy Conservation and New Energy Vehicle Demonstration and Promotion Leading Group (SNEVLG) to trickle down national and provincial policies and to coordinate relevant municipal departments. The government mandate to shift completely to clean energy buses—accompanied by generous national and local government subsidies that significantly lowered the upfront cost—supported the fast and full electrification of the bus fleet in Shenzhen. The combination of purchase subsidies from national and local governments together contributed more than 60 percent of the total procurement cost of the electric buses from 2015 to 2017, which was critical for its large-scale adoption. The municipal government of Shenzhen also made significant efforts to resolve the land availability issue for constructing new charging stations.

The main private stakeholder was the bus manufacturer. The manufacturer provided warranties that cover the lifetime of a bus in Shenzhen, its maintenance support as well as training for operator staff. Such warranties not only relieved the operator's concern over technology uncertainty and reduced the maintenance cost but also incentivized manufacturers to keep innovating and improving their electric bus performance. Another important private stakeholder is the charging service provider who functions as a conduit between the grid company and bus operators by evaluating grid capacity and providing additional transformer and power lines as necessary.

Besides government and industry partners, the SZBG also worked closely with private companies and nonprofit organizations including Huawei, Didi Chuxing and the International Association of Public Transport (UITP) running pilot programs on intelligent dispatch systems, on-demand bus services, and autonomous driving technologies. Furthermore, the SZBG conducted passenger satisfaction surveys every year to evaluate its service and to make adjustments—passengers expressed very high satisfaction with the electric bus service, and the SZBG was able to maintain a stable ridership against the overall declining bus demand with the expanding metro system.

Selecting Technology to Fit Operational Needs and Constraints

At the early stages of electrification, 2009–2013, EV technologies were not widely tested, and technical specifications of vehicles varied among manufacturers. At the same time, bus operators also lacked the technical knowledge to evaluate specifications. The SZBG has gained a critical understanding of the technology from a small-scale pilot and learned to specify the vehicle and charging needs that fit their own operation requirements and constraints. The SZBG has established a technology department, whose major mandate is to facilitate technology selection and adoption. The technology department studies the available technologies on the market and coordinates the needs from relevant departments inside the SZBG including operation and fleet management, maintenance and repair, financial, procurement, information technology, human resources, and strategic investment.

Aiming for large-scale adoption in a very short time, the SZBG decided to choose a vehicle model that would require minimal changes to the existing bus routes and schedules. Unlike other cities that tested different electric bus technologies, Shenzhen remained dedicated to a single, proven vehicle technology—electric buses with a large battery—to achieve the daily mileage of its required operation. Shenzhen's electric buses are dominated by the BYD K8 bus—67 percent of the fleet—that is 10.5 meters long with a theoretical 250-kilometer battery range, featured by two-hour direct current (DC) fast charging or 4- to 5-hour alternating current (AC) slow charging. With an average daily operation distance of 190 kilometers, these buses could run a whole day, and would only need recharging at night for most routes. Over the ten-year period, the SZBG and the manufacturers worked together to improve the technology and optimize the vehicle configurations based on operation feedbacks, and created a more mature and standardized product.

In selecting of charge technology, the SZBG decided to use DC fast charging stations to overcome two of the most prominent issues of charging speed and the lack of space at depots—DC fast charging allows multiple buses to be charged at the same charging terminal without moving them. The SZBG also considered several alternative charging modes such battery swapping and wireless charging but did not choose those due to various reasons including technical constraints, financial viability, charging efficiency, and impact on the grid.

Finding Viable Business Model to Improve Financial Efficiency

The key challenge for electric bus adoption around the world is its high capital cost, even though the price of the electric bus has dropped significantly since the SZBG started its electrification process. Even with sizable national and local government subsidies, the purchase cost of electric buses is still much higher than conventional buses. The need for charging facilities also increases the costs, and the land acquisition or rent for charging stations adds to the initial investment needs.

The SZBG introduced a financial leasing model that used a financial leasing company that purchases and owns the vehicles and leases them to the SZBG for a period of eight years, with a lifecycle warranty for key parts offered by bus manufacturers. The SZBG takes ownership of the vehicles after the leasing period is over. The batteries are returned to the manufacturer to recycle and dispose, while the bus body is sent for scrappage and metal recycling. Since the leasing period equals the total life of the buses, this arrangement turned the high-cost procurement into more manageable annual rental or lease payments. The charging facilities including charging stations and transformers are owned by the owners of depots, who can be the SZBG or a charging service provider, while the government owns the power supply lines. This arrangement turned out to be a common model followed in China, and has nurtured a healthy and competitive market for charging service providers including the participation of grid companies. Based on this whole-vehicle lease financing, the SZBG established a viable model where players with different specializations are responsible for the businesses of their own expertise while bearing the risks that they are in the best position to manage. The charging service provider and the SZBG fleet operators can then focus on the operation and management of the charging facilities and the bus fleet respectively.

Upgrading the Digital Systems and Training Staff for Better Operation and Management

By considering both operational needs and electricity prices, the SZBG fits the charging arrangements into its operational plan. The SZBG conducts performance and efficiency checks of each route in every six months and makes appropriate refinements depending on the running distance, shifts, and charging time. Charging facilities and shifts for charging were also carefully designed to accommodate the large charging demands at night. For example, using the charging terminals with four plugs allowed four buses to be charges simultaneously—reducing the need to move electric buses at nighttime.

Electrification works concurrently with information and technology as a lot of real-time data from the vehicles and charging facilities can be collected and managed. With the electrification, the SZBG upgraded its bus dispatch and management system to support efficient and safe operations of electric bus fleets. Three systems were integrated to form SZBG's Intelligent Transportation Center (ITC): bus operation management system, safety management system, and repair and charging management system. The integration of charging terminal information and bus management system reduces drivers' range anxiety, improves operation efficiency and safety, and offers potential for more efficient asset management and better services to passengers.

On the other hand, comprehensive and well-planned training for all staff in the SZBG was crucial in making the electrification transition a smooth process without laying off a single employee. Operational differences mandate training for existing bus drivers to be eligible to drive electric buses including requirements to pass a driving test and a knowledge test. For maintenance staff, a step-by-step staff transformation plan—training, re-assignment, incentives, talent attribution, and compensation—was devised for each team in each maintenance and repair workshop, mindful of the differences with the new system based on specialty, age, and experience.

Overcoming Obstacles in Building the Charging Infrastructure

The prerequisite of charging infrastructure is one of the main operational differences between diesel and electric buses, and the network of charging stations had to be built over time. The rapid rollout of electric buses from 2016 to 2018 required a large amount of land for charging stations, which was challenging for a large and densely populated city like Shenzhen. Furthermore, charging buses escalated local electricity demand, sometimes requiring transformers and additional power lines to be added to increase zonal grid capacity. The lack of space for building charging infrastructure has been a bottleneck for electrification.

On one hand, by leasing charging facilities and purchasing charging services, the SZBG transferred the land acquisition risks, including ownership rights, resettlements, land use changes, and land lease disputes to the charging service providers. On the other hand, the Shenzhen Municipal Government has relaxed land use regulations and provided incentives to find available land for charging stations. By 2020, the SZBG has 1707 charging terminals at 104 locations (including its own depots, bus terminals, as well as public parking lots, parks), reaching a ratio of 1:3.5 of charging terminal to the electric bus. Nine charging service providers constructed and managed these charging facilities. The majority of the charging terminals are equipped with 150-kilowatt (50 percent) and 180-kilowatt (19 percent) DC fast chargers with different configurations based on the charging arrangement. The number of charging terminals, charging plugs, and power of the charging terminals were decided based on the land availability at the location of the charging station, number of buses to be served, space requirements, speed of charging terminals, grid capability, and other factors. Realizing the scarcity of charging facilities and space for new charging facilities as the main obstacle, the SZBG decided to remain with DC fast charging—as opposed to AC slow charging, battery swapping, or wireless charging—to ensure operational efficiency. The SZBG also explored and encouraged innovations in network charging and flexible charging cabinet to overcome the charging bottleneck.

Financially Viable Only with Subsidies and Significant Environmental Benefits

With government subsidies and the manufacturers' lifetime warranty, the total cost of ownership (TCO) of electric buses is 35 percent lower than the diesel fleet for the SZBG. However, if the subsidies are excluded, the TCO of battery electric buses (BEB) is 21 percent higher than diesel buses (DB). The electrification of public transport significantly reduced greenhouse gas (GHG) emissions and air pollution in Shenzhen. The lifecycle GHG emission of an electric bus is only about 52 percent of the emission from similar sized diesel buses in Shenzhen. Electrifying one 10.5-meter bus saves 274 tons of carbon dioxide in its 8-year lifetime. The electrification of the SZBG buses saves 194,000 tons of carbon dioxide annually. The electrification also contributes to a significant emission reduction of air pollutants including CO, NO_X, $PM_{2.5}$ and PM_{10}. Subsidizing electric buses provides strong economic benefits while making technology financially viable for the bus operator, taking the results from the estimation of environmental benefits and TCO. Higher subsidies than economic benefits are justified at the beginning with electric buses being a new technology, but subsidies should be downscaled and phased out gradually once the technology gets to scale. If the other benefits from bus electrification such as noise reduction, passenger and driver comfortability improvement, grid stability improvement and easier data collection to improve bus operation are included, the economic case for BEBs would only grow stronger.

Passenger satisfaction significantly increased because of the transition to electric buses. According to a regular satisfaction survey, bus users rated comfortability, safety, and affordability much higher due to smoother rides with an electric engine. Electric buses also run quieter than diesel buses, and the smell of diesel exhaust at bus stations has disappeared. Additionally, the bus fare has been maintained at the same low level for passengers, leading to overall positive user feedback.

The transition to a new fleet helped improve public transport services. The SZBG fully explored new mobility solutions to provide customized public transport services to the public that demonstrated synergies between electric and smart mobility. The SZBG co-founded Didi Youdian Technology Company in 2016 to cover on-demand services that complemented traditional fixed-route bus operations. They also invested in a mobile application to integrate more urban mobility services in the creation of a mobility-as-a-service (MaaS) platform.

The SZBG leveraged government's support for electrification to reform and revive the struggling taxi sector, taking advantage of government subsidies and lower operating costs of electric taxis due to its much lower energy cost and the waived license fee. SZBG's taxi subsidiary companies were 100 percent electrified by the end of 2018 with a total of 4,681 electric taxis, following a viable business model where all stakeholders collaborated to benefit. The cost of operating electric taxis is almost 30 percent lower than the cost of operating gasoline taxis. However, charging time is a big hindrance and takes about three hours per day of operation, considering travel time, wait time, and charging time. The SZBG explored innovative measures to enhance efficiency and generate revenue such as developing a one-stop service complex, small parcel delivery, school taxi, traffic police support, advertising and marketing campaign, and driving data collection. By the end of 2018, 11,571 charging terminals were available to electric taxi charging in Shenzhen, and the network continues to expand with the growing demand of electric private cars.

In This Report

Electrification of public transport provides an opportunity to achieve multiple objectives: low-carbon urban development, reduction of local air pollution, creation of jobs, and higher acceptance of public transport by residents. However, owing to higher capital costs versus diesel or gas alternatives, the rapid evolution of product technologies, limited operational experience, and lack of trained personnel, the adoption of electric buses has been slow worldwide.

Electric buses require different operational and financing schemes due to their higher fleet costs, the need for charging infrastructure, and additional land requirements to park and charge the buses. To be successful, electric urban buses must be approached as a coherent system that embraces the vehicle, the infrastructure, the operation, the users, and the financial sustainability. Finally, their introduction involves a new set of stakeholders, such as electric utilities and battery manufacturer companies and stronger collaboration with local government agencies that usually have higher stakes in these projects because of the provision of subsidies.

Although many of the operational lessons are transferable to other cities in emerging economies, the successful transition not only depends on technology but also political will. Probably the most important first step in the transition of electric mobility is providing a vision with stronger targets. The Shenzhen case study provides references and recommendations to cities for the deployment of electric buses based on the comprehensive analysis of the journey of the SZBG.

The case study is organized into four main parts:

Part I: The Policy and Enabling Environment of Electrification of Buses in Shenzhen

Part II: The Business Model and Implementation of SZBG’s Transition to Electric Mobility

Part III: Assessing the Costs and Benefits of SZBG’s Transition to Electric Mobility

A Separate Brochure: Key Steps of Bus Fleet Electrification for Cities

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1

Policy and Enabling Environment

Chapter 1

The Eco-System and Policy Environment

1.1 Context

The transport sector is facing a major transformation. Technological advancements play an important role in decarbonizing the transport sector as part of global climate change mitigation efforts. The International Energy Agency (IEA) estimates that electrification of the global vehicle fleet of public transport buses will comprise about 30 percent of projected emission reductions in transport by 2050 (IEA 2017). The electrification of public transport provides an opportunity to achieve low-carbon development and the reduction of local air pollution, if the transition is well designed and coordinated among a wide range of stakeholders. However, owing to higher capital cost versus gasoline or diesel alternatives, rapid evolution of product technology, limited operational experience, and lack of trained personnel, the adoption of electric buses has been slow worldwide.

In China, the transport sector was the fastest growing sector for carbon dioxide emissions, reaching 986 million tons of carbon dioxide equivalent from fossil fuels in 2019 (EU 2020). China has placed great emphasis on the promotion of electric mobility since 2009, motivating to reduce local and global emissions, strengthen the local automotive industry, and reduce oil dependency. In the public transport sector, with strong promotion from all levels of governments, China's urban transit bus fleet by the end of 2019 consisted of more than 324,000 electric buses, which indicates an increase from 0.33 percent in 2013 to 46.8 percent in 2019 (MOT 2020). China is the only economy worldwide which has large-scale implementation of electric buses, and is one of the early adopters to have had the operational experience of a whole lifecycle. These lifecycle experiences and lessons learned from electric mobility programs are extremely valuable to the rest of world to understand the technology, policies, infrastructure, and operational design and meet the requirements of successful adoption and transition.

One of the earliest adopters of electric mobility was the city of Shenzhen. Shenzhen’s electrification experience offers a rare opportunity in understanding the challenges of enacting wide scale, system level changes from a small electric bus pilot to the whole public transport mobility system. Shenzhen became the first city in the world in 2017 that fully electrified its urban transit fleet of 16,359 electric buses.[1] In addition, Shenzhen is approaching the goal of fully electrifying its taxi fleet of 21,609 taxis—99 percent electrified at the end of 2019 with 21,485 electric taxis.

Located in China's south-eastern province of Guangdong, adjacent to Hong Kong SAR, China, Shenzhen was designated an economic special district of China in 1978. Shenzhen has a subtropical climate with average temperature of 23℃ and annual precipitation of 1935.8 millimeters. The city has a population of 13.43 million (end of 2019) and an area of 1,991 square kilometers.[2] With a gross domestic product (GDP) of 2.42 trillion yuan (approximately USD 356 billion) in 2018,[3] Shenzhen is one of the most developed cities in China—ranked third in the Chinese Cities Economic Ranking 2018.

Shenzhen is a vibrant young city with rapid motorization. Shenzhen started to implement the purchase restriction policy on cars in 2014. The policy limits fewer than 100,000 vehicles being allowed to register each year, with license plates allocated by a combination of lottery and auction. As a result, the number of private cars has been increasing at a much slower pace after 2014. As estimated, Shenzhen had 3.37 million automobiles[4] (figure 1-1) by 2018. Nevertheless, share of daily trips by Shenzhen residents using nonmotorized transport continued shrinking, dropping from 57 percent in 2010 to 52 percent in 2016 (figure 1-2). Public transit buses and subway systems are important transportation modes. Shenzhen's first metro line started operation in 2004 and expanded rapidly since then, with eight lines of 289.5 kilometers long. The mode share by metro rose from one percent in 2010 to seven percent in 2016, and rose further afterward lifting more public transport shares.

Figure 1-1 Number of Motorized Vehicles in Shenzhen 2010–2018

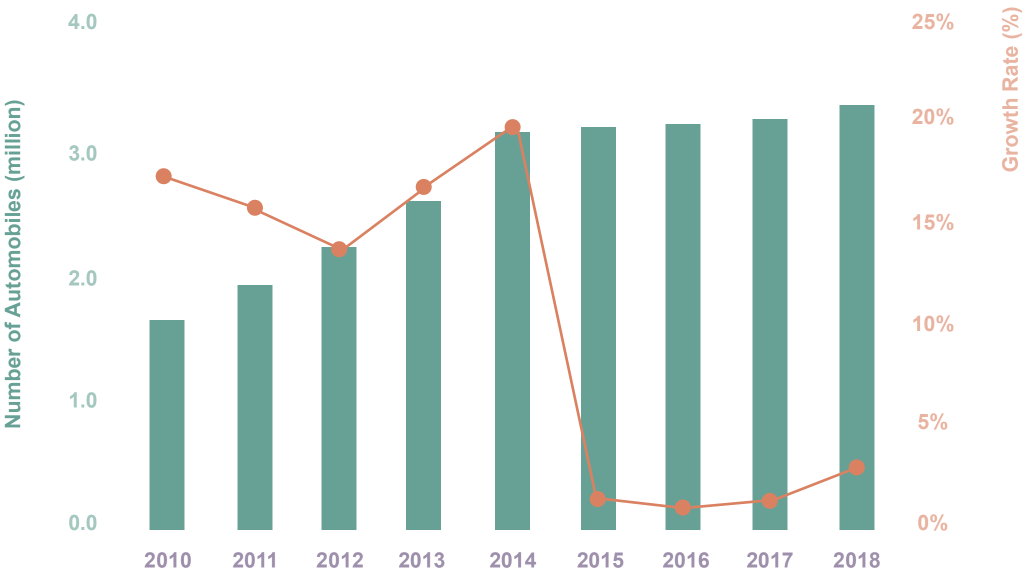
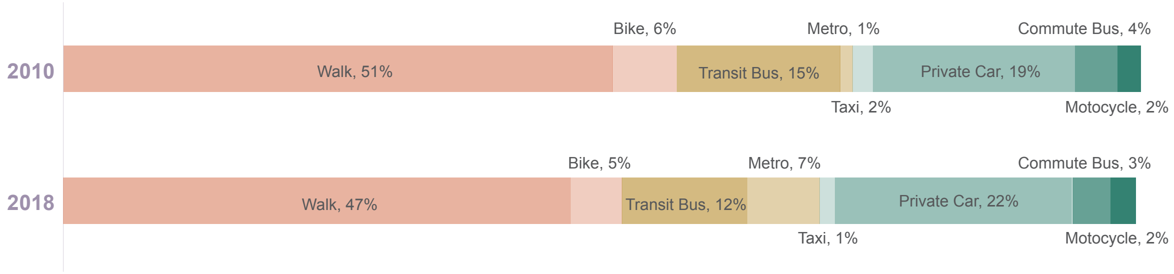


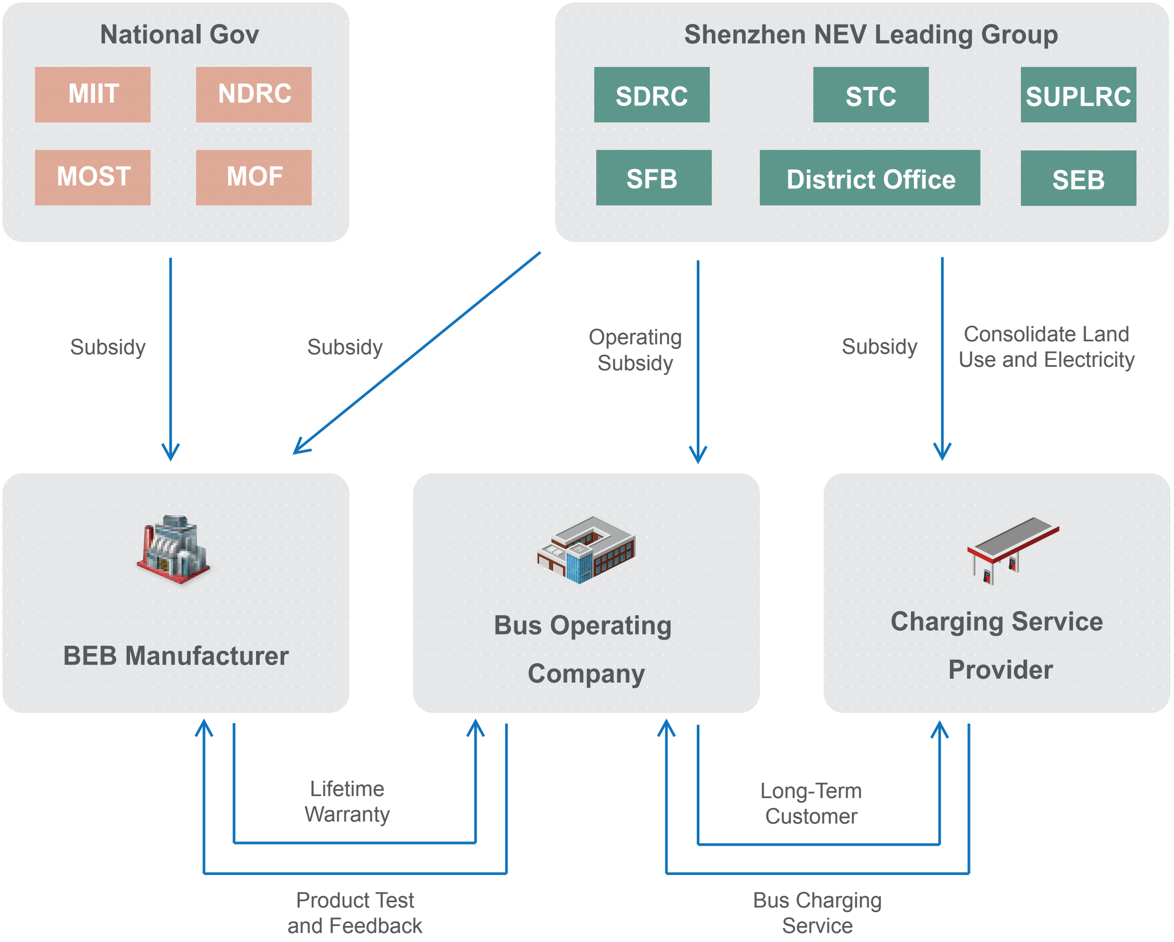
Figure 1-2 Shenzhen Transportation Mode Share in 2010 and 2016



1.2 The Electric Mobility EcoSystem

Shenzhen's success in electrifying its entire bus fleet in record time was a joint effort by private and public entities. Stakeholder analyses recognize the complexity and importance of coordination between different entities in the transition to electric mobility, and the relationship between them. The roles and interactions of public and private players in the ecosystem are shown in figure 1-3.

Figure 1-3 Interaction of Government and Industry



Note: National and local governments provide purchase subsidies to the electric bus manufacturer. The Shenzhen local government also provided subsidy for bus operating companies and charging station companies. In this way, the government departments relived the financial burden for all its industry partners on the business chain. Lifetime warranty and battery change offered by the BEB manufacturer in accordance to negotiation and contracts helped ease the bus operating companies on the uncertainty of technology. Feedback and recommendations on the BEB product design also promote the product evolvement for the manufacturer. The charging companies take care of the construction and operation of the bus charging stations, which also facilitate the bus operating company's smooth transition from traditional buses to electric buses.

1.2.1 Role of the Government

At National Level

With the motivation of reducing imported oil dependency, strengthening national automotive industries, and improving air quality, the national government initiated the national new energy vehicle (NEV) promotion strategy. The Ministry of Industry and Information (MIIT), National Development and Reform Commission (NDRC), Ministry of Science and Technology (MOST), and Ministry of Finance (MOF), known as the "four ministries", led the promotion and development of the NEV industry and prioritized the electrification of buses. Other ministries, such as the Ministry of Transport (MOT)—responsible for the rollout of new energy buses and taxis—play supporting roles.

Among the four ministries, MIIT plays the leading role as it formulates the industrial development plan and coordinates the NEV development, administrative, and supporting departments. MIIT also maintains a catalog of NEV models that are qualified for governmental subsidy. The Communication and Clearing Center under MIIT collects data of NEV sales and subsidy amount, verifies them, and evaluates the required annual operating mileage. MIIT is also responsible for organizing multiministry meetings to discuss the policy and coordination mechanism among different ministries.

For example, MIIT organized a crossministry meeting on May 14, 2019 to discuss the roles and task assignments among different ministries to enhance the safe operation of NEV. Ministries that attended the meeting included NDRC, MOT, Ministry of Finance, Ministry of Public Security, Ministry of Ecological Environment, Ministry of House and Urban Development, Ministry of Transport, Ministry of Commerce, Ministry of Emergency Response, and Commission of National Assets. This level of coordinated meetings was held regularly or ad hoc to discuss emerging issues, potential policies and the allocation of responsibilities among ministries. In each ministry, one office acted as a focal point of NEV. This mechanism discussed and coordinated policies regarding every aspect of NEV.

The four ministries established a program called "Ten cities one thousand NEVs" in 2009 that challenged ten cities across China to deploy at least 1,000 electric vehicles in each city each year for three years. Shenzhen was among the first batch of demonstration cities under this national electric vehicle demonstration program that began its electrification journey.

National policies and guidance are then passed on to provincial and municipality levels through series of directives.

At Provincial and Local Level

Guangdong Province, where Shenzhen is located, established a coordinated meeting mechanism for different provincial-level departments to discuss policies at the provincial level. These meetings also serve as a mechanism to pass national level policies and directions to the municipality level.

The primary motivation behind the Chinese local government's support of NEV deployment is to promote local tax-paying industries and improve local air quality. Three municipal-level agencies are playing critical role in the process.

Shenzhen NEV Leading Group: The municipal government established the Shenzhen Energy Conservation and New Energy Vehicle Demonstration and Promotion Leading Group (SNEVLG) in December 2009 in response to emerging opportunities of electric mobility. The main municipal government departments involved are the Shenzhen Development and Reform Commission (SDRC), Shenzhen Transportation Commission (STC), Shenzhen Finance Bureau (SFB) and the Shenzhen Urban Planning, Land and Resources Commission (SUPLRC). Hosted at the Shenzhen Development and Reform Commission (SDRC), SNEVLG comprises the mayor's office, the SDRC, STC, SFB, SUPLRC and district offices. SNEVLG works as the platform for communicating and facilitating cooperation among the municipal departments in promoting NEV development.

Shenzhen Development and Reform Commission: The SDRC takes the leading role in the NEV development of Shenzhen. The SDRC developed regulations and oversees the process of the NEV purchase subsidy program. It also sets subsidy application requirements, reviews and approves these applications. Moreover, the SDRC also interprets national and local regulations, issues guidance principles, and provides local incentives and subsidies to EV manufacturers, vehicle dealers, vehicle operators, and charging operators.

Shenzhen Transportation Commission: The STC is the supervisory authority of the transport sector of Shenzhen. The STC supervises and approves the routes and bus stops, reviewing and updating them twice a year. It also bears the responsibility to evaluate the performance of bus operating companies based on the trip frequency at rush hour, the safety of the operation, feedback from bus riders, and ridership volumes.

The STC was initially skeptical at the early stage of bus electrification with concerns of higher costs, risk to service quality, and the associated financial burden to the bus operating companies (Huang and Li 2019). However, when government agencies reached consensus on full electrification, the STC actively facilitated the adoption of electric buses and provided operational subsidies for bus operating companies. The STC also supports the construction of charging infrastructure in coordination with SUPLRC.

1.2.2 Incentive Policies of Bus Electrification in Shenzhen

Bus Purchase Subsidies

China's national government provides subsidies based on the electric vehicle range, battery energy density, and other metrics to promote the electrification of vehicle fleets and the development of the technology. The national purchase subsidy was matched by Shenzhen's local government for the NEVs purchased in Shenzhen.[5] The local subsidy amount was the same as the national subsidy until 2016. Subsidies started to decrease since 2017, and the local subsidy could not exceed half the amount of the national subsidy (table 1-1).

Table 1-1 National and local purchase subsidy for electric buses (thousand yuan)

Year	Model	Length (m)		
	Subsidy (Thousand yuan)	6-8 meters	8-10 meters	10+ meters
		Light duty	Medium duty	Heavy duty
2013–15	National	300	400	500
2013–15	Local	300	400	500
2016	National	60–250	96–400	120–500
2016	Local	60–250	96–400	120–500
2017–2020	National	90	200	300
2017–2020	Local	45	100	150

The combination of purchase subsidies from national and local government together contributed more than 60 percent of the total procurement cost of electric buses from 2015 to 2017.

Charging Infrastructure

Shenzhen announced the Blue-Sky Sustainable Action Plan (the Shenzhen Blue Plan) in April 2018. The plan aims for an annual average PM2.5 quality of lower than 26 ug/m3. The plan emphasized ten key areas covering electrification of transportation among others to meet its targeted goal. The Shenzhen Blue Plan provided subsidy for the construction of charging stations for all types of EVs. Every charging terminal received a subsidy of 600 yuan per kilowatt for direct current (DC) fast charging. Alternating current (AC) charging facilities with power rates exceeding 40 kilowatts received a subsidy of 300 yuan per kilowatt whereas AC charging facilities rated less than 40 kilowatts received a subsidy of 200 yuan per kilowatt (SFB and SDRC 2019).

In addition, during the large-scale rollout stagewhere the land availability for charging stations became a bottleneck for electrification, the Shenzhen local government made great efforts to address this issue, encouraging land allocation by government agencies and providing a simplified, fast-track review and approval process for land use applications of charging infrastructure construction. See detailed discussion in section 5.1.

Operation Subsidy

Like most other cities in China, transit bus operation in Shenzhen relies heavily on the municipal government subsidy. With diesel bus operation, the subsidy fills the gap of fare revenue and operation cost for the bus operator. Additional subsidy was provided to incentivize the operation of electric buses especially at the early stage. According to an official document from Shenzhen Finance Bureau and Shenzhen Municipal Transportation Commission, the operation subsidy for electric buses in Shenzhen was calculated based on the annual mileage of the bus operation—6.6 yuan per kilometer per bus with annual mileage of more than 64,000 kilometers, with a cap at 70,000 kilometers. For example, the STC provided 244,000 yuan (USD 34,531) per bus each year of operation subsidy to the SZBG with the diesel bus operation. Battery electric buses (BEBs) receive 420,000 yuan (USD 59,821) per bus each year from the STC for their operation.6 This operation subsidy alone recovers about 87 percent of the operating costs for running electric buses in the SZBG.

1.2.3 Industry and Private Sector

Bus Operating Companies

The bus operating companies are on the frontline of bus electrification. They face the challenges of high investment, potentially high operation costs, the uncertainty of evolving technologies, and shortfalls in the number of and the location of the charging stations. They need to make procurement decisions on the electric bus acquisitions, adopt operation changes such as route and charging as well as manage the transition of bus drivers and maintenance staff. The top three bus-operating companies that provide the majority of transit bus service in Shenzhen are Shenzhen Bus Group (SZBG), Eastern Bus Company (EBC) and Western Bus Company (WBC), consolidated in 2007 from many smaller private companies.

Shenzhen is not only the base of China's leading EV maker, BYD, but the city also hosts the headquarters of several large battery companies. Electrification of buses has led to increasing involvement of organizations that did not have a big role in the city's public transport ecosystem previously including vehicle manufacturers, charging service providers, and grid companies.

Bus Manufacturers

The relationship between local governments and the original equipment manufacturers (OEMs) based in their territories is interdependent. While the local government relies on local industries for GDP growth and tax collection, the local industries rely on the government for better industry policies, subsidies, and joint promotion of products. Sharing responsibility with OEMs has been underlined as a prerequisite for the successful operation of electric buses.

Collaboration with bus operating companies closely allows manufacturers to detect and improve technological deficiencies related to the early electric bus models. With the benefit of frequent communication and feedback from bus operators, bus manufacturers can upgrade their vehicle technology at a faster pace. On the other hand, the manufacturers provide an extended warranty on the key parts of the electric bus that covers the lifetime of a bus in Shenzhen. The manufacturers also provide technical and maintenance support as well as training for bus operators to relieve their concern on the uncertainty of the technology. This cooperation provided the SZBG with more confidence in their ability to operate electric buses, and provided significant relief on operational costs.

Charging Service Providers

Charging service providers—who typically are responsible for the construction and operation of charging stations—benefit from investment in the charging facilities that enabled them to enter the charging market for long-term revenues, especially the earlier movers. Charging service providers function as a conduit between grid companies and bus operators by assessing grid capacity and providing additional transformer and power lines as necessary. Some grid companies also enter the market to provide charging services.

1.2.4 Bus Passengers

Passengers are the users of the system and their satisfaction is the ultimate objective of operating companies and governments. The SZBG conducts passenger satisfaction surveys every year and evaluates its service according to six criteria: affordability, convenience, safety, regularity, comfort, and driver's service. Passengers showed very high satisfaction level of electric bus services. According to the same survey, and of relevant importance, comfort is the most important aspect for passengers, followed by safety and affordability. Passenger interviews showed that the cleaner and smoother ride of an electric bus contributed to high satisfaction in comfort. The buses run more quietly than diesel buses, and the smell of diesel exhaust at bus stations has disappeared.

The stakeholders and their roles in the ecosystem for the electrification of buses in Shenzhen are summarized in table 1-2 (see next page).

Table 1-2 Stakeholder in Shenzhen Bus Electrification

Sector	Sub-Sector	Department and Groups	Roles and Responsibility in NEV Development
Government	**Central Government**	**NDRC:** National Development and Reform Commission	Initiate the NEV development plan
		MOST: Ministry of Science and Technology	Guide technology development
		MIIT: Ministry of Industry and Information Technology	Lead the NEV industry development
		MOHURD: Ministry of Housing and Urban-Rural Development	Manage land allocation and requirements for constructing charging facilities
		MOF: Ministry of Finance	Manage NEV related incentive policy
	Local Government	**SDRC:** Shenzhen Development and Reform Commission	Initiate the NEV develop plan for Shenzhen
		SFB: Shenzhen Finance Bureau	Manage the NEV related local subsidies
		STC: Shenzhen Transportation Commission	Supervise the transportation industry in Shenzhen; manage the adoption and operation of transit bus companies
		SUPLRC: Shenzhen Urban Planning, Land and Resources Commission	Support charging facility construction and operation
		SEB: Shenzhen Electricity Bureau	Coordinate the connection of charging stations to the electricity grid
		District offices	Facilitate land use and electricity connection for charging stations
Industry	**Public Bus Operating Companies**	Shenzhen Bus Group, Eastern Bus Company, Western Bus Company	Purchase, operate and maintain electric buses
	NEV Manufacturers	BYD, NJGD, WZL	Provide electric bus products, and maintenance and repair services and training
	Financial Agency	Bank of Communications	Provide financial services
	Charging Industry	Charging facility provider, i.e., Potevio, Winline	Provide charging facilities and management
	Power Grid	China Southern Power Grid (CSG)	Provide electricity connection to the grid and related infrastructure
End User	**Bus Passengers**	Passengers	Ride electric buses, and provide feedback to bus companies

Notes

1 Shenzhen Urban Transportation Planning Center, Shenzhen Transport Annual Report 2018

2 http://worldpopulationreview.com/world-cities/shenzhen-population/

3 https://www.chinadaily.com.cn/a/201902/28/WS5c7720fda3106c65c34ebd70.html

4 http://wap.sz.gov.cn/zfgb/2017/gb1007/201706/t20170612_6992333.htm

5 To be eligible for the purchase subsidies, the NEV needs to be listed in the "Recommended Model Catalogue". MIIT has maintained the national-level eligible NEV model catalogue, and SDRC has been managing and updating the city-level NEV model catalogue, which overlaps but with some difference with the national-level catalogue.

6 Subsidy of Electric Bus During Promotion Period in Shenzhen, Shenzhen Finance Commission and Shenzhen Transportation Commission, 2017, http://www.sz.gov.cn/zfgb/2017/gb1007/content/post_4983581.html

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6 Palmer, Kate, James E. Tate, Zia Wadud, and John Nellthorp. 2018. “Total Cost of Ownership and Market Share for Hybrid and Electric Vehicles in the UK, US and Japan.” Applied Energy 209 (January): 108–19. https://doi.org/10.1016/j.apenergy.2017.10.089

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Chapter 2

Shenzhen Bus Group and Its Electrification

2.1 Shenzhen Bus Group

Shenzhen is served by three major bus operating companies: the SZBG, Eastern Bus Company (EBC), and Western Bus Company (WBC). All three are joint ventures with public and private shares. The three companies run routes in the central urban area and outer districts. Meanwhile, several other small bus-operating companies run a small number of bus routes in suburban areas.

The SZBG is the oldest company among the three major bus companies, having started its bus service in 1975, under the name of Bao'an County Shenzhen Town Bus Company. At this humble stage, they only operated one route with two buses and had twelve employees. The company was restructured as a state-owned bus operating company in 1983. It was restructured again as a joint venture company with investments from Hong Kong SAR, China in 2004. The SZBG has three major stakeholders: public share (55%), Kowloon Motor Bus of Hong Kong SAR, China (35%), and others (10%).

Among the three main bus operating companies, the SZBG serves 319 routes, had 5988 buses in operation in 2019, and carried about 594 million passenger trips in 2019 (table 2-1). Overall, the SZBG accounted for a little more than one third of the number of routes, total kilometers, and total passenger trips of the three major companies (table 2-2). The average annual running distance for each bus was similar for the three bus operating companies with about 61,000 kilometers per bus each year.

Table 2-1 Operational data of the three transit bus companies in Shenzhen (2019)

	Number of Routes	Length of Routes (km)	Number of Buses	Annual Bus-Travel Distance (million km)	Annual Passenger Trips (million)	Ticket Fare Revenue (million yuan)
SZBG	319	6,932.11	5,988	365.49	594.01	1,290.11
EBC	269	7,218.74	5,795	356.37	470.21	1,187.02
WBC	332	6,937.28	4,976	304.91	453.26	1,004.43
Total	920	21,088.13	16,759	1,026.77	1,517.48	3,481.57

Source: The Shenzhen Bus Group Annual Report 2019

Table 2-2 Per route bus statistics of the three transit bus operating companies in Shenzhen (2019)

	Average Route Length (km)	Average No. of Buses per Route	Annual Bus-Running Distance per route (million km)	Annual Passenger Trips per Route (million)	Annual Travel Distance per Bus (thousand km)	Annual Passenger Trips Carried per Bus (thousand)
SZBG	21.73	18.77	1.15	1.86	61.04	99.20
EBC	26.84	21.54	1.32	1.75	61.50	81.14
WBC	20.90	14.99	0.92	1.37	61.28	91.09
Average	22.92	18.22	1.12	1.65	61.27	90.55

SZBG's buses are operated by five bus subsidiary companies divided into 67 bus fleets. The business areas of the SZBG include city bus, medium- and short-distance bus services, taxis, vehicle rental service, vehicle parts, vehicle repair and maintenance, housing, property management, hotel, advertising, and retail operations. With the introduction of electric vehicles, the SZBG has also entered the market of electric vehicle (EV) charging infrastructure including design, construction, operations, and maintenance.

The SZBG receives substantial amounts of subsidies from Shenzhen municipality based on the total mileage of bus services provided. Besides the subsidy, the main revenue of the SZBG is ticket fare of bus and taxi services (figure 2-1). The bus service is considered public welfare in Shenzhen, so the fare is kept low. With the subsidy, the SZBG turned in profits of 101 yuan million in 2018 (figure 2-2).

Figure 2-1 Total Income of SZBG in 2018 (million yuan)

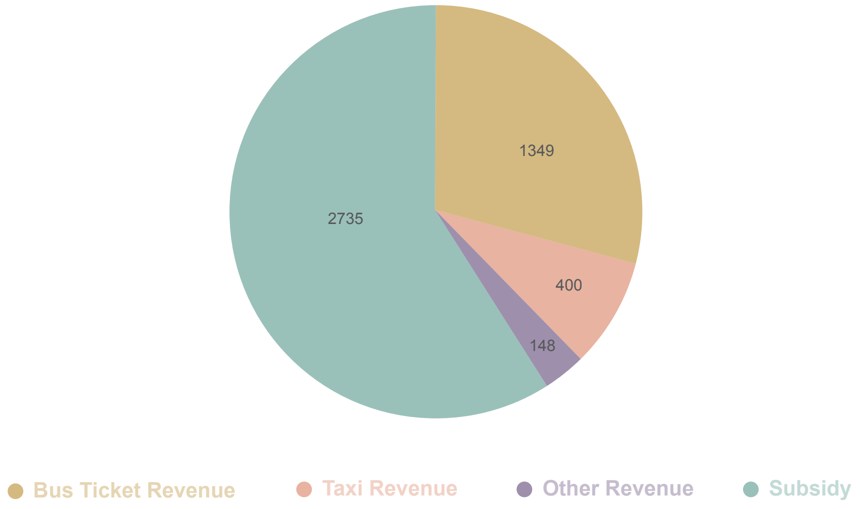
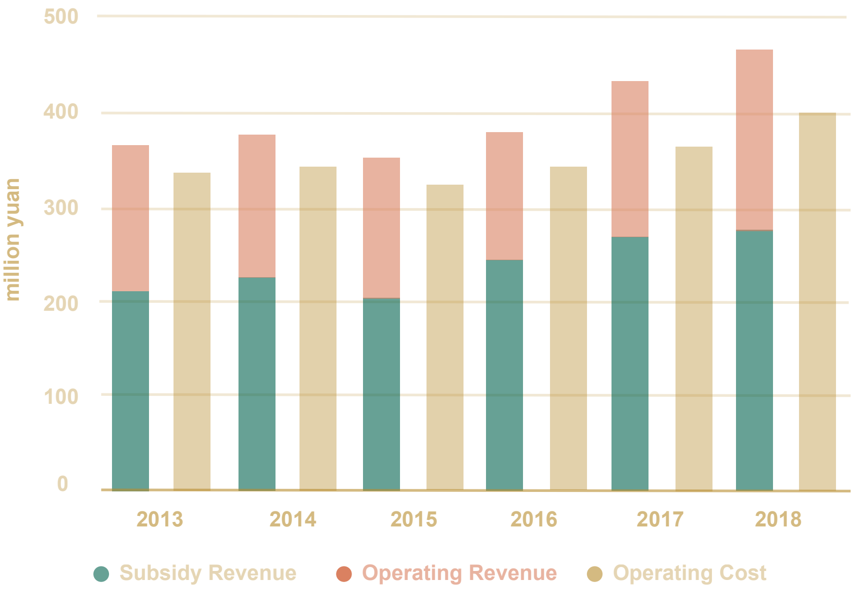


Figure 2-2 Comparison between Revenue and Operating Cost of SZBG 2013–18



2.1.1 Routes and Fare

The SZBG operated nearly 330 service routes with 5,998 buses, as of December 2019 (table 2-3).

Table 2-3 Different type of bus lines of SZBG

Type of Line	Function	Operating Hour	Fare
Routine and main bus lines (202 routes)	Regular fixed bus routes	6:30 - 23:00	2 yuan ($0.28) or 10 yuan ($1.4) for long-distance trips
Branch lines (45 routes)	Connect communities to metro stations or shared bus terminals	6:00 - 20:00	1 yuan ($0.14)
Express lines (29 routes)	Connect business centers and large communities with few stops in-between	6:30 - 23:00	1-2 yuan ($0.14-0.28)
Night lines (20 routes)	Night operation	23:00 - 6:30	1-2 yuan ($0.14-0.28)
Rush hour lines (34 routes)	Additional service provided during peak commuting hours with fewer stops (some operate only one direction)	morning peak (07:00 - 09:00) and evening peak (17:00 - 19:30)	3-7 yuan ($0.43-1.00)

Note: $ refers to USD. The number of routes operating in the SZBG are under continuous adjustment, so the numbers vary through the report at different stages.

Figure 2-3 SZBG's Bus routes

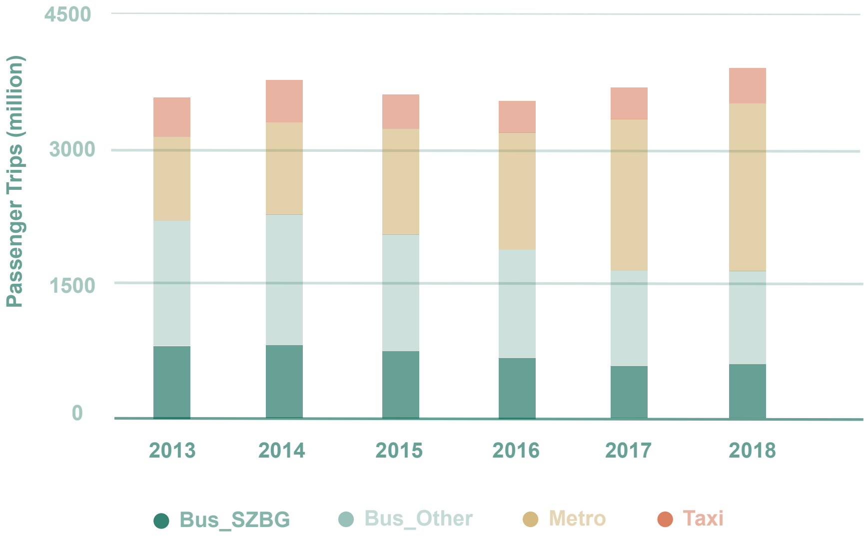
Note: Display from the SZBG's Intelligent Transportation Center Operation Management System. Light blue lines are the routine lines in operation at the time.

SZBG's bus routes vary in length from 2–74 kilometers, though most vary between 12 and 28 kilometers (figure 2-3). Each route has 18 buses on average, but some routes do operate with as many as 75 buses. Passengers pay between one and ten yuan, while most routes are priced at two yuan.

2.1.2 Ridership

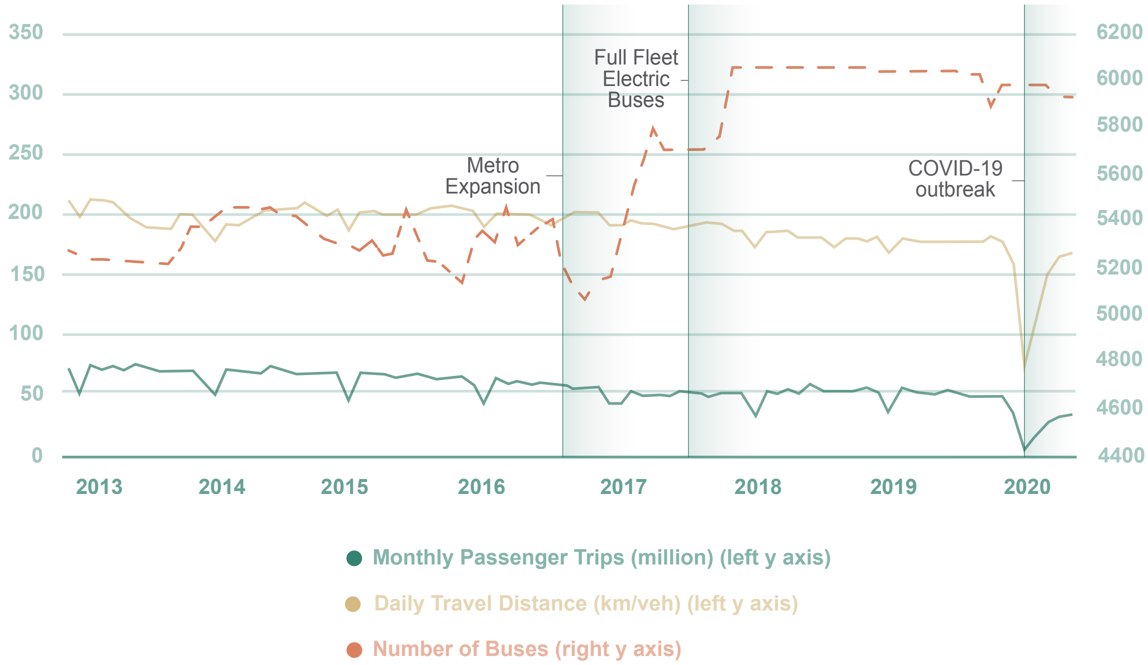
Shenzhen's bus and the metro system support the bulk of public transport modes while ten percent of passenger trips are made by taxi. With the metro system expanding rapidly, the annual bus passenger ridership dropped from 2.2 billion in 2013 to 1.6 billion in 2018. Patronage of the SZBG buses dropped from 833 million riders in 2013 to 607 million in 2018, decreasing eight percent annually on average (figure 2-4). Shenzhen's metro network development plan of 2016–2030 would increase its service to 32 lines, with 1142 kilometers in operation by 2030. Bus ridership continued declining after the metro line extended from 178 to 286 kilometers in October 2016 (figure 2-5). The role of bus services in Shenzhen is to provide more feeder services to the metro network. Consequently, the bus network has been restructured to provide a more flexible service to the passengers.

Figure 2-4 Public transport trips in Shenzhen



Source: SZBG Annual Report 2014–19.

Figure 2-5 Passenger trips and number of buses before and after fully electrification



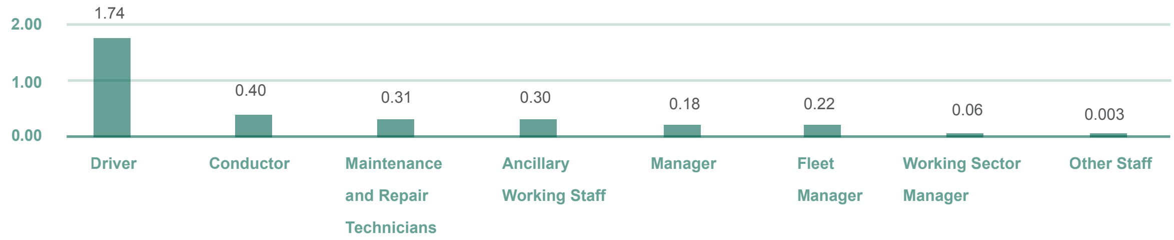
Note: The x axis represents the year and month of the events. After the extension of the metro network in October 2016, the bus operating distance (yellow line) and the bus passenger trips have been dropping gradually. After full electrification in July 2017, the monthly passenger trips (green line) were maintained stable until the COVID-19 outbreak in January 2020.

However, with the full electrification of its bus fleet in July 2017, the SZBG witnessed a ridership increase of 2.4 percent. SZBG's bus ridership started to rise slightly following its full electric replacement for two years into 2019 until the COVID-19 outbreak. However, how much of this increase was because of the electrification is unclear, as Shenzhen also introduced on-demand services as well as more flexible routes to connect suburban communities and metro stations about the same time.

2.1.3 Staffing

The SZBG had 27,460 employees on its payroll in March 2019, most of whom were drivers (figure 2-6) (see next page).

Figure 2-6 SZBG's different categories of employees per electric bus as of 2019



2.1.4 Bus Fleet

Among the entire SZBG bus fleet of 5,967 buses, 4,654 were heavy-duty buses with a bus body length of more than ten meters and 1,313 were medium-duty buses of less than ten meters. The fleet is primarily composed of buses from BYD (81%) and Nanjing Golden Dragon Bus (NJGD) as shown in table 2-4. The dominant model BYD K8 is 10.5 meters long and has a 250 kilometer-battery range, characterized by a two-hour DC fast charging or 4–5-hour AC slow charging (figure 2-7).

Table 2-4 Electric bus models of SZBG fleet in the end of 2020

Model #	% of fleet	OEM	Model	Length (m)	Number	Procurement Year	Lifetime (years)
CK6120LGEV1	3.18%	BYD	K9B	12	190	2013	8(+2)
CK6100LGEV2	66.87%	BYD	K8	10.49	3990	2015-17	8(+2)
NJL6859BEV9	16.21%	NJGD	H85	8.49	967	2016	5(+2)
BYD6100LLEV	2.56%	BYD	C8A	10.49	153	2016	8(+2)
BYD6100LSEV	0.50%	BYD	K8S	10.2	30	2016	8(+2)
BYD6711HZEV	0.55%	BYD	K6	7.1	33	2016	5(+2)
BYD6100LSEV1	0.67%	BYD	K8S	10.35	40	2017	8(+2)
BYD6110LLEV	4.19%	BYD	C8B	10.69	250	2017	8(+2)
NJL6859BEV43	1.09%	NJGD	H85	8.49	65	2017	5(+2)
BYD6850HZEV5	1.84%	BYD	K7	8.49	110	2019	5(+2)
BYD6100LGEV9	0.17%	BYD	K8	10.49	1	2019	8(+2)
NJL6680EV4	1.68%	NJGD	H60	6.8	100	2019	5(+2)
BYD6700B2EV1	0.64%	BYD	B6	6.99	38	2020	5(+2)

Note: '+2' represents the lifetime can be extended for 2 years based on actual usage.

Figure 2-7 Dominant bus model in SZBG
BYD K8

2.1.5 Charging Infrastructure

The SZBG worked closely with charging operators or charging service providers on the charging station construction and operation. The SZBG had 104 charging stations for their buses by the end of 2019 (figure 2-8). An additional ten stations are under the construction and about 20 more stations are planned for construction. The 104 available charging stations supply a total of 1,707 charging terminals with 2,989 charging plugs.

Figure 2-8 Locations of charging stations and maintenance workshops of SZBG

Note: Display from the SZBG's Intelligent Transportation Center Charging and Maintenance System. Light dots with a flash sign inside are charging stations; dots with a tool sign inside represent maintenance workshops. Light blue color means the occupancy rate is less than 50%; light green color means the occupancy rate is more than 50% but less than 80%; orange color means the occupancy rate is more than 80%.

2.1.6 On-demand Bus Services

On-demand electric bus services including the Youdian bus and U+ minibus service were introduced for travelers via the Youdian Chuxing application on mobile devices. The application was jointly developed and operated by the SZBG and DiDi Chuxing Company—the top ride-hailing company in China.

The Youdian bus service was launched in 2016 to meet commuting demand with direct services that were not covered by regular bus routes. With the Youdian Chuxing smartphone application, passengers can request a direct bus service between an origin and destination pair, either joining an existing route request or adding a new route. If the proposed new route receives enough passengers, then the customized bus service would start operation. The bus routes are constantly updated based on passengers' demand. Typically, this service is more expensive than the regular bus fare and passengers can purchase tickets to reserve a seat using their mobile phone. Approximately 1,008 Youdian bus routes were operated in 2018.

U+ minibus service was launched in 2019 to serve first- and last-mile mobility. It is a dynamic on-demand service without fixed routes or stops—so called micro-transit. The service can respond to the passengers' real time travel requests. The application matches passengers' demand with the minibuses' routes so that their routes in this system are dynamic and subject to minor detours to allow sharing while accommodating individual requirements.

2.2 SZBG's Bus Electrification Journey

The SZBG electrified its bus fleet over eight years from 2009 to 2017 (table 2-5). The procurement was phased, dividing bus procurement in batches.

Table 2-5 Timeline of Shenzhen bus electrification

Time	Event
May 2008	First hybrid bus in trial operation
June 2009	10 hybrid buses in service
July 2011	101 electric buses and 26 electric minibuses in service
September 2012	First bus line with all electric fleet launched
November 2015	545 electric buses, 100% electrification target set by the STC
June 2017	Electrification completed with 6053 electric buses

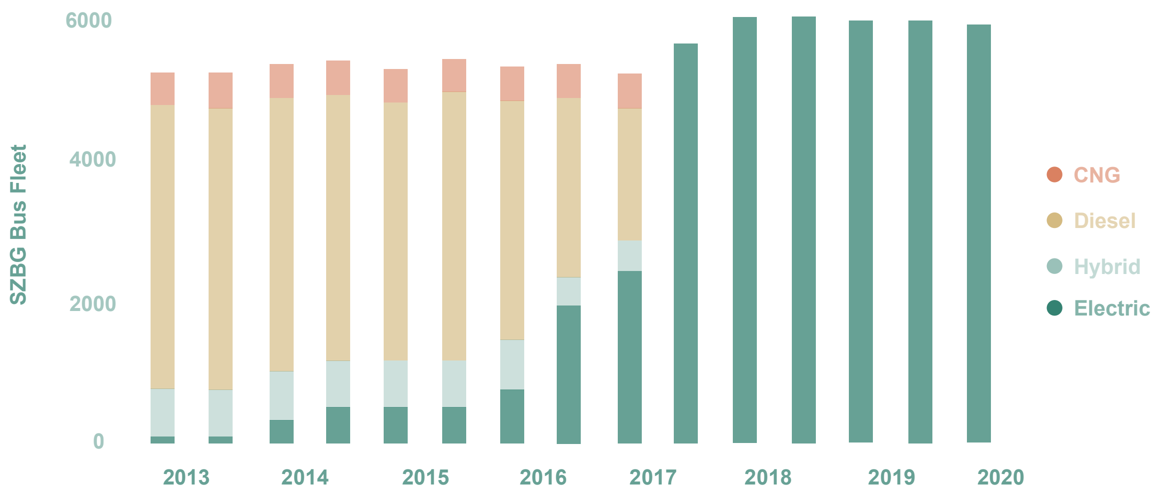
The electrification has three phases: a demonstration stage in 2009–2011, followed by targeted electrification from 2012–2015, and large-scale electrification from 2016–2017.

China's nationwide NEV promotion started with the "Ten Cities with One Thousand Electric Vehicles" demonstration program in 2009. Shenzhen was one of the ten leading cities selected for early demonstration. The SZBG was one of the first operating companies to purchase the WZL plug-in hybrid electric buses at that time. These plug-in hybrid buses turned out to have less reliability and higher outage rate during operation than diesel buses and BEBs, hence the management team decided to shift to a full-electric strategy soon after this purchase. Since then, these hybrid buses get phased out after eight years of operation, and the SZBG has not purchased anymore.

In 2011, Shenzhen hosted the International 26th Universiade1and launched 101 Build Your Dream Company (BYD) K9 model buses, all of which were BEBs. All newly purchased buses from 2011 onward by the SZBG were BEBs. One hundred and ninety BYD K9 buses and 210 A10 buses from WZL (see detailed fleet composition in table 2-4) were added to the SZBG electric bus fleet in 2013. With the operation of the vehicles in these two stages, the SZBG has built confidence in the use of new technology for transit buses.

Three batches of 1,600, 3,573 and 355 electric buses were procured from 2015 to 2017, completing the fleet electrification. The SZBG became the first transit bus company worldwide with a 100 percent electric bus fleet with 6,053 buses on June 8, 2017. All the 16,539 buses across the entire three bus-operating companies in Shenzhen were electric by the end of 2017 (figure 2-9).

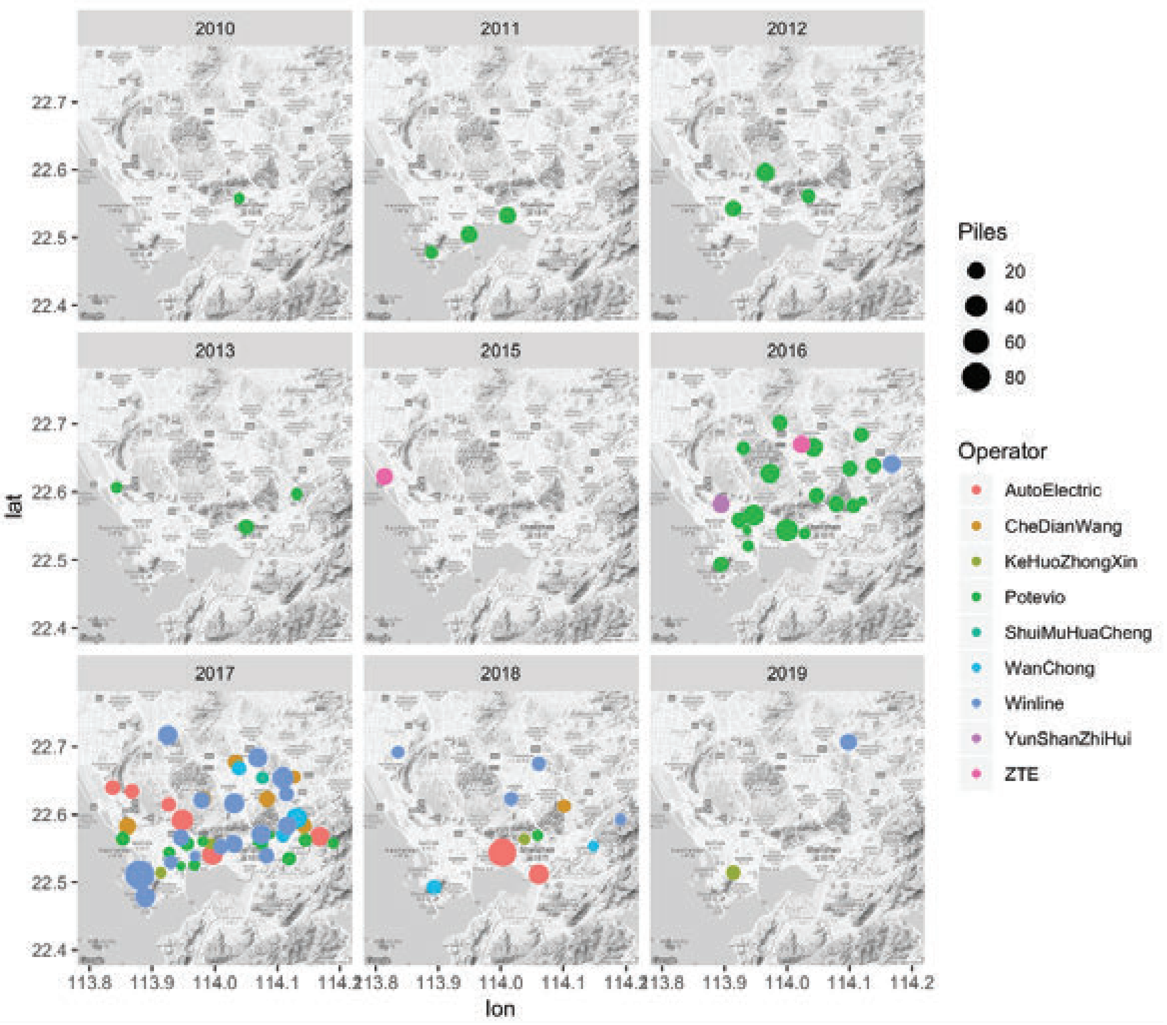
Figure 2-9 The Electrification journey shown in bus composition of SZBG fleet



Note: The chart states the number of buses with different fuel at every half year. With more electric vehicles replaced traditional buses in the fleet, the SZBG reached 100% electric bus fleet in July 2017.

The SZBG first planned charging stations at bigger terminal stations serving multiple routes to provide service for buses running on several different routes. Longer routes and more frequent operations were provided with another charging station at the other terminal of the route. After several years of development of charging infrastructure, most of the routes have access to at least one charging station at the terminal of each route.

Figure 2-10 SZBG charging stations, available years and operators



Charging operators provide the construction, operation and management of the charging infrastructure. Potevio Group Corporation (Povetio, green dots) and Winline Technology (Winline, blue dots) in figure 2-10, are the two largest charging operators who provide the SZBG with most of the charging facilities. Potevio Group Corporation built and provided most of the charging stations for the SZBG. After 2017, more companies entered the market and built a significant number of new bus charging stations. Before constructing any charging station, the SZBG communicates frequently with the charging facilities provider on multiple factors including location, size, charging speed, and charging capacity of the stations. The SZBG pays the charging operators the electricity fees and a charging service fee.

Notes

1 http://www.newsgd.com/specials/Universiade/default.htm

Reference

1 Huang, Ping, and Ping Li. 2019. “Politics of Urban Energy Transitions: New Energy Vehicle (NEV) Development in Shenzhen, China.” Environmental Politics 0 (0): 1–22. https://doi.org/10.1080/09644016.2019.1589935.

2 Wang, Yunshi, Daniel Sperling, Gil Tal, and Haifeng Fang. 2017. “China’s Electric Car Surge.” Energy Policy 102 (March): 486–90. https://doi.org/10.1016/j.enpol.2016.12.034.

4

Part I Key Lessons: Coordination and Collaboration

One of the main challenges in urban mobility in cities in China is the lack of cross-agency communication and coordination. Departments within the same municipal government are often reluctant to share information, and sometimes compete for resources with overlapping responsibilities. Unlike traditional bus companies, bus manufacturers and gas stations who dealt with mature products and clear supply chains, the electric bus was new with unclear roles and responsibilities among players. With more sectors and players involved, the transition to electric public transport requires even wider scale of coordination and policy synergy. Uncertainties of the technology and supply chain as well as demand response also require a viable model for all stakeholders to collaborate.

Shenzhen's Solutions

Coordination: Shenzhen municipal government established the Shenzhen Energy Conservation and New Energy Vehicle Demonstration and Promotion Leading Group (SNEVLG) that engages all levels of its diverse stakeholders to participate actively through frequent deliberations to achieve consensus and cooperation among different parties towards the same goal—promoting NEV development.

Collaboration: The Government, vehicle manufacturers, charging service providers, and bus operators collaborated closely through a viable business model with risks and costs allocated to the appropriate party. SZBG's close dialogue with the transportation bureau, the development and reform commission, the state-owned assets supervision and the administration commission put SZBG's agenda to the forefront of the policy development. Manufacturers provided extended warranties for the key parts of the electric buses, especially the batteries. While increasing the purchase price of buses, it shifted the technology risk to manufacturers who have the highest technical capacity to manage such risks, so are incentivized to keep innovating and improving bus performance. SZBG's close partnership with the bus manufacturer—for example, onsite supervision at the manufacturing stage—and the charging service provider—service standard and depot renovation—proved to be critical in overcoming the technology maturity, financial, and operation challenges. The SZBG also collaborated productively with private enterprises and nonprofit organizations including Tencent, Huawei, BYD, Didi Chuxing, the Urban Transportation Association, and Haylion Technology to explore innovations on intelligent dispatch systems, on-demand bus service, route optimizations, and autonomous driving technologies.

Public Consulting and Participation: The SZBG cares about the voice of the passengers. The SZBG conducts three types of activities to address their concerns. SZBG's first campaign “Friends of the Bus” in 2010 is an online and offline service where passengers can leave comments and take part in events such as focus-group forums and polls. By doing so, the SZBG was able to ensure comments from passengers were addressed efficiently using an online platform. Also, the SZBG regularly hosts offline events to get to know its passengers. Further, the SZBG collects large datasets to understand their customers: SZBG's intelligent dispatch system was built upon collecting detailed traveling origin and destination data of its passengers and the bus operation. The SZBG can analyze the demand and onboard occupancy to optimize the routes further and improve its quality of service.

2

Business Model and Implementation

Chapter 3

The Business Model

3.1 Ownership and Financing

Even with sizable national and local government subsidies, the purchase price of electric buses is still much higher than conventional buses. The SZBG used a financial leasing model that introduced a financial leasing company for instance, of a bank, that would purchase and own the vehicles and lease them to the SZBG. The bus operating company would take ownership of the vehicles after the leasing period is over. Since the leasing period equals the total life of the buses, this arrangement turned the high-cost procurement into a much easier manageable annual rental or lease payment.

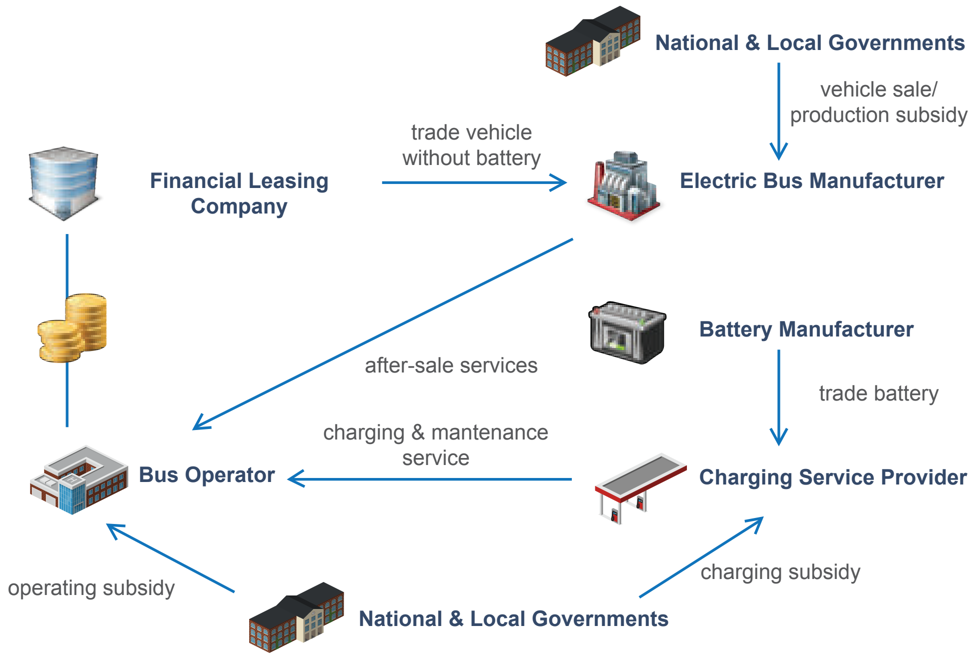
The SZBG has used two business models during its electrification process, the early stage bus-battery separation lease model and the later whole-vehicle lease model.

3.1.1 Bus-battery Separation Lease

At the early stage of the electric bus deployment from 2011–2013, vehicle technology was not mature, especially with the reliability of batteries. At that time, vehicle manufacturers usually did not produce batteries, and therefore did not offer warranties for batteries. The SZBG acquired the battery and the vehicle separately to minimize the operational and financial risks of battery deficiency. In practice, the Shenzhen government signed a concession agreement to allow one state-owned enterprise (SOE), Potevio Group Corporation (PGC), to be the charging service provider that purchased and took ownership of the batteries. PGC also provided guarantees for the SZBG to the financial leasing company—the financial leasing branch of the Bank of Communications—that purchased the electric vehicles without batteries and then leased the buses to the SZBG. The SZBG paid annual leases over eight years to PGC for batteries and to the financial leasing companies for the buses with a leasing agreement. In addition, the SZBG paid an annual service fee for PGC to provide charging and battery maintenance and recycling services (figure 3-1).

The early batch of electric buses acquired in 2011 used this model when Shenzhen hosted the Summer Universidad. This model worked in overcoming upfront financial barriers by shifting financial risks to financiers, charging service providers, and vehicle manufacturers. However, the technology was still nascent in the developing stage, and the poor quality of the battery for the initial batches not only led to PGC's financial loss but also disruptions of SZBG's bus operation.

Figure 3-1 Bus–Battery Separation Financial Leasing Model



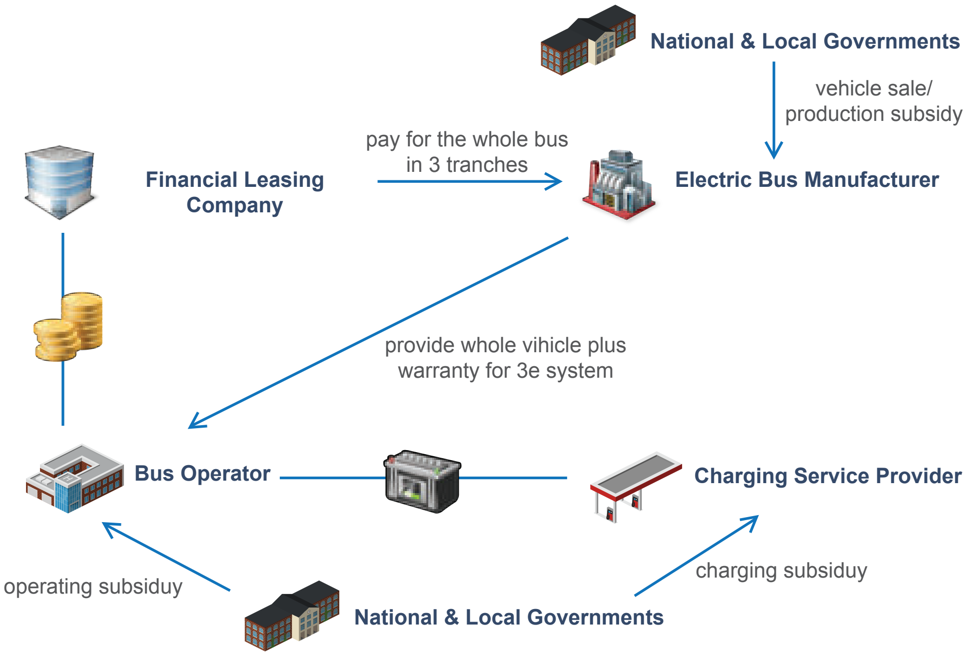
3.1.2 Whole-vehicle Lease

As the purchase price of electric buses decreased from 2015 onward and battery reliability improved, and government subsidies for electric bus purchase and operation stabilized, the SZBG no longer needed a commissioned SOE to provide guarantees to get reasonable rates for the leases. Financial leasing became the whole-vehicle lease model, where the SZBG directly worked with the financial leasing company to lease the whole bus. With the leasing plan, the SZBG pays the lease seasonally to the financing leasing company with an annual interest of about four percent over the lifetime of the buses which is eight years. The manufacturers were paid in three payments of 60 percent, 30 percent and 10 percent of the purchase contract value—and did not include the purchase subsidies that were paid directly to the manufacturers by the government—by the financial leasing company as the acceptance payment, mid-term use payment, and retention payment over the lifecycle of BEBs.

The bus manufacturer provides lifetime warranty1 for the battery, electric motor, and controller, known as the “3-e system” according to the contract signed. Charging service providers construct and operate the charging facilities while the SZBG pays the charging service fee. This is more efficient than the bus–battery separation model because fewer parties are involved with lower transaction costs. SZBG’s financial leasing model has demonstrated a viable way to overcome the financial barrier of electrification (figure 3-2).

Based on this whole-vehicle lease financing, the SZBG established a viable model where players with different specializations are responsible for the businesses of their own expertise while bearing the risks that they are in the best position to manage. The buses and batteries are owned by the financial leasing company with lifecycle warranty for key parts offered by bus manufacturers. The charging facilities are owned by the owners of depots, which can be the SZBG, charging operator, or others. The charging service provider and the SZBG fleet operators can then focus on the operation and management of the charging facilities and the bus fleet respectively.

Figure 3-2 Whole-Vehicle Lease Financial Leasing Model



3.2 Allocation of Responsibilities within SZBG

- ***SZBG headquarters*** plans and adjusts the bus routes or stops and reports to STC for review and approval. STC may also request route and stop changes based on needs at the network level or for emergency or event needs. All bus schedules are made at the central bus dispatching center in consultation with dispatchers from each subsidiary company. The headquarters plans the budget for maintenance and repairs and provides guidelines to the subsidiary companies. SZBG headquarters also coordinates with other parties such as the vehicle manufacturers, charging facility operators, and the grid.

- ***SBG subsidiary companies,*** including subsidiary electric bus and taxi operators, are responsible for the actual operation including drivers and dispatchers, maintenance and repairs of vehicles, and facilities in depots. Specifically, fleet operators manage buses and taxis, conduct daily safety checks and inspections while the workshops at depots handle maintenance and repair works.

3.3 New Business Model for Electric Taxis

The SZBG started its taxi operation with only 150 traditional internal combustion engine (ICE) vehicles in 1992. By mergers and acquisitions, its taxi fleet grew to about 6,000 taxis managed by 13 subsidiary taxi companies. Nine of them are operating in Shenzhen and four of them run businesses in other cities.

The SZBG started a joint venture with BYD in 2010 to establish a subsidiary taxi company Pengcheng Electric Taxi (PCET) and piloted the first 100 electric taxis. More pilot programs followed from 2011 through 2014, bringing the total number of SZBG-owned electric taxis to 850. Large-scale conversion started in 2017 with strong government support and mandate. By the end of 2018, the SZBG was managing approximately 7,700 taxi drivers and was the owner of 4,681 taxis operated in Shenzhen, all battery electric and accounting for about one-fourth of the total taxi fleet in Shenzhen.

Before the electrification, the taxi business in Shenzhen was facing challenges; operating costs were increasing with the rapid economic growth in Shenzhen, but the taxi fare was highly regulated. Taxi drivers were contemplating changing jobs as income kept falling. The SZBG saw the potential to reform and revive the taxi sector by leveraging government support to develop NEV.

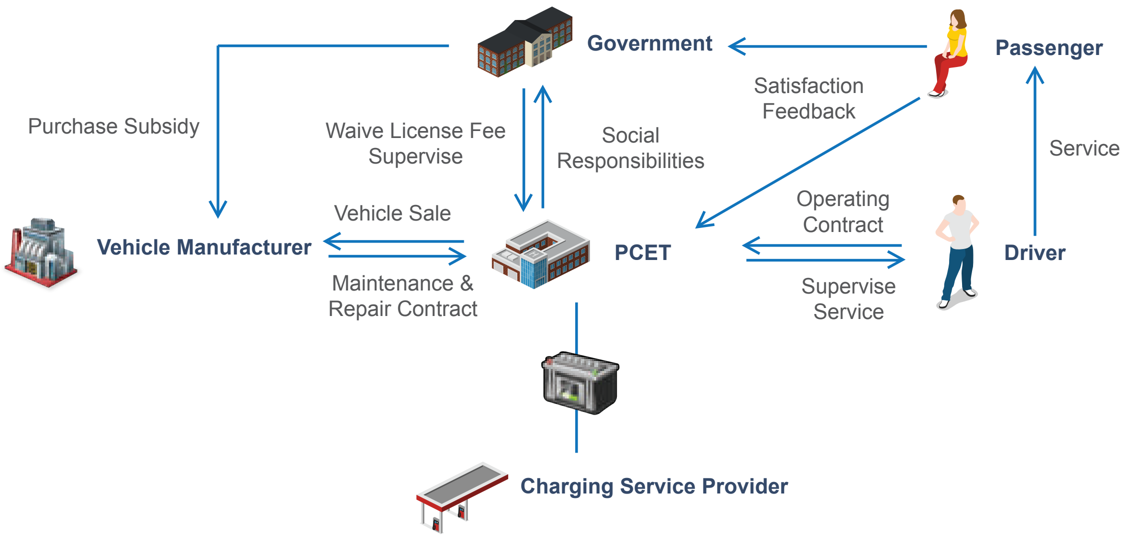
Table 3-1 Operating cost comparison of electric taxis and gasoline taxis (yuan/1,000km)

Operating costs (yuan/1,000km)		Electric taxis	Gasoline taxis	Difference
Fixed costs		614	653	-6.00%
1)	Depreciation	227	107	113.01%
2)	License fee	0	264	-
3)	Labor cost	292	210	39.26%
4)	Other fixed	95	73	29.31%
Variable costs		456	889	-48.63%
1)	Energy	310	791	-60.75%
2)	Maintenance & Repair	146	98	49.21%
Total		1,071	1,542	-30.57%

Source: PCET 2014, Large-Scale Operation and Management of Pure Electric Taxi Fleet

Assuming a fleet size of 800, the cost of operating electric taxis is 30.57 percent lower than the cost of operating gasoline taxis (table 3-1) , mainly due to its much lower energy cost by switching from gasoline to electricity—the waived license fee for NEV offset both higher vehicle depreciation and labor cost. The SZBG developed a business model for electric taxis to maximize technical specialty and risk management capacities. PCET signed operating contracts with individual drivers, who would pay PCET a fixed fee—monthly vehicle rental plus maintenance and repair fee. PCET covers the vehicle purchase, and maintenance and its repair services are provided by the vehicle manufacturer via a contract. PCET collaborates with charging service providers to offer charging services. Drivers get all the revenue deducting the monthly fee to PCET and charging (figure 3-3). Using this model from 2012 when PCET was running 800 electric taxis, the operation of PCET turned profitable.

Figure 3-3 Collaboration Model of PCET (based on PCET 2014)



Note: Based on PCET 2014.

According to the interviews with taxi drivers, changes to drivers' income appear to be different; some decreased and some increased after the electrification. The nonoperating hour for charging time—three hours per shift at the early stage when charging stations were scarce—meant a significant loss of revenue compared to the ten minutes of gas-refueling time. Competition from ride-hailing taxi service companies such as Didi Chuxing also contributed to this matter. Range anxiety still exists; drivers at certain times have to give up more profitable long-distance trips—for example, to the airport or Dongguan City—because of the potential need of charging. On the other hand, the taxi company PCET for instance, decreased the fixed monthly fee of 8,000 yuan per vehicle for a single-shift taxi or 11,000 yuan for a double-shift taxi after the electrification to compensate for the loss of operating time. The fixed maintenance fee of 1,500 yuan per month is also less than gasoline taxis, and drivers can liberate themselves from concerning any vehicle malfunctions. Moreover, the charging cost is significantly less than fuel cost, saving 100 yuan per day of operation. The SZBG also created a bonus system based on the result of drivers' evaluations that incentivized drivers to provide better service. These bonuses rewarded outstanding performances on energy-saving, mileage bonus, good conduct bonus and service excellence. These bonuses kept the SZBG being competitive in both the labor and taxi market.

Notes

1 Battery producers provided four years of warranty.

Chapter 4

Acquiring and Managing an Electric Vehicle Fleet

- Innovative financing model to overcome high upfront acquisition costs by sharing the risk of technology uncertainty
- Open bidding procedures to ensure the competitiveness of electric bus's quality and price
- Lifetime warranty for the 3-e system from manufacturers lowers the technical and financial risks of bus operators
- Operator's involvement in the manufacturing process for technical improvement, for example, the onsite manufacturing supervision
- Professional charging service providers to construct and operate charging; The issue of land availability for charging infrastructure especially in the urban core
- The local grid capacity expansion might make up as much as one third of the total investment cost of a charging station by consulting with local grid

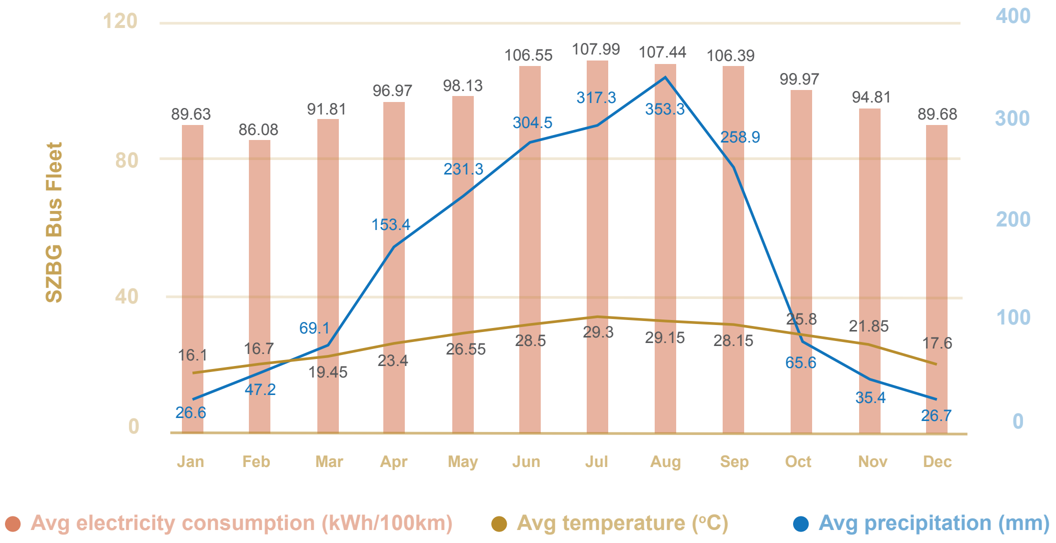
4.1 Planning and Technology Selection

Before launching the new electric bus fleet on the road, massive preparation and analyses were undertaken. The various type of works included analyzing the existing bus routes, choosing the right bus type, providing training courses to bus drivers and electricians, and evaluating the potential impact on the electricity grid to ensure the capacity was compatible with the new charging demand.

4.1.1 Analysis of climate, topography and bus routes

Climate: Shenzhen has a subtropical marine climate with temperature between 0°C and 40°C and an average temperature of 23°C. While warm climate is generally good for electric bus operation,[1] summer's extreme heat requires air conditioning that consumes additional electricity, and that shortens the running distance per charge. Data of SZBG bus fleets (figure 4-1) show that the average electricity consumption of electric buses per 100 kilometers in summer is 19.3 percent more than non-summer months. This additional energy consumption of almost 20 percent—or reduction of running distance—by switching on air conditioning is higher than the ten percent estimated by previous research.1 The heat also increases the safety risks of electric buses. Although the SZBG sustains incident-free operations, the very early stage of electrification had encountered a few incidents where batteries had caught on fire due to extreme heat or external force. At temperatures greater than 50°C, the battery discharge capacity would gradually go down and the battery, without adequate cooling mechanisms, runs the risk of catching fire. High temperatures together with the heat of battery charging can cause problems of overcharging and thus affect the lifespan of the battery. Manufactures are implementing more stringent tests on batteries to minimize risks of it catching fire.

Figure 4-1 Electricity consumption of SZBG buses and climate in Shenzhen in 2019



The summer in Shenzhen can be hot with frequent rainfalls, storms and even typhoons that average about 193.3 centimeters of precipitation annually. Urban flooding and wading due to heavy rainfall could also impact the operational safety of electric buses. Risks of electricity leakage during flooding had caused batteries to submerge in rainwater. To deal with it, the SZBG regulates that if any sections of road are submerged by 15 centimeters or more of rainwater, electric buses would need to detour the service to other roads.

Topography: Shenzhen's topography is primarily flat with some hills—most road networks do not have steep gradients. The survey to BYD indicated that even with steeper gradients, different engines could be selected to accommodate the topography.

Bus routes: The SZBG operated 327 bus routes in 2015 before its large-scale electrification, with nearly 5,000 diesel buses and 101 electric buses. The bus routes ranged from several kilometers to more than 50 kilometers long, with an average route length of 20.2 kilometers and a running distance of 229 kilometers per day per bus. The running distance requirement and the locations of charging stations—availability of space in terminals and depots—were important input for the procurement of buses and charging facilities.

4.1.2 Selection of bus model

Multiple factors influence the choice of the right bus model including average daily running mileage, ridership, weather condition, road condition, and the ease of adoption. The first step was to select small capacity or large capacity battery of the buses (Table 4-1).

Table 4-1 Pros and cons of two electric bus types

	Large capacity electric bus	Small capacity electric bus
Pros	**Longer running distance:** Existing models of electric bus can support 200–500 km with full battery **Easier for adoption:** Running distance comparable to diesel bus and the daily running mileage allow electric bus to replace diesel bus without significant re-routing **Interchangeable:** Electric bus ready to run any route if needed and supply increased demands from other routes easily **Less reliance on the locations of charging facilities**	**Lighter:** Although most urban roads designed to accommodate heavier freight trucks too **More Affordable:** battery costs less **Short charging time:** Typically, a 10–15-minute charging at terminal could run a roundtrip
Cons	**Heavier:** A 10.5-m long electric bus is about 15% heavier than a diesel bus **Longer charging time:** Based on charging facilities and battery, the charging time with high-power DC charging takes about 2 or 3 hours **More expensive:** Battery costs 40% of the total price of 10.5-m electric bus	**Shorter running distance:** **Heavy reliance on coordination with charging facilities.** Electric bus needs to be charged after several routes, which requires charging available at the right place; therefore, careful adoption on different route

After considering these factors, the SZBG decided to adopt the large capacity electric bus model with daily running distances comparable to their traditional diesel buses so that minimal changes to existing bus routes and schedules were needed.

BYD K9 and WZL A10 were two of the earliest bus models launched by the SZBG in 2011–2013. Initially, owing to low battery energy intensity, fewer passenger seats, and battery depreciation, both models suffered service issues and were used on shorter or less frequent routes. The battery range on the ground was about 180 kilometers or even less and was unreliable as its state of charge (SOC) dropped frequently. Thus, frequent maintenance was needed because of malfunctions or breakdowns. In 2011, two electric buses had to replace one diesel bus to maintain the same level of service.

Model BYD K8, procured in 2016–17, is an upgraded model of K9 based on feedbacks and suggestions from the SZBG after deploying K9 for a period. BYD K8 is smaller in size but can carry 87 passengers, which almost doubles the passenger capacity of the K9 model. Therefore, not only the battery energy density was improved, the size of the battery is also smaller on K8. Further, the battery packs were also reorganized to sit under the cabinet of K8. As a result, passenger capacity expanded in K8. BYD K8, as the dominant model, operates on the main bus routes. The NJGD bus models, procured in 2016–17, are smaller buses that operate primarily on branch routes.

The electric bus fleet in the SZBG dominantly features a single, reliable vehicle model–BYD K8, which is 10.5 meters long with about 250 kilometers running distance under ideal conditions. With DC fast charging facility, this model can be fully charged in about two or three hours with proper technical requirements under the safety instruction for hot weather and water protection for batteries. With minor adjustment of bus scheduling, one electric bus model procured in 2015–17 could replace one traditional diesel bus in the bus fleet. The average daily operation distance for the 10.5-meter electric buses in Shenzhen in 2019 was 190 kilometers; electric buses could run a whole day and only needed recharging at night on most routes.Technology improvements have given bus operators more options to suit their operational requirements. Bus performance in running distance and malfunction rate caught up quickly with the high-power-density batteries and more mature electric engine and control systems (table 4-2).

Table 4-2 Key performance parameters compared

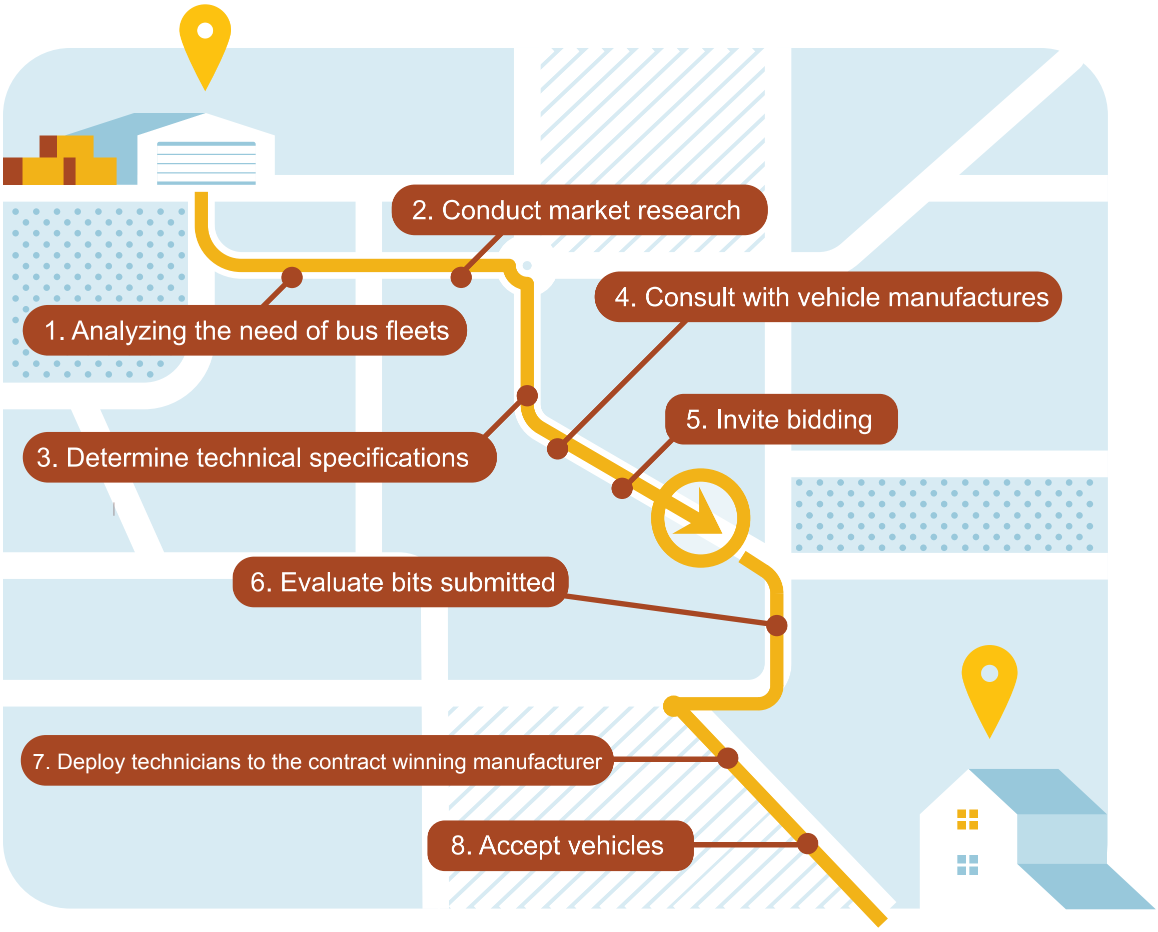
	Conventional diesel bus	Electric bus procured in 2011–15 (BYD K9)	Electric bus procured in 2015–17 (BYD K8)	Latest electric bus procured (BYD K8S)
Length (m)	10.5	12	10.5	10.5
Nominal battery capacity (kwh)	/	324	292	330
Advertised running distance with full tank or battery (km)	500	250	250	400
Running distance in real life (km)	About 400	180 or less	About 200	About 330
Energy efficiency (/100 km)	33 liters	140 kWh	100 kWh	70 kWh
Battery-system energy density (Wh/kg)	/	90	110	140

4.2 Acquiring the Vehicles

4.2.1 Procurement Process

While the financial leasing company owns the electric buses for their eight-year lifecycle, the actual user, the SZBG, bears the responsibility of procurement to acquire high-quality products at competitive prices. In the whole-vehicle lease model, the SZBG procures the buses through a process of eight steps (figure 4-2).

Figure 4-2 SZBG procures electric vehicles in eight steps



Since SZGB is an SOE, the Shenzhen municipal government requires these procurements to be implemented via public bidding. The bidding is organized by Shenzhen International Tendering Company Limited, a state-owned tendering company responsible for public tenders in Shenzhen. Shenzhen International Tendering Company Limited, together with some representatives from the SZBG, select the evaluators from an expert pool. The evaluators formed the bid evaluation committee that evaluates the bids based on a combination of scores for technical specifications, offered price and warranties, and services provided. After the manufacturer is selected, the SZBG would send their own technicians to the manufacturing plants to ensure vehicles are made to the operation standard, and acquire knowledge of maintenance and repair. After every batch of vehicle is delivered, the SZBG technicians then would perform a thorough inspection of the vehicles before concluding the whole procurement process.

The SZBG implemented most of its bus procurement during 2015–17, acquiring 1,600 buses in 2015, 3,573 buses in 2016, and 355 buses in 2017. Since the purchase subsidies were paid directly from the government to the vehicle manufacturers and only depended on technical parameters such as size and range that did not vary among manufacturers, the bus purchase prices in subsequent discussions did not include government subsidy amount. Several different models of electric buses were procured via open bidding, on average saving 20 percent and 11.3 percent from estimated costs after bidding and contract negotiation respectively. While more than 70 different electric bus manufacturers operate in China, they usually participate in biddings in provinces where they have a local presence. In the latest bidding process from the SZBG, only two manufacturers—NJGD and BYD—participated (table 4-3, table 4-4, table 4-5).

Table 4-3 SZBG bus procurement results in 2015

Vehicle type	Number	Winning manufacturer	Cost estimate per bus (million yuan)	Winning price per bus (SZBG paid to manufacturers) (million yuan)	Subsidies received per bus by manufacturers (million yuan)
180 pure electric bus (10.5 m)	180	BYD	0.90	0.81	1
420 pure electric bus (10.5 m)	420	BYD	0.90	0.73	1
1,000 pure electric bus (10.5 m)	1,000	BYD	0.81	0.58	1

Source: SZBG

Note: The winning price is the price after government subsidy.

Table 4-4 SZBG bus procurement results in 2016

Vehicle type	Number	Winning manufacturer	Cost estimate per bus after subsidies (million yuan)	Winning price per bus (SZBG paid to manufacturers) (million yuan)	Subsidies received per bus by manufacturers (million yuan)
7 m bus	33	BYD	0.40	0.24	0.6
8 m bus	967	NJGD	0.40	0.319	0.8
10.5 m bus	2,390	BYD	0.73	0.58	1
High floor bus	153	BYD	0.73	0.58	1
Double decker	30	BYD	1.30	1.26	1

Source: SZBG

Note: The winning price is the price after government subsidy.

Table 4-5 SZBG bus procurement results in 2017

Subject matter	Number	Winning manufacturer	Cost estimate per bus after subsidies (million yuan)	Winning price per bus (SZBG paid to manufacturers) (million yuan)	Subsidies received per bus by manufacturers (million yuan)
10.5m High floor bus	250	BYD	1.05	0.93	0.45
10.5m Double decker	40	BYD	1.8	1.66	0.45
8m bus	65	NJGD	0.7	0.592	0.3

Source: SZBG

Note: The winning price is the price after government subsidy.

Buy-Back of Old Diesel Buses: As an SOE, all buses owned by the SZBG are managed by the state-owned asset committee. Per government requirements, it is important that the total value of state-owned assets be handled properly. The SZBG and the vehicle manufacturer negotiated that the winning manufacturer would buy back the old diesel bus fleets at a price of 5 percent of the after-subsidy purchase price. Since BYD won most of the bids, BYD bought back many of the old diesel fleets based on their usage and depreciation. Diesel buses in relatively good condition that meet the local operation standards could return to service other areas; otherwise, they were decommissioned by BYD via a locally registered vehicle decommissioning companies.

4.2.2 Technical Specifications and Warranty

The technical specification of buses includes vehicles, main parts, ancillary facilities and air conditioning (figure 4-3). This section (4.2.2) uses the largest batch of buses procured in 2017 as an example.

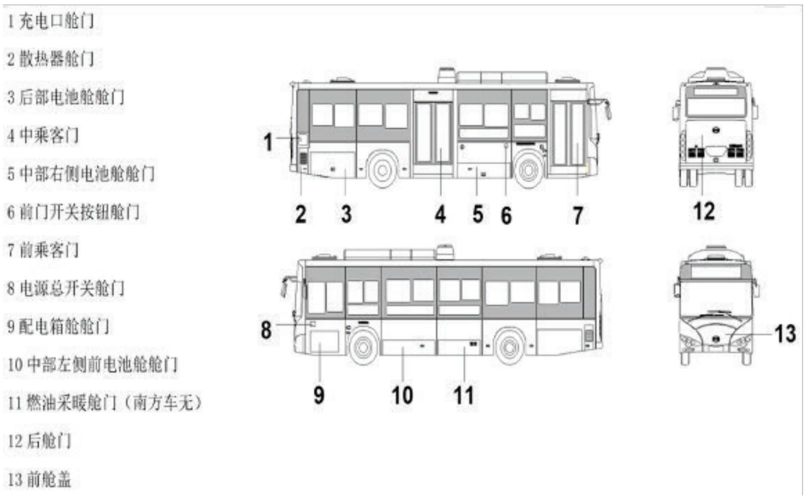
4.2.2.1 Vehicle Specification

The main vehicle specifications include size, structure and dimension, power battery type (conductive DC charging), minimum battery capacity (varies from 115–250 kWh), and C-rate2 (>=0.5C, SOC from 0%–100%). Also included are the national and local technical, safety, material, charging, communication, battery and system requirements or standards, and testing protocols that EVs must comply with. The same model of buses can have different specifications (table 4-6).

Table 4-6 Specification of bus model in SZBG

Model	Sub-Model	Capacity (kWh)	Voltage (V)	Length (mm)	Width (mm)	Height (mm)	Power Output (kW)	Max. Passengers	Gross Weight (kg)
C8	C8A	290.08	518	10490	2500	3520	180*2	24–44	17500
	C8B	255.74	473.6	10490	2500	3520	180*2	24–46	17950
	K8	291.6	540	10490	2500	3150	90*2	87	17800
K8	K8S	331.56	614	10200	2500	4200	100*2	72	18000
	K8S	253.44	422.4	10200	2500	4200	100*2	77	18000

Figure 4-3 K8 bus specifications



1. Charging Hatch
2. Radiator Hatch
3. Rear Battery Compartment Hatch
4. Middle Passenger Door
5. Middle Right Battery Compartment Hatch
6. Front Door Switch Botton Hatch
7. Front Passenger Door
8. Main Power Switch Hatch
9. Distribution Box Hatch
10. Middle left Front Battery Compartment Hatch
11. Fuel Heating Hatch (vehicles in the south do not have)
12. Rear Hatch
13. Front Hatch

4.2.2.2 Main Parts and Ancillary Facilities

Power System: Technical specification and warranty requirements for power battery include specific requirements for cooling for the hot and humid weather in Shenzhen. Specifically, the drive motor and control system has specific requirements for heat and humidity resistance as with the electronic control system of battery management system (BMS), electronic control unit (ECU) and other sensors, and an onboard monitoring unit. Other parts include an air compressor, axle, turning and braking systems, suspension, and tire, etc. Manufacturer bidders who do not meet these specifications will have points deducted from their technical scores.

Ancillary Facilities refer to on-board GPS and dispatching systems, smart card readers, cash collectors, TV and media systems, and Wi-fi.

Air Conditioning: Cooling capacity (e.g., >= 26,000 kcal/h for 10.5m buses) and energy efficiency ratio (>=2.2)[3] are the most important parameters.

4.2.2.3 Warranty

Vehicle manufacturers provide various lengths of warranty on batteries, electric motors, and controllers or the 3-e system. At the bus-battery separation lease stage, the battery warranty was only set for four years. At a later stage, vehicle manufacturers provided eight years of warranty on 3-e system for buses that the SZBG purchased, and a lifetime warranty on 3-e system for electric taxis with requiring manufacturers come to the site within four hours to resolve any malfunction. Smaller repairs had to be resolved in six hours while 3-e systems faults had to be corrected within 48 hours. The warranty also requires the manufacturers to replace batteries when the state of charge (SOC) falls below 80 percent.

4.2.2.4 Vehicle Safety

To address the safety concern, the Technology and New Energy Department and the Procurement Department of SZBG have developed specifications to ensure the safety of the vehicle to be procured.

The SZBG requires manufacturers to meet a set of high safety standards for battery packs. These standards include a protection level that is no less than IP67—which represents a high water and dustproof battery pack—and satisfactory operation safety in extreme temperatures ranging from minus 20°C to 65°C. Besides the safety standards applied to the battery packs, the SZBG established an additional set of requirements on signal interference, insulation, and convenience of repair and maintenance for motor and control systems. Subsequently, the manufacturing procedure and material used, overall structural integrity, proper protection of the wiring and parts and the flame resistance performance were set to the highest acceptable standards for the vehicle’s chassis. Manufacturers were also required to build in automatic fire extinguishing devices to protect passengers and drivers in case of fire incidents.

4.2.2.5 Onsite manufacturing supervision

An advantage the SZBG had was co-location with one of the leading electric bus manufacturers, Build Your Dreams Company (BYD). After BYD won the bids, the SZBG formed a manufacturing supervision expert team, and sent technicians to BYD’s plant for onsite supervision and training. These technicians not only accumulated skills in maintenance, repair and troubleshooting of the newly procured vehicles, they also monitored and provided valuable suggestions to the manufacturer about technical specification, selection of materials, production process, location, and composition of parts. The SZBG sent more than 100 technicians providing 875 suggestions, 761 of which BYD incorporated on its electric bus design for the batch of 3,573 buses in 2016. The SZBG sent approximately 30 technicians who provided 359 suggestions, 277 of which were incorporated for the batch of 355 buses in 2017. As a result, the quality of the buses was improved and maintenance and repair needs were reduced through using structurally stronger materials for the bus frame, which provided more efficient wire position and bundling, improved waterproof, dustproof, the rustproof performance of chassis and body, and with some oversight, flaws in the assembling process correction. BYD, in turn, also benefited from the onsite manufacturing supervision of the SZBG as it helped improve the design and production process of buses.

After initial years of learning and operation, the technical specification for batches procured later witnessed the following trends.

- More coverage of the warranty, more detailed description in the bidding documents, and for a longer period: the warranty for the key parts, mainly the 3-e system, had to be provided for the entire life cycle.
- Higher standards in line with the technology progress: for instance, higher battery energy density, longer running distance, faster charging speed, integrated controllers, battery cooling methods—that is, shift from air- to liquid-cooled battery system as an effort to prolong battery life—and electronics protection standard. These improvements aligned with the continuously updated technical requirements for receiving subsidies from national and local governments.
- More ancillary facilities were included to provide more smart services such as accessibility facilities, a voice guidance system for the blind, smart monitoring device, and driver zone barriers.

4.2.3 Electric Taxi Fleet Procurement

Taxi procurement went through similar processes as buses in accordance with SZBG's company rules. Manufacturers also bought back and decommissioned replaced internal combustion engine (ICE) taxis. National and local governments provided purchase subsidies—44,000 yuan per vehicle from the national government and 22,000 yuan per vehicle from the Shenzhen government—which rendered the out-of-pocket procurement price of electric taxis comparable to the traditional taxis.

Similar to the practice employed for electric buses during the manufacturing stage, each subsidiary taxi company sent its technicians to the manufacturer's plants to learn about its maintenance and to oversee the manufacturing process of the electric taxi. SZBG's dominant electric taxi model is the BYD e6 (table 4-7).

Table 4-7 BYD e6 key specifications

Dimension (mm)	4560 (Length), 1822 (Width), 1630 (Height)
Weight (kg)	2175
Battery Capacity (kWh)	82
Mileage (km)	300
Passenger Capacity	5

The SZBG has several key technical requirements on the major parts of the vehicle: reliability of battery life for power battery to reduce the need to change battery in the five-year lifecycle of the taxi; the energy density to reduce the battery weight and to increase distance per charge; the safety feature; and the charging frequency and charging speed. The motor and control system specifies the component size and weight, reliability, energy efficiency, noise and vibration control, speed range, and torque.

4.3 Operating Electric Buses

The SZBG undertook several measures to overcome the challenges of its operations. These measures included refining the operational plan and scheduling for each line, optimizing charging arrangement, and the use of intelligent bus dispatch and management systems. The adoption of the large capacity electric bus made these measures relatively easier to implement. However, the SZBG has been making constant route adjustment and optimization—routine and ad hoc. While the routine optimization occurs twice a year, the ad hoc optimization gets implemented as the road condition and passenger's demands change. The SZBG deployed smaller batches of electric buses at the very beginning of the electrification process using a learning-by-doing approach. Some routes were divided in half and moved under the management of different fleets, and some bus stops were rearranged. With better technology (see the evolution of bus technical specifications in table 4-2 and table 4-6) and accumulated experience, the SZBG could eventually manage to operate the same number of buses in service while maintaining service.

4.3.1 Operation Plan Adjustment

The SZBG has more than 300 routes in daily operation. It conducts regular performance and efficiency checks of each route every six months and makes appropriate refinements depending on the running distance, shifts, and charging time.

- Ensuring bus frequency to meet the demand: SZBG collects passenger-flow data thrice a month of workdays, weekends, and holidays to optimize scheduling based on actual demand.

- Routing adjustment to new metro routes: With the development of Shenzhen's metro service, the function of the urban electric bus changed from backbone to a more feeder role to complement the metro service. Some longer bus routes were shortened to provide feeder-line services.

- Emergency response plans: Each fleet or route has an emergency response plan for any extreme weather, electricity offcuts at charging stations, accidents, sudden driver shortage, and holiday passenger surges to ensure that bus services remain at an acceptable level.

- Charging arrangement for electric bus: Typically, three types of shifts for bus lines in SZBG:

- Morning shift (early morning to early afternoon)

- Afternoon shift (early afternoon to late night)

- One-day shift (morning to night)

The typical charging arrangements for electric buses are:

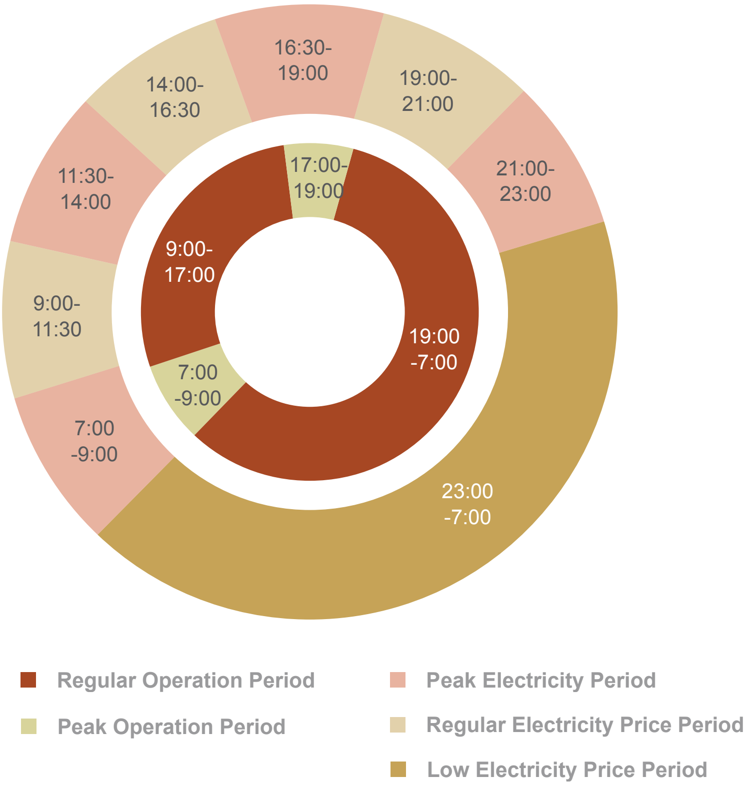
- All electric buses receiving full-charging at night (23:00 – 7:00 hours)

- In most cases, those morning shift and afternoon shift can run for the whole shift

- The one-day shift would need a quick charge during the daytime up to the SOC needed to finish the day's operation (fully charged at night)

Operational needs and electricity prices at the different times of day dictated charging arrangements (figure 4-4).

Figure 4-4 The philosophy of charging arrangement to minimize the electricity costs



As all electric buses are scheduled for full charging during nighttime (23:00–7:00 hours), charging facilities, and different shifts for charging need to be carefully designed to accommodate the large charging demands at night. Traditionally, one DC charging terminal has one charging plug to charge one electric bus (figure 4-5 left). But to maximize the number of electric buses charged at the same time, SZBG negotiated with the charging service companies to modify some of the charging terminals with four plugs (network charging as discussed in section 5.2; see figure 4-5 right). Each charging terminal's output is fixed, therefore each charging plug charges at quarter of the power to each bus when all four plugs are used simultaneously for charging. Although lower power requires a longer time to charge, this arrangement has the benefit that it does not require moving electric buses at nighttime.

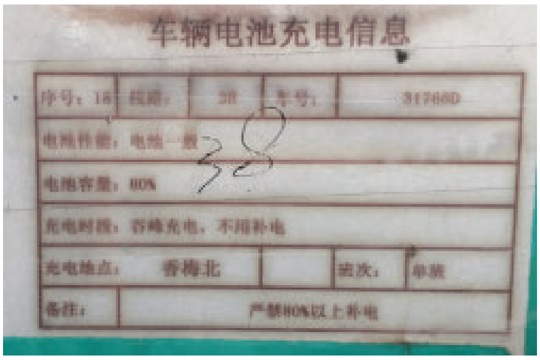
Figure 4-5
Charging terminal with one plug (left)
and charging terminal with four plugs (right)

For example, bus terminal Xiangmei Bei in Shenzhen has 17 charging terminals each of 150 kilowatts. The charging speed depends on the power of the charging terminal and the specifications of the battery. One-to-one charging is provided to the first batch of 17 buses for the first round of overnight charging. With the remaining state of charge and a 150-kilowatt charging terminal, charging usually takes one to two hours. The second batch of buses receives a one-to-four capacity, so that 17 charging terminals can charge up to 68 buses at the same time. With each charging plug of about 40 kilowatts, the charging usually takes six hours.

Each bus carries a charging guidance card to ensure that drivers know when and where to charge (figure 4-6). The SZBG tries to keep the number of electric buses to be charged during the daytime to a minimum to lower the cost of electricity. Therefore, bus route operators design their scheduling and charging arrangements to lower the percentage of daytime charging. The SZBG provides incentives, such as a bonus to bus route operators, if the percentage of daytime charging is lower than the benchmark. Bonuses are paid to the fleet management as part of their salary.

Figure 4-6

Charging guidance card on board of Line 38



车辆电池充电信息

序号：16	线路：	38	车号：	[illegible]
电池性能：电池一般				
电池容量：80%				
充电时段：[illegible]充电，不用补电				
充电地点：	香梅北		班次：	[illegible]
备注：	严禁80%以上补电			

38

Note: The card provides detailed information on the current SOC of the bus battery (80%), charging time (overnight charging with no supplementary charging in the daytime), charging location (Xiangmei Bei) for one bus under Bus line No.38.

4.3.2 Upgraded Bus Management System

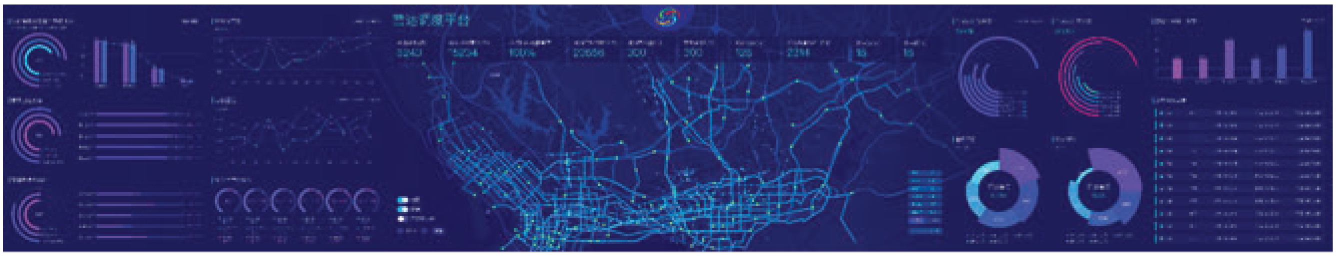
Electrification works concurrently with information and technology as a lot of real time data from the vehicles and charging facilities can be collected and managed. With the electrification, the SZBG upgraded its bus dispatch and management system to support efficient and safe operations of electric bus fleets. Upgrades included the following three modules:

- Dispatching module: to account for electric bus running duration and charging needs.
- Battery monitoring module: added by collecting battery real time data from each electric bus's control area network (CAN).
- Charging terminal monitoring and charging arrangement module: to collect real time information of each charging terminal.

After the upgrade, real time battery data of all electric buses under the SZBG are integrated into the Intelligent Transportation Center (ITC) and are used to improve operational efficiency. The ITC integrates three main management systems: bus operation management system; safety management system; and repair and charging management system. With charging terminal information integrated with a bus management system, dispatchers can give specific commands on charging and parking to drivers. This reduces drivers' anxiety about remaining battery power and their unnecessary runs to charging stations.

The bus operation management system analyzes traffic patterns and service performance in real time (figure 4-7). By collaborating with the ride-hailing company Didi Chuxing, a large amount of real time traffic data from Didi Chuxing is available to help forecast traffic conditions. This information is sent to the dispatching module and to the passenger information boards at bus stops to show the forecasted bus arrival time. Fleet managers can obtain data including previous day's overall passenger heat map, route's ridership, fare income, real time vehicle movement as well as real time streaming of onboard cameras to make minor adjustments to the dispatch headway or resolve potential safety issues.

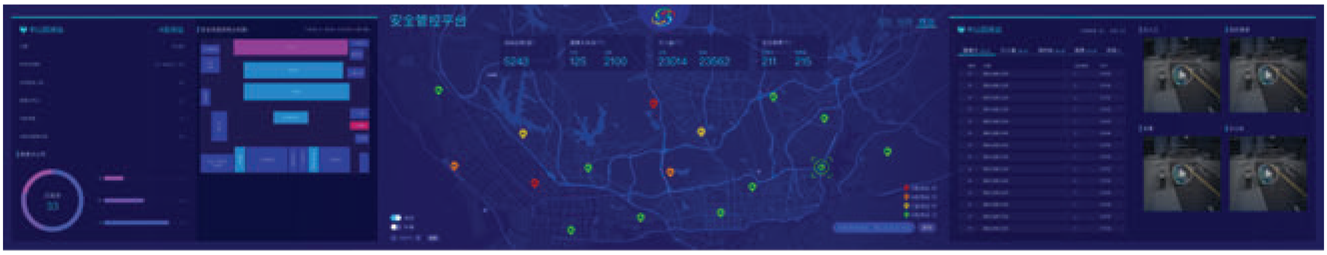
Figure 4-7 Display of the bus operation and dispatching platform in the ITC



Note: the left panel shows from top to down, left to right: performance score, on-time performance of dispatching, dispatching ratio, fleet size, passenger distance, operating revenue; the middle panel shows the routes and buses in operation; the right panel shows from top to down, left to right: daily cumulated number of buses in operation, total passenger trips, passenger distance, and bus shifts by subsidiary companies, as well as the dispatching ratio and the list of headway abnormality at the far right.

The safety management system of the ITC has played a critical role in SZBG's electric bus operation. The SZBG worked with the SMTC to collect and map all the historical traffic accidents and violation, so that it can dispatch its safety management personnel and fleet management to perform an on-site inspection of operation in the corresponding area. For every bus route, the fleet manager organizes a monthly service meeting to update any changes in the locations with potential safety hazards, and discusses proper mitigation actions to be taken by drivers. The data from the video monitoring system installed inside and outside the bus are collected to analyze passenger occupancy and comfort level. The SZBG requires fleet management to keep video footage for a minimum of 14 days so that fleet management can identify drivers' violation of any safety regulation. These data also help the SZBG develop personalized training packages to improve drivers' skills and safety habits further. The video data also help analyze the fatigue level of drivers to lower safety risks, via a module of the safety management system. The system can either send out a verbal alarm to the driver or to management depending on the severity of the fatigue level in real time so that proper action can be taken. Selected vehicles in the SZBG fleet are also testing the advanced driver assistant system (ADAS) developed in 2019 to assist the driver reduce or eliminate blind spots. At the depots, the safety management system provides a color-coded map to categorize the safety requirement level of different functional areas within the depot as well as real time video footage of the depot (figure 4-8).

Figure 4-8 Display of Safety Management System of the ITC



Note: the left panel shows basic information on a selected depot, including the layout of the depot. The middle panel shows the safety risk ratings of the depots, with the red color highest and the green color lowest. The right panel shows the safety facilities in the depot including security cameras, fire extinguishers, fire hydrants, etc. as well as the live feeds from the on-site cameras to the far right.

The SZBG fully explored new mobility solutions to provide customized public transport services to the public and demonstrated the collaboration of electric mobility and smart mobility. The SZBG founded Didi Youdian Technology Company in 2016, along with Didi Business Service Company and Shenzhen Beidou Application Technology Research Institute. The SZBG plans to expand its mobile application further to integrate more urban mobility service to create a mobility-as-a-service (MaaS) platform.

4.3.3 Training of Bus Drivers

The differences in driving patterns between diesel bus and electric bus in the SZBG include:

- ***Longer Braking Distance:*** Since the electric bus is heavier because of the battery packs, its braking distance is longer than that of traditional diesel buses, increasing collision risks.
- ***Electric Engine and Control:*** The engine pedal of an electric bus is more sensitive than a traditional pedal, which requires gentler driving at departure.
- ***Safety Check by Drivers:*** Safety checks are needed at the start of each shift. The items and requirements to check for an electric bus differ significantly from a diesel bus.

Operational differences necessitated training for existing bus drivers to be eligible to drive electric buses. The Training Center of the SZBG developed a set of courses for no less than 72 hours and hands-on driving training for all drivers at the beginning stage of electrification, including requirements to pass a driving test and a knowledge test.

1. Knowledge training: The course covers content in EV technologies, operation safety, safe driving behaviors, maintenance guide and contingency management. The test includes both theoretical and practical knowledge. The drivers need to pass the test with a minimum of 90 points out of 100.

2. Test-driving requirement: To assist drivers transitioning from a traditional to an electric bus, each driver needed at least 50

kilometers of empty-bus driving practicebefore being eligible to operate an electric bus with passengers. The whole training process was supervised in a controlled environment and recorded on videos.

3. Online platform for continuous learning: The training center also developed a self-paced online learning platform in 2018 for drivers to take appropriate lessons or to follow their interest. This platform offers more than 300 courses to all staff members.

4.4 Maintenance and Asset Management

4.4.1 Vehicle Maintenance and Repair Need and Costs

Compared with conventional internal combustion engine buses, electric buses in general have fewer maintenance and repair needs.

- ***Power and Transmission System:*** Electric motor, gear decelerating drive, and motor controller of electric buses have a more straightforward mechanical structure and provide higher transmission efficiency.

- ***Drive and Brake System:*** While the frame and axle of electric buses do not vary much from conventional buses, most electric buses use air suspension systems, which are lighter, more energy efficient, and less noisy than leaf-spring suspension. The air suspension system is also superior in maintenance and repair needs. Tire wear is more for electric buses because of heavier weight. Electric buses also use disc brakes that require less maintenance work than drum brakes.

- ***Air Conditioning and Others:*** Inverter air conditioner—used to control the efficiency of the compressor which can help achieve 30 percent better energy efficiency[2] than regular air conditioner units—is fully welded, therefore has fewer maintenance and repair needs.

- Maintenance checks and repair workload between electric and conventional buses differ.

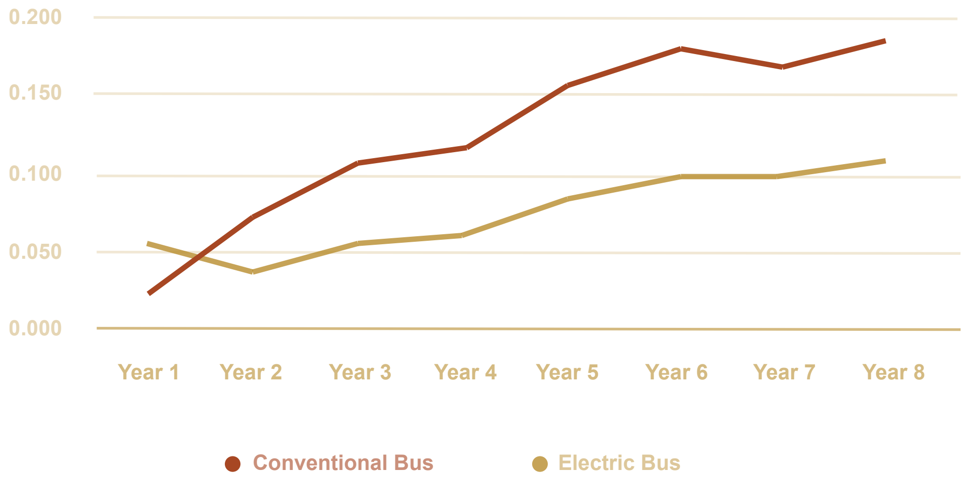
- Regular inspection, daily inspection, and level I maintenance (every 4000–5000 km) remain the same, with increased emphasis on the safety inspection.

- Low maintenance need, including level II maintenance (every 20,000 km) and workshop repairs, is reduced especially on mechanical defects. However, work on electronic parts increases.

- Overhaul maintenance and whole-component repairs mainly on engine and body are significantly reduced for the electric bus. The maintenance for the 3-e system is covered by manufacturer warranty.

- Storage need is significantly reduced as the type and stock of repair materials and components are fewer.

Figure 4-9 Number of defects of conventional and electric buses per 1,000 vehicle kilometers running

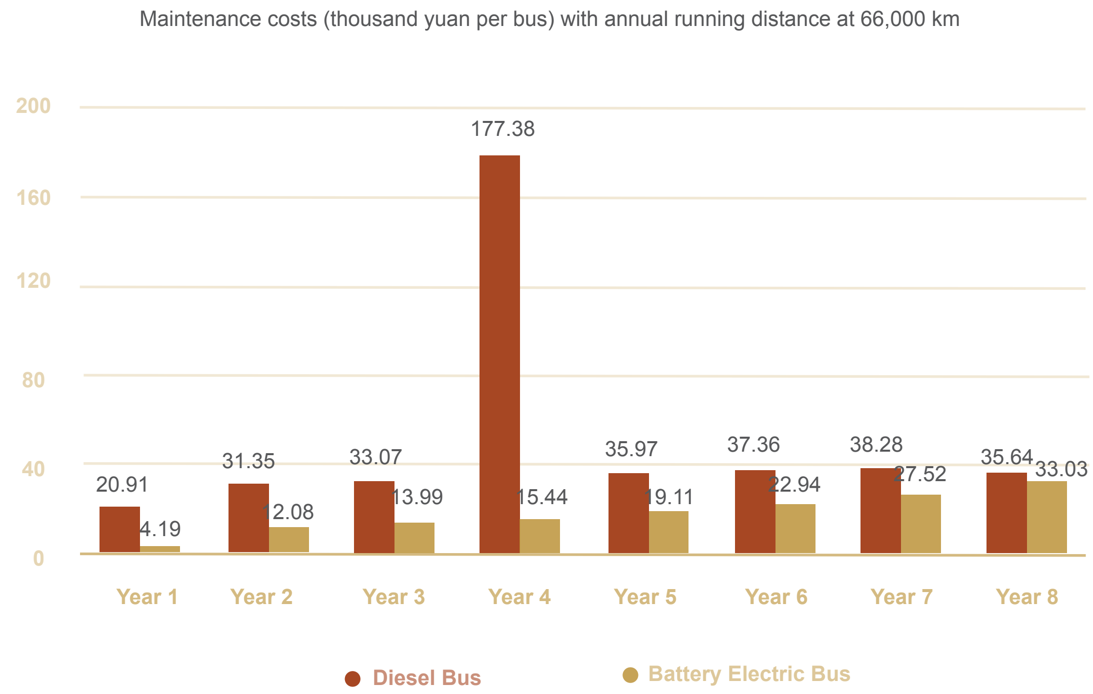


Note: Data for electric buses are the average of the 10.5m BYD K8 procured in 2016, and the data on the later years are based on reasonable assumption; data for conventional buses are the average of the 11m buses in SZBG's fleet.

Electric buses had a higher defect rate in year-one (figure 4-9) because of technical modifications and adjustments made to the vehicle model at the initial deployment stage. About half of all the defects for electric buses at the two year-two stage were on the 3-e systems that were under manufacturer warranty. Other repair issues include compressor defects and battery degradation.

Data from one earlier batch of electric buses (BYD K8) that the SZBG procured in 2016 show that the total maintenance and repair costs for electric buses were much less than those of conventional buses in the early years (figure 4-10). Because the K8 model was procured in 2015–16, only the first four years of maintenance cost are available. The maintenance cost of year five to eight were assumed with 20 percent annual growth rate from year four, because it is expected the maintenance of chassis, bus bodies and other parts of the electric bus in the later years will cost more. 3-e system warranties from the manufacturer also reduce SZBG's maintenance costs significantly. Diesel buses require overhaul maintenance every four years, targeting mainly diesel engine and transmissions that incur a substantial cost. Although the annual maintenance cost of tires of the electric bus is about 30 percent more than diesel bus on account of its weight, it is estimated the total maintenance costs of the electric bus lifetime are about 30–40 percent of the traditional diesel bus.

Figure 4-10 Cost comparison of maintenance and repair between SZBG's diesel and electric buses



Note: Data for electric buses are the average of the 10.5m BYD K8 procured in 2016, with the maintenance data for the first four years in reality and assumed costs from year 5 to 8 with a 20% annual growth rate to include further maintenance requests. Data for diesel bus are the average of the 11m buses which was in SZBG's fleet. The surge of the cost in year 4 represents the overhaul maintenances on diesel engines and other key parts. Diesel buses are basically discarded in the eighth year, so no sharp increase in maintenance costs at the end of the eighth year.

Data from one earlier batch of electric buses (BYD K8) that the SZBG procured in 2016 show that the total maintenance and repair costs for electric buses were much less than those of conventional buses in the early years (figure 4-10). Because the K8 model was procured in 2015–16, only the first four years of maintenance cost are available. The maintenance cost of year five to eight were assumed with a 20 percent annual growth rate from year four, because it is expected the maintenance of chassis, bus bodies and other parts of the electric bus in the later years will cost more. 3-e system warranties from the manufacturer also reduce SZBG's maintenance costs significantly. Diesel buses require overhaul maintenance every four years, targeting mainly diesel engines and transmissions that incur a substantial cost. Although the annual maintenance cost of tires of the electric bus is about 30 percent more than diesel bus on account of its weight, it is estimated the total maintenance costs of the electric bus lifetime are about 30–40 percent of the traditional diesel bus.

Battery

At initial stage of the electric bus deployment, Shenzhen piloted the bus-battery separation lease (车电分离). However, PGC which purchased and managed the battery had not specialized in handling batteries. Consequently, the poor battery quality supplied in the initial batches led to PGC's financial loss and disrupted SZBG's bus operation. Shortly after, the SZBG moved battery ownership and management to the vehicle manufacturers who provided lifetime warranty with promise of battery replacement when its capacity fell below 80 percent. Some buses experienced battery degradation as early as at their 50,000-kilometer mileage. In the SZBG, most of the batteries on the BYD K8 model needed to be replaced after 2–2.5 years; for other bus models, the replacement cycle was about 3–4.5 years. Manufacturers would only replace the battery after multiple repair attempts. Also, manufacturers usually only replace batteries partially, that is, some cells of the battery pack each time, as long as the refurbished battery meets the SOC requirement. It is fair to assume that on average, the replacement cycle is four years that is, one bus gets two battery packs in its lifetime.

China's regulation requires EV manufacturers to bear the responsibility of battery recycling which is why the residual price of the battery is considered zero for the operator. BYD takes recycles old batteries as agreed with the SZBG. According to BYD, the vehicle and battery manufacturer developed a cascade-utilization plan for power batteries depending on their remaining capacity. Those with relatively high capacity would be used for storage after capacity optimization. Low capacity batteries would be disassembled, and the valuable metal being recycled. The SZBG started the recycling of over 700 tons of power batteries from its first batch of 200 retired electric buses in March 2020. The SZBG and the PGC (the owner of the batteries) are working with Shenzhen Recycle Environmental Technology Company Limited to conduct the cascade-utilization of these batteries, designing products for energy storage, telecommunication base station power reserve, and solar PV lamps.

4.4.2 Maintenance and Repair Technicians

The human resource and technical departments of the SZBG developed a maintenance and repair technician staffing standards and transformation plan at the beginning of the electrification which is critical in facilitating SZBG's electrification transition. They assessed staffing requirements for different types of technicians based on detailed analysis of staffing and new requirements of workloads and skill levels. They developed a step-by-step staff transformation plan—training, re-assignment, incentives, talent attribution and compensation—for each team in each maintenance and repair workshop, considering the difficulty of transformation based on specialty, age, and experience.

To illustrate, one high-maintenance workshop at Caopu in Shenzhen was considered the most difficult one to adapt as it focused on highly specialized and streamlined engine and body repairs and work. The SZBG worked with BYD and turned Caopu Workshop into a BYD electric vehicle service center, providing 3-e-system component maintenance and repairs, body repairs, and warranty services to the SZBG and other bus companies in Shenzhen. The total number of maintenance technicians has decreased slightly, with the frontline maintenance technician to bus ratio including workshop management went down from 0.37 in 2016 to 0.30 in 2018.

Table 4-8 Maintenance and repair staffing transformation plan after the electrification

Specialty	Target Staffing	Old Staffing	Difference
Electromechanical technician	619	0	619
Mechanical technician	709	1286	-577
Electrician	152	174	-22
Spray painter and panel beater	188	249	-61
Others	0	56	-56

After electrification of the fleet, only 55 percent of the original labor force of mechanical technicians was needed, while a large number of electromechanical technicians had to be added (table 4-8). The SZBG practiced an elite and mass training approach in transforming the skill sets of technicians to electromechanical technicians.

- Training by electric bus manufacturer: SZBG's technical department has sent over several batches of maintenance technicians to BYD, the bus manufacturer's plant, for onsite training since January 2016. These elite maintenance technicians, numbering 128 accumulated maintenance, repair, and troubleshooting skills on the newly procured vehicles including the 3-e system. They also provided valuable suggestions to the manufacturer on the design of the buses.

- Training by vocational school supported by the SZBG: The affiliated technical training school provided specialized training course and the course was largely subsidized by the SZBG. Among the 1800 mechanics at the SZBG, more than 1200 of those have successfully acquired the electrician certification to perform electric-bus maintenance as of mid-2019. These transformations needed several months of training, learning, and certification to ensure a smooth and safe transition to an electric bus fleet. The SZBG also offered incentives and rewards if the maintenance technician progressed to obtain national skill level certificates such as EV battery maintenance technician. The company also hosted several internal technical competitions for maintenance staff.

4.4.3 Toward Systematic Asset Management

As a state-controlled joint venture, SZBG's assets are supervised directly by the state-owned Assets Supervision and Administration Commission of Shenzhen with the main purpose of preventing loss or misuse of state-owned assets. As a public service provider that receives annual subsidies from an affluent city government, asset management of SZBG was limited to ensuring operation and safety while having less incentive of reducing lifecycle cost or asset value appreciation. Inventory was limited to meeting the demand of storage and repairs.

After the electrification, the SZBG placed a lot of emphasis on charging and set up an energy management system to be certified by ISO 50001. While maintenance and repair standards and procedures are set up to minimize service disruptions and ensure safety and environmental compliances, the component of funding and valuation is lagging. With its ambition to be the model in electrification of public transport in the country and the world demonstrating the successful reform of SOE, the SZBG is working toward systematic asset management that incorporates a full-fledged asset management plan and capital investment planning.

Figure 4-11 Digital display of depot and vehicle information in the ITC

a. Depot information

b. Vehicle information

The digital management systems of the ITC (figure 4-11) have established a solid foundation for systematic asset management. The platform monitors the occupancy level of repair and maintenance workshops and charging stations to schedule maintenance and repair works. The depot management system also tracks workshop workflow including the time and other service information of individual vehicles. With data accumulated, the SZBG is planning to provide all vehicles with predictive maintenance service based on wearing status and parts simulation as well as an online maintenance manual that connects to the CAN.as an online maintenance manual that connects to the CAN.

4.5 Operating and Managing Electric Taxis

An electric taxi differs in its characteristics in operation compared to traditional taxi vehicle mainly because of its charging requirements. At an early stage of electrification, a three-hour nonoperating period was essential in each shift, which included driving to the charging station, a wait time of about an hour at the charging station, and a charging time of about 1.5 to 2 hours with DC fast charging. The SZBG implemented numerous measures to increase the operation efficiency and viability of its electric taxi service.

4.5.1 Increase Double-Shift Taxis

In Shenzhen, some taxis are operated by one driver for a whole day—the single-shift taxis—and some are operated by two drivers on day and night shifts. After electrification, the SZBG re-negotiated the contracting terms with taxi drivers to increase the percentage of double-shift taxis. While single-shift drivers are less affected by charging need as they need to rest during the full day, the double-shift drivers for the SZBG could use the electric taxi more efficiently, and lower SZBG's investment costs of vehicles as well as the nonoperating time. With double-shifts, drivers were required to charge their taxis fully in between shifts at a charging station when two drivers mutually agreed. The shift change in Shenzhen usually occurred during 03:00–08:00 a.m. and 15:00–-20:00 p.m. At an early stage when the charging stations were insufficient and distance per charge was shorter, taxis needed to charge at shift change as well as during their shift. The taxi operator arranged to stagger the charging schedule assigned to drivers living in different zones during their shift-changing time.

4.5.2 Maintenance and Repairs

Technicians have been trained at the manufacturer's plant about the maintenance of electric taxis. After electric taxis were deployed, all subsidiary taxi companies continued their technical collaboration with the manufacturer—inviting BYD's technicians to taxi workshops for learning advanced knowledge and techniques as well as shared learning sessions. The SZBG arranged annual competitions among technicians and awarded the most outstanding. The SZBG also focused on compiling the experience accumulated by these technicians and shared such experiences as online courses to all its technicians.

With the joint venture with vehicle manufacturers and trained technicians, the taxi maintenance workshops of the SZBG were certified to be able to provide maintenance and repair services to other BYD e6 cars. Meanwhile, BYD has also gained valuable data and experiences from these maintenance and repair works to improve the quality of vehicles.

4.5.3 Intelligent Charging and Management System

The need of charging batteries has been a major obstacle to operate any taxi efficiently. Thus, improving the charging management system has been critical to tackle this challenge. The system monitors and analyzes real time status of the vehicle—remaining power and vehicle location—and the charging terminal—queueing and pricing—and sends charging reminders or suggestions to drivers, and other relevant data to charging stations and taxi operators for improving the efficiency.

SZBG's taxi subsidiary is developing an integrated taxi management system. This system plans to include more functions for driver management: vehicle management through defect alert; battery monitoring; maintenance statistics and reminder; charging and dispatching management including troubleshooting and repair of charging terminals; and maintenance management, scheduling and status checking. The system can also analyze facial expression of drivers during operation to identify fatigue and send alarms to alert tired drivers, and protect their safety.

4.5.4 Safety and Emergency Response

Taxi drivers are the key to ensure safety. All taxi subsidiaries of the SZBG have emphasized training for all drivers on the safe operation of EVs including knowledge and driving practice. PCET organizes monthly safety study groups to discuss typical safety cases, risks, and mitigation measures specific to electric vehicles. The intelligent management system also sends reminders and alerts to drivers in real time, monitoring the GPS data as well as camera feeds inside taxis. Drivers' performance and behaviors are reported regularly and evaluated with financial incentives. PCET also developed an emergency response plan and conducts semi-annual fire drills and evacuation drills for taxi drivers.

Interviews of taxi drivers in Shenzhen, conducted by this study, showed that while the electric taxis are in general easier to drive with better vehicle control—can go with empty shift, can go closer to the curb—several major traffic safety risks of the electric taxi fleet persist. Such risks have contributed to the increase of taxi accident rates in Shenzhen. i) Vehicles are much heavier, so the braking demands longer time and distance especially when it rains. ii) Drivers report larger blind spot of BYD e6 at the front and side of the car because of a very wide A-pillar, or front pillar, and a flatter windshield and a longer front face. iii) It is quieter inside the vehicle—some drivers are not aware of the speed, so speeding occurs more often, and drivers seem to get more fatigued on highways.

4.5.5 Leveraging Assets for Revenue Generation

Taxi Hubs: The SZBG further plans to develop some of the taxi charging locations at terminals, depots, and parking lots into one-stop service complex with functions such as public charging, maintenance and repairs, car wash, convenience stores, entertainment, psychological consultation as part of the employee assistance program (EAP), apartments, advertising, and logistics. Some of the maintenance workshops with skilled technicians could become authorized service centers for other EVs.

Parcel Delivery: With the advancement of intelligent transport systems (ITS), SZBG's taxi fleet and other on-demand vehicles can potentially move to other tasks during low demand times or when on empty mileage. For example, PCET launched a few initiatives to offer more diverse services. For example, PCET's collaborates with a courier company SF Express to use taxis to deliver small packages within the city. In the trial period, SF Express provided the software support and orders, and PCET assigned about 1,000 electric taxis to provide small parcel delivery services with minimal impact on operation costs. This parcel delivery service turned out to have generated significant income for drivers, far exceeding earnings collected from passengers during the COVID-19 outbreak and recovery time.

School Taxi: PCET also started an internal trial of a school taxi. PCET provided mobile application-based service to transport schoolchildren. Their application (app) provides parents real time video footage of the respective taxi as well as the location of the taxi, indicating details for students' departure and arrival information on their way to school. All of PCET's taxis are equipped with panic buttons that report to the respective police department, and the guarantee of children's safety offered by this service makes it much more attractive than a regular street-hail or privately hired vehicle.

Traffic Police Support: PCET is developing a program that allows taxi drivers to help the traffic police. Taxi drivers receive notifications of nearby traffic regulation violations or crash and can take photos at the violation of crash sites when the police are absent and far to reach. The taxi drivers who submit valid photos are rewarded afterward.

Advertising: PCET has also worked with Meituan-Dianping, an e-commerce and food delivery company, for local commercial advertising and marketing campaigns using its electric taxi fleet.

Driving Data: The SZBG is considering leveraging the large amount of data collected by the fleet for revenue generation as a huge asset. Driving data and vehicle diagnostics are used as training datasets for autonomous driving by large-scale manufacturers such as SMIC and Ford. The SZBG also piloted putting more sensors like the millimeter-wave radar on buses to collect more data for such purposes.

Notes

[1] According to research using data from various cities, extreme low temperatures in winter impact the battery charging time significantly. Statistics show that under minus 25°C, charging time slows down by 38.9 percent than that at 25°C. In addition, extreme low temperatures raise challenges for the motor and heating system.

[2] The C-rate is a measure of the rate at which a battery is being charged or discharged. It is defined as the current through the battery divided by the theoretical current draw under which the battery would deliver its nominal rated capacity in one hour.

[3] Energy efficiency ratio (EER) for the air conditioner is the number of British thermal units (BTU) the air conditioner is pulling out per hour divided by watts of power consumed. The higher the ratio is, the more efficient the air conditioning unit.

Chapter 5

Acquiring and Managing Charging Infrastructure

- Selection of optimum electric bus models based on climate, topography, existing bus network and technology
- Training to drivers and maintenance staff key for operation, more electromechanical technicians instead of traditional mechanists
- Electric bus routes and network should be continuously optimized on demand, functionality and charging facilities
- The latest electric bus model supports continuous running for a whole day in most urban scenarios, and supports 1:1 replacement of diesel buses during operation
- An intelligent bus management system is an important tool for successful operation and asset management

5.1 Acquiring Charging Infrastructure

The SZBG was a pioneer bus operator in electrification. With the lack of technical capacity—and therefore no charging operation permit—at the beginning of the electrification meant that the SZBG could not own or operate the charging infrastructure initially. A charging service provider owns the charging station and the transformer, while the government owns the power supply lines. This arrangement turned out to be a common model in China, and in a way, has nurtured a healthy and competitive market for charging service providers including grid companies.

The charging service provider performs two main tasks:

- Constructing charging infrastructure, including charging terminals, transformers, and other charging related facilities.
- Providing charging services, which include hiring technicians to perform daily charging and maintenance service.

Selection of the charging service provider also follows similar steps as with other procurement of electric buses. The SZBG had 1,707 charging terminals at 104 locations for buses by June 2019. The investment cost of a single charging terminal ranges between 200,000 and 1,000,000 yuan. The cost includes the devices of the charging terminal, the reconstruction of the surrounding area, the transformer, the grid line expanded, and the land ownership or lease. Apparently, for a large charging station with many charging terminals, such investments are significant. Costs of financing costs and research and development (R&D) also affect profitability (details in chapter 6).

The charging facilities for electric buses impose additional loads on the electricity grid. A report by NRDC (Xiong et al. 2019) showed that concentrated charging of electric vehicles would additionally burden the regional electricity grid, and unmanaged charging activities would magnify such burden. In the scenario of unmanaged charging, the burden of China's national electricity grid would increase by 13.61 and 153 gigawatts in 2020 and 2030 respectively. Besides, the high-power needs of charging facilities, especially fast charging, would result in harmonic current（谐波电流）and impulse voltage（冲击电压）challenging the power grid corporation. All these projected consequences would have to be considered in the design and construction of charging stations by a closer coordination with the local grid authority.

Whether capacity of the power substation is sufficient or whether a special power conduit needs to be added or whether a transformer substation capacity needs to be expanded, not only makes up as much as one third of the total investment cost, but also causes uncertainties of approvals and delays by the power supply bureau to approve any expansion. The SZBG was fully aware of the potential impact and expansion work on the electricity grid. During the initial phase of electrification, the SZBG collaborated with leading charging companies on the market and coordinated with the grid and authorities. Since the ownership of private electric cars was still low in 2015, such collaboration enabled opportunities to generate stable revenues for charging companies and lowered the risks that SZBG faced in capital investment, technology and coordination.

According to interviews with some large charging operators, building and operating charging stations for electric taxis are more profitable—where investment breaks even in about three years under the subsidy policy in Shenzhen—than those for buses, whose break-even time takes four to five years. This is because taxi charging stations can also provide services to private cars and other service vehicles. The revenue includes government subsidies—at 0.6 yuan per watt—and a service fee for charging. The bus charging stations in Shenzhen are reserved only for charging electric buses owing to safety considerations.

Potevio Group Corporation and Shenzhen Winline Technology (SWT) are the top two charging station companies providing infrastructure for the SZBG. PGC is the largest charging station company and the earliest player in providing charging facilities for electric buses, taxis, light delivery trucks, and other private EVs in China. As discussed previously, PGC was not only the charging facility provider but also the owner of the bus batteries leased to the SZBG from 2009 through 2015. The SWT, established in 2007 in Shenzhen, leads in producing charging equipment with multiple charging outlets. PGC is an SOE and was a critical actor during the demonstration phase. The SWT on the other hand, is a private company entering the market at a later stage of large deployment. Several other companies joined the market after 2016 to develop charging infrastructure with incentives provided by the Shenzhen government; more than a dozen major companies operate charging stations throughout Shenzhen.

The Challenge of Land Availability: After the early deployment of electric buses and construction of charging facilities at several major bus depots, land availability in Shenzhen quickly became the biggest challenge. Difficulty in finding lands with a clear title and ownership meant much higher costs, long delays, and other uncertainties for the construction and operation of the charging infrastructure. Although the SZBG transferred the land acquisition risks—ownership right, the potential of resettlement, land use changes, lease disputes to mention a few—to the charging service providers, the lagging progress of charging stations on account of land unavailability became the bottleneck in the deployment of its electric bus fleet at the initial stage. The SZBG piloted the network charging concept of one charging terminal with multiple charging plugs to save the need for space at depots, as more space is required if buses need to be moved for charging at night.

The land availability issue became even more severe when the taxi fleet was electrified. The Shenzhen government has made significant efforts since 2018 to address the land availability issues to remove bottlenecks and delays attendant on construction and operation of charging infrastructure.

i) Allocating the goal of charging station construction for taxi fleet to each district government to be accountable and monitor the progress.

ii) Encouraging government agencies such as Urban Management Bureau, Water Supplies Bureau, and the New Development District who have government-owned land such as parks, parking lots, and water treatment plants, to allocate land for charging infrastructure.

iii) Relaxing and simplifying the land use approval process for the construction of charging infrastructure and its ancillary facilities such as transformer room, rain shelter, restroom, by assigning them as temporary building and temporary land use category; lowering the approval authority to district level; and setting the compensation standard to industrial benchmark land price for temporary land use or short-term lease.

5.2 Technical Specifications

The technical specifications for charging infrastructure include requirements for charging mode, power output, and monitoring and management systems.

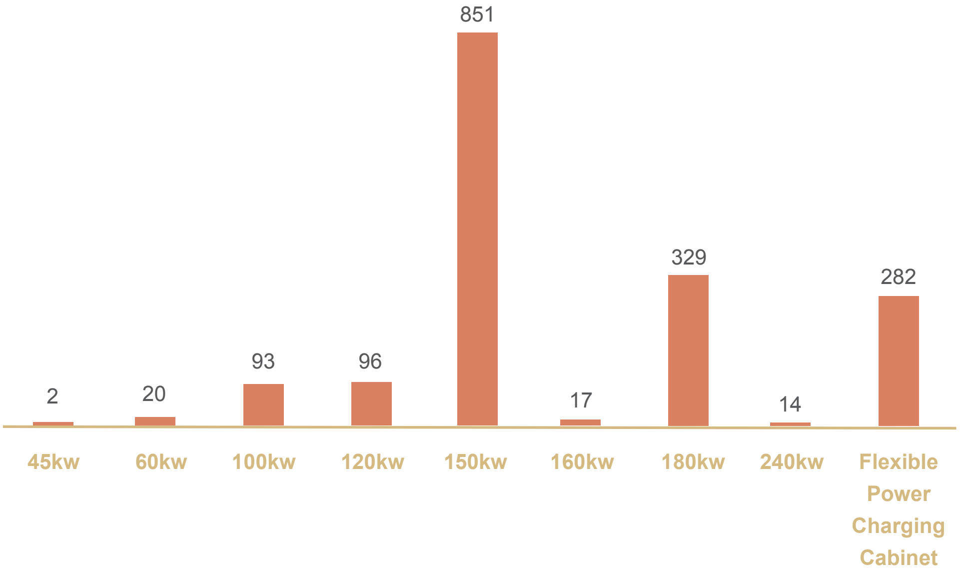
The selection of charge mode was determined by bus fleets charging needs, available technology, and costs. The SZBG decided to deploy DC fast charging stations with AC–DC transformers installed in the charging station to transform the AC from the city grid to overcome two of the most prominent issues of charging speed and the lack of space at depots. Despite higher costs, compared to AC slow charging mode with onboard transformers, DC charging with the transformer built at the bus depot or charging stations has three advantages that the SZBG considers important. i) Reduction of potential malfunction spots on the buses especially when technology is still nascent—it is easier to inspect and fix technical problems at the charging terminal rather than on individual vehicles. ii) Power output allowing faster charging speed, with C-rate[1] of 0.5, 40 percent faster than AC charging (C-rate of 0.3), or more buses to be charged in reasonable time. iii) More flexible in location of charging terminals which can be easily upgraded without the extra cost of upgrading all individual buses.

Several alternative charging modes were also considered, for example, battery swapping and wireless charging. The SZBG did not select the battery swapping option because of the following factors: i) Since batteries by different manufacturers use different standards, battery swapping can only happen within the same manufacturer or even the same vehicle model. ii) Safety is still a big concern in swapping, given the weight and size of the battery pack, requiring redesign of the vehicle structure. iii) The swapping needs additional working space and the efficiency is still low, which is extremely costly and causes bad customer experience especially in the urban core area where the demand for battery swapping is high. iv) Battery cost; battery swapping usually requires 50 percent of redundancy in battery, which implies much higher costs. v) Unviable battery ownership; the existing government subsidy policy assumes one battery per vehicle—the manufacturer cannot claim subsidy if it does not own the battery, and the operator or user does not have an incentive to swap their battery because they might get an old battery. Wireless charging has the advantage of convenience and flexibility, but the existing technology of wireless charging still cannot compete in charging efficiency. Furthermore, wireless charging would have much larger impact on the grid than DC fast charging as it requires an even larger power output due to significant energy loss.

The power output of the charging terminals is a major technical specification as the charging speed depends heavily on it. The SZBG piloted a network charging in 2016 with a compact design of one charging terminal equipped with several charging plugs to handle four buses at the same time. Although it takes longer time to charge, this arrangement significantly reduced the need to move buses at nighttime, which overcomes the difficulty of moving buses within insufficient space at depots and saves labor cost. For example, at Ziweige Station, 63 buses can be charged using five charging terminals without moving any bus. A more flexible charging concept was later introduced to adjust the power output of each charging plug to achieve the best efficiency and reduce.

The SZBG charging terminals allocate the power output distribution (figure 5-1).The majority of the charging terminals use 150 kilowatts (50%) and 180 kilowatts (19%) DC fast chargers.

Figure 5-1 SZBG charging terminals by power output



As technologies advanced, the SZBG required charging terminals to have a modular design. The modular design aided maintenance and repairs as technicians could easily remove that part to be replaced to minimize service disruption. Typically, the charging service providers require manufacturers to provide more than two years of warranty of charging facilities.

The charging monitoring and management system needs to manage the payment, defects of charging equipment and maintenance, reporting, and to interface with dispatching, operation, and other systems. One important requirement is that the provider should share all the data and information related to charging with the SZBG, who also has the authority to publish the data. All software is expected to have lifetime warranty with free upgraded services.

Technical Standard: The SZBG has developed a technical standard to convert traditional bus terminals and depots to accommodate charging, environmental and safety standards, and monitoring procedures for both diesel and electric vehicles, charging stations, and depots. Although the workshop has less waste water after the electrification from the elimination of oil change, it still has an increased obligation to handle hazardous materials. Technical standard compliance is important for the large-scale construction of a charging infrastructure. The Shenzhen government urged the Shenzhen Power Supply Bureau to develop technical standards to construct charging stations, and the technical specification of electric vehicle charging system was formally implemented in 2015. In addition, the Pengcheng electric taxi company under SZBG's control drafted another document "Specification of Electric Taxi Charging and Depot Facility" that was submitted to the Union Internationale des Transports Publics (UITP) standard committee in November 2019 as a standard for international adoption. The final approval of the specification standard was pending at the publication of this report.

5.3 Operating Charging Facilities

Nine operators constructed and manage the 1,707 charging terminals that the SZBG has for its buses. the PGC and SWT are the major two operators which control the biggest shares—35% and 33% respectively.

Malfunctions of charging facilities affect charging, especially when the charging terminal–bus ratio is low, and place reliance on the service quality and response time of charging operators. According to SZBG's fleet technical staff, large operators like the PGC and SWT tend to have better service and faster response. For example, the SWT provides a 24-hour repair team. Some charging providers store backup charging modules onsite such as one backup module per four charging terminal, and stock backup parts in the local factory. The two largest operators also use their staff or contractors to charge the vehicles besides maintaining and managing the charging facilities, monitoring the charging and payment, and conducting maintenance and battery testing. The operators' charging staff are in general well trained to minimize safety issues from mishandling. The SZBG staff or bus drivers were permitted to move the buses at night to charge in turn when the charging terminal–bus ratio was low.

5.4 Taxi Charging Infrastructure

At the first pilot in 2010, PCET relied on the bus depots owned by the SZBG to construct its first two charging stations and worked with a charging service provider to ensure the operation of its first 100 BYD e6. Later as the shareholder of PCET, BYD joined forces to construct more charging stations including underground ones to meet the demand of later deployment of electric taxis.

The charging infrastructure for electric taxis has a unique challenge. Unlike BEBs which return to a specific depot for overnight charging, electric taxis need to offer 24-hour service. An electric taxi depends on the facility to charge at any close-by location when needed. Instead of a large cluster of charging infrastructure in one location, it became imperative to have a large number of charging facilities at widespread locations.

BYD e6 shares the same charging protocol as other electric passenger cars. Thus, during the electrification process, the SZBG actively reached out to other business entities that offered charging infrastructures at various locations such as public parking lots, shopping malls, and residential areas to open their charging services for their electric taxis. The SZBG launched its own business as a charging service provider in 2018 and started construction of some charging stations to match the demands of electric taxis and other electric passenger cars.

By the end of 2018, 11,571 charging terminals were available for electric taxi charging in Shenzhen. The charging terminal network continues to expand with the growing need for electric private cars.

Notes

1 The C-rate is a measure of the rate at which a battery is being charged or discharged. It is defined as the current through the battery divided by the theoretical current draw under which the battery would deliver its nominal rated capacity in one hour.

References

1 Xiong, Y., Zhang, Y., et al. n.d. “Analysis on Developing a Healthy Charging Service Market for EVs in China”. Retrieved October 23, 2019, from http://nrdc.cn/information/informationinfo?id=204&cook=1

Part II
Key Lessons:

Technology (im)maturity

At the early stages of electrification in China, 2009–2013, governments gave substantial support to the automobile industry and their related companies to develop China's electric vehicle industry, resulting in many new EV manufacturers. The vehicles and the technologies were not widely tested, and the technical specifications of vehicles varied among manufacturers. Consequently, much uncertainty and many risks persisted in the early adoption of the electric bus. As technologies developed some sophistication on battery, electric engine, control system, and supply chain integration, EVs improved significantly, and market competition eliminated poor performers. Basic EV standards were established, but still many EV manufactures in the market continued selling products of a range in quality.

Bus operators, lacking technical knowledge or capacity to evaluate different specifications of vehicles, face higher risks in picking and using (both vehicle and charging) technologies during their lifecycles. It resulted in unsatisfactory performances such as running distance, malfunction rate, or charging speed to name a few. For example, some early batch of buses that SZBG had procured, experienced serious battery degradation and a number of buses had to stay in depot waiting for repairs for a significant time.

Using pilots: SZBG procured about 100 electric buses for piloting during 2011–13. Although the performance of those electric buses was poor, the pilot allowed SZBG to understand the technical characteristics and requirements so that SZBG could improve its business model, implement procurement,

Technical capacity: With the pilots, SZBG had opportunities to engage the main stakeholders in the EV ecosystem, including government and industry policy makers, manufacturers and researchers. The communication with the industry improved their technical knowledge and capability to select the right type of electric buses for its operation. SZBG also established a technology R&D department, whose major mandate was to understand the latest EV and charging technology and give recommendations to management. SZBG invested significant resources into capacity building and staff training, for drivers, maintenance technicians, as well as management and administrative staff. Recruitment, vehicle manufacturer's plant onsite supervision, technical competition, staff reporting card and bonus, certification, and continuous and comprehensive training are some leadership measures that have reaped good dividends. It has been an impressive achievement that SZBG has kept all its labor force intact through the electrification transition.

Close partner with manufacturer and charging service provider: Through continuous dialogue with the EV industry and market research, SZBG had the ability to identify robust manufacturers and to partner with them. Over a ten-year period, SZBG and the manufacturers worked closely to keep improving the technology and optimizing vehicle configurations and quality based on operation feedback. For example, SZBG has provided hundreds of pieces of practical advice to EV manufacturers via onsite supervision during manufacturing stage that improved the quality of vehicles SZBG procured. SZBG technicians also got first-hand instructions from manufacturers on how to use the vehicles to maximize efficiency and prevent problems. For example, SZBG incorporated the tips to maximize battery life into the charging protocols for drivers and charging service providers such as charging fully before pulling the plug, charging no more than twice of the battery capacity per day, and performing passive battery balancing by leaving low-SOC buses to discharge on depots. The close partnership between operators and manufacturers not only reduced the technical risks of operators, but also led to improvements in successive generations of electric buses.

Extended manufacturer warranty: SZBG required an extended warranty of eight years for the key parts of electric bus to lower the risks of immature technology. Because of this, manufacturers are incentivized to provide the best quality of electric buses to lower their risks through the long duration of the warranty.

Developing standard: SZBG worked with partners in developing the standardization of adoption and operation of electric buses and taxis. SZBG worked with Shenzhen Standardization Research Institute in October 2019 and developed noteworthy standards: “Management specification of operation safety for battery electric bus”; “Emergency treatment specification of operation safety for battery electric bus”; “Technical Specification for Maintenance and Repair of Pure Electric Taxis”; and the “Comprehensive Charging Station Infrastructure Specification”. SZBG is also a member of both the Bus Committee and the Ride Hailing Committee of the Union Internationale des Transports Publics (UITP), an international organization of public transport service provision. SZBG worked with UITP on promoting its standards as international standards.

Financing

The key challenge for electric bus adoption around the world is the high capital cost in comparison with the traditional diesel buses. The price of the electric bus has dropped significantly since 2009 because technology evolves and economies of scale set in. The price of the model BYD K8 procured in 2015 was 1,580,000 yuan per bus without subsidies; and the similar model in the market costs only 800,000–900,000 yuan in 2019. Although the price keeps dropping, the procurement price of the electric bus is still twice the price of a traditional diesel bus, especially of the large-battery ones with acceptable running distance.

The Chinese government started giving purchase subsidies to incentivize the adoption of EVs in 2009. The subsidies started to decline since 2016, and it is planned that no subsidies will be provided in the near future (the complete phasing-out was postponed to 2022) to allow full market competition between EVs and traditional vehicles. The phasing-out of subsidies encouraged EV manufacturers to improve their efficiency further and reduce the cost of manufacturing and price. Charging facilities are also part of the main costs for electrification. Land acquisition or rent for charging stations requires large amount of initial investment for larger adoption.

Financial Leasing: SZBG actively negotiated with manufacturers, financial agencies and other industrial departments, and together they developed innovative procurement solutions (chapter 3). Financial leasing helped lower the initial capital cost.

Taking Advantage of Subsidies: The pilots and regular dialogue with the industry helped SZBG better understand the EV development and policy evolution, which allowed SZBG to choose the optimum time for electrification. When a relatively mature electric bus model appeared in 2015, and subsidies were anticipated to decline, SZBG decided to take the full advantage of subsidies from all levels of government to lower the initial costs of electric buses.

Collaboration with Charging Service Providers: Charging facilities are also part of the main cost and the technology risks. SZBG chose to collaborate with the charging service providers, who invest and operate charging stations and services, to ease the initial investment and technology risks.

Operations and Management

Shenzhen is a fast-growing city with expanding urban areas and construction that lead to changing travel demands and unpredictable traffic conditions. The bus routes are subject to change as the metro network expands. The electric bus operation faces additional limitations because of battery running distance and lack of charging facilities. Land availability in Shenzhen quickly became the biggest challenge after early deployment of electric buses and construction of charging facilities at several major depots.

Large-battery bus: On account of very limited depot space and scarce charging facilities available, SZBG chose the large-battery electric bus with long-running distance to minimize the charging need and disruption to operation. Large battery buses are also more flexible to adapt to a changing demand and operate under unpredictable traffic congestion. The chosen model allows to leverage the lower electricity price at night and maximizes battery life due to fewer charging events.

Improve fleet operations: Every bus route has a detailed bus scheduling with detailed considerations on different bus arrangements, charging arrangements and emergency response procedures to ensure that the route adapts to different situations. The scheduling is refined every month after analyzing the ridership and traffic data.

Operation-oriented charging mode: Realizing the scarcity of charging facilities and space for new charging facilities as the main obstacle, SZBG decided to stick with DC fast-charging (as opposed to AC slow charging, battery swapping, or wireless charging) to ensure operational efficiency. SZBG also explored and encouraged innovations in network charging and flexible charging cabinet to overcome the charging bottleneck.

Intelligent management systems: SZBG relies increasingly on technology and data for bus ridership analysis, dispatch optimization and charging arrangements. SZBG also uses mobile technology to provide customized on-demand bus service.

3

Assessment of Costs and Benefits

Chapter 6

Total Cost of Ownership

- The total cost of ownership (TCO) of BEBs without subsidies is about 21% higher than diesel buses; the subsidies reduce the TCO of BEBs by 35%
- The purchase price of BEB without subsidy was nearly triple the price of diesel bus in 2016 in Shenzhen; the price difference has since declined
- BEB’s energy and maintenance costs together are significantly lower (about 44%) than diesel bus over its lifetime
- TCO analysis if charging stations confirms that charging infrastructure is a profitable business with charging service fees

6.1 Introduction

Electric vehicles have gained much attention and are promoted by many countries, not only for their emission reduction potential but also because of operational cost savings. Breetz and Salon (2018) analyzed the TCO of battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), and internal combustion vehicles (ICEVs) in 14 metropolitan cities and found that the TCO of BEVs are still more expensive, and concluded that government subsidy was essential for BEV deployment. Most literature find that the initial capital cost of the EVs is higher, but the operational cost of energy and maintenance is lower than that of conventional fuel alternatives (Breetz and Salon 2018; Wu et al. 2015). This chapter investigates the TCO of electric buses using actual financial and operational data from the SZBG.

We estimated the TCO of bus operation, covering the capital cost, maintenance cost, energy cost, taxes and fees, which occur over the lifetime of the BEB and DB. We also conducted a sensitivity analysis to analyze how much each of the variables investigated would affect the TCO results, including a Monte Carlo simulation to see combined effects by changes of multiple variables.

6.2 Bus TCO

Our study developed a TCO model to compare the cost of ownership between a BEB and a comparable DB.

The municipal government set eight years as the lifetime of heavy duty transit buses to operate in Shenzhen to ensure reliability and safety of the bus's operation (table 6-1). In other countries, the lifetime of 12 years is more common for transit buses; and the effect of a bus's lifetime on TCO will be analyzed using sensitivity analysis. The bus routes were reorganized considering both BEB drive range and extended metro network. Overall, the daily driving distances were shortened and more routes were reorganized to connect the residents' communities with metro stations. For a TCO comparison of DB and BEB, we calculated years between 2016 and 2024 for analysis to set the same lifetime and annual driving distance. The per kilometer energy and maintenance costs of DB are based on earlier experience data.

Table 6-1 Basic setting of BEB and DB

	Diesel bus	BEB
Lifetime of ownership	8 years	8 years
Annual driving distance	66,000 km	66,000 km

6.2.1 Selection of Sample Buses

This study selected the BYD K8 (CK6100LGEV2) to represent the BEB model because it represents 66 percent of SZBG's fleet after their shift to full electrification. This study selected the Yutong 10.5-meter diesel bus (ZK6105HG1A) as the comparable diesel bus model. The Yutong diesel bus model was SZBG's dominant model before electrification (table 6-2).

Table 6-2 BEB and diesel bus model configurations

Bus picture		
Vehicle Model	CK6100LGEV2	ZK6105HG1A
Propulsion fuel	Electricity	Diesel National VI standard
Length (m)	10.490	10.500
Width (m)	2.500	2.500
Height (m)	3.150	3.050
Curb weight (kg)	11700	10300
Gross vehicle weight (kg)	18000	16500
Total maximum passengers or seats (including driver and passengers)[a]	87/32	95/32

Source: www.chinabus.com

Note: Seat numbers of 87/32 mean 32 seats, with a total passenger capacity (including standing passengers) of 87.

6.2.2 Replacement Rate

If a single BEB can accomplish the driving task of a DB, the replacement rate should be one. The earliest BEB models (BYD K9 and WZL A10) were only adopted on specific routes with a shorter distance and not able to fully replace diesel bus trips. The estimated replacement rate for regular routes was about 0.8 out of 1. SZBG's existing BEB fleet, comprising mainly BYD K8s, is fully able to cover all the routes. Through SZBG's refined management and operation, the existing BEBs can achieve a replacement rate of one, without the additional number of buses.

6.2.3 Bus TCO Model

The TCO model reveals all the costs related to ownership and operation over the lifetime of a bus. The TCO equation 6-1 and equation 6-2 encapsulates our approach.

$$\mathrm{TCO} = Cost_{capital} + \sum_{t=1}^{T} \frac{Cost_{operation\_t}}{(1+r)^{t-1}} - \frac{ResidualValue}{(1+r)^{T}} \quad \text{Equation 6-1}$$

$$Cost_{operation\_t} = Cost_{tax\ and\ fees\_t} + Cost_{energy\_t} + Cost_{maintenance\_t} \quad \text{Equation 6-2}$$

Where:

- TCO is the present value of the total cost of ownership for the ownership period
- $\mathrm{Cost}_{\mathrm{capital}}$ is the purchase cost, which can be paid one time at procurement or financed over the lifetime of the bus, and includes procurement tax and registration fee
- $\mathrm{ResidualValue}$ is the resell price or scrappage value of the bus at the end of the ownership period
- $\mathrm{Cost}_{\mathrm{operation\_t}}$ includes the insurance and fees, electricity or fuel cost and annual maintenance cost
- r is the annual discount rate
- T is the period of total ownership

Additionally, the Chinese national and local governments provide purchase subsidies to promote BEB adoption. In this study, the subsidy is reflected in the capital cost by subtracting the allowance from the market price.

The TCO model presented in this study only includes the direct costs associated with bus use and ownership. The indirect costs such as deliberate scheduling efforts for BEB operation and charging, labor costs of drivers, mechanists or technicians and refueling or recharging staff are excluded.

6.2.3.1 Capital Cost

As a big corporate client, the SZBG receives bulk purchase and enterprise discounts. The price (table 6-3) may not represent the market price for individuals or smaller bus buyers. Additionally, the national and local governments provided generous subsidies to bus manufacturers to promote the adoption of electric buses. The results are presented with and without subsidies. The subsidy for electric vehicles in China has been extended to 2022 (instead of ending in 2020) to alleviate the economic impacts of the COVID-19 pandemic on the automotive industry. However, the fiscal subsidy will phase out eventually, and where it does not exist in many other jurisdictions, the no-subsidy scenario is an essential reference for other cities.

Table 6-3 Bus price and subsidies

	Bulk procurement contract price in 2016 (thousand yuan)	National Subsidy in 2016 (thousand yuan)	Shenzhen municipal Subsidy in 2016 (thousand yuan)
BYD-K8	1580	500	500
Yutong diesel bus	508	0	0

The SZBG substituted most of the diesel buses, 5528 of them, , with BEBs in only two and a half years during 2015–17. Procuring this large volume of BEBs put a tremendous financial burden on the company. The SZBG worked with the financial leasing company and developed a leasing plan to procure electric buses. The SZBG procured electric buses based on their demand and specification, and the financial leasing company paid for the BEBs to the manufacturers. With the leasing plan, the SZBG pays the lease quarterly to the financial leasing company with an annual interest of 4.16 percent over the eight-year lifetime of the buses. We simplified the calculation by applying for the annual payment at the end of each year to the financing leasing company and converted the annual payment to present value with the discount rate. The capital cost for diesel bus is assumed with the same financial plan and same interest and discount rate as of the electric buses.

6.2.3.2 Operation Cost

Energy Cost

The annual energy cost in each year is the cost of fuel or electricity consumption (equation 6-3).

$$Cost_{energy\_t} = Price_{energy\_t} \times EE_{energy\_t} \times Distance_{energy\_t} \quad \text{Equation 6-3}$$

EE_{energy_t} is the energy efficiency of fuel or electricity consumption per kilometer. The diesel price has fluctuated in the past years. We used the average bulk purchase price of diesel at 5.09 yuan per liter.

The energy cost of BEB consists of the price of electricity and charging service fee which varies based on the time of the day (table 6-4). SZBG's average charging ratio at peak, normal and valley times was 12.5 percent, 24.1 percent, 63.4 percent respectively. Therefore, the weighted average price of 0.8576 yuan per kilowatt hour is used for our base calculation (table 6-5). With the variation of the electricity price of time of day and service fees, we set the range of energy cost of 0.6511 to 1.4476 yuan per kilowatt hour for the sensitivity analysis.

Table 6-4 Electricity Price Scheme

	Time of Day	Hours	Industry Electricity Price (yuan/kWh)	Service Fee (yuan/kWh)	Total (yuan/kWh)
Peak	9:00-11:30, 14:00-16:30, 19:00-21:00	7	1.0516	0.396	1.4476
Normal	7:00-9:00, 11:30-14:00, 16:30-19:00, 21:00-23:00	9	0.6991	0.396	1.0951
Valley	23:00-07:00	8	0.2551	0. 396	0. 6511

Table 6-5 Weighted average price of electricity and diesel

Diesel (yuan/L)	Electricity (yuan/kWh)
5.09	0.8576

Energy efficiency varies with buses running on routes that differ in speed, acceleration, the slope of the road, drivers' driving habits, and other factors. The SZBG provides training and incentives for the bus drivers, encouraging them to improve the energy efficiency for both BEBs and diesel buses (table 6-6). BEB's energy consumption data in year one to four are based on the actual statistics from the SZBG, and the later four years are estimated conservatively with a five percent annual growth rate—considering the deterioration of electric motor and the gradually replaced battery cells.

Table 6-6 Diesel and electricity consumption efficiency

Energy consumption efficiency	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
DB (L/100 km)	37	38	38	37	38	39	38	38
BEB (kWh/100 km)	94	92	98	104	109	114	120	126

Maintenance Cost

Over the eight years of a bus's lifetime, diesel buses undergo scheduled regular maintenance every 20,000 kilometers to check the status of the bus, repair or replace small parts, fill up fluids, check and replace tires if needed, fix wear-outs and prevent further malfunction. In the fourth year of operation, diesel buses receive overhaul maintenance to check the engine, chassis and bus body, and more thorough check and repair. Based on SZBG's statistics, the average maintenance cost of a diesel bus is 0.779 yuan per kilometer.

The electric engine and transmission components are far simpler in a BEB. Additionally, the BEB technology has improved since the SZBG adopted it in 2015, and as a result, the rate of malfunction dropped substantially. With greater confidence in their products, the BEB manufacturers provide lifetime warranty for BEBs' 3-e system. This has led to significantly lower maintenance cost, labor cost, and on-campus repairs compared to diesel buses. The maintenance cost typically consists of tire replacement cost, regular and advanced maintenance costs.

Tire Replacement

The tire replacement cost for a diesel bus is about 90 yuan per 1000 kilometers. Tire replacements for BEBs are slightly higher at 125 yuan per 1000 kilometers for two reasons. First, the total weight of the vehicle is higher than the diesel bus. Second, BEB's have in-wheel electric motors playing a role in the propulsion and braking process, which wear down tires. As a result, the tire cost for the BEB is about 38.8 percent higher for the SZBG.

Regular Maintenance

During regular maintenance for diesel buses, a maintenance crew performs a series of tasks including an oil change, tire rotation, transmission fluids refill, brake fluids refill as well as checking or replacing a variety of mechanical parts.

Maintenance for BEVs is substantially lower because of the simplicity of the technology. The most essential parts are the electronics—the battery, the electric motor, and the electronic controllers or the 3e system—which are included in the manufacturer's warranty contract over the entire operating period of the bus. Technicians from the SZBG estimate that the regular maintenance cost has dropped from about 600 yuan per 1000 kilometers for diesel buses to 200 yuan per 1000 kilometers for BEBs.

Overhaul Maintenance

Overhaul maintenance for the diesel buses is scheduled at the end of the fourth year of each bus's operation. The process includes testing and repairing the engine, air conditioner compressors, and bus body. The tests also cover: the braking system, usually replacement of the oil seal; the transmission system, replacing the clutch and drive shaft; the electronic system, replacing the generator and lighting lines; the power system; and the malfunctioning parts of the steering system, knuckle and booster. The overhaul maintenance costs for a diesel bus are approximately 160,000 yuan on average, about 30 percent of the capital cost.

The manufacturer provides a lifetime warranty for the motor, battery, and electric control systems for BEBs. The bus body also consists of aluminum alloy instead of steel that does not need to be replaced over its lifetime. Therefore, BEBs do not require an overhaul maintenance schedule. Based on data from the SZBG, for the first four years of operation, the maintenance cost of BEBs can be as low as 17 percent of the diesel bus's maintenance cost. However, the maintenance cost increases gradually in the next four years. Similar to the energy efficiency data, we adopted the actual data of diesel buses and the first four years for BEBs (table 6-7), and made a conservative estimation for BEBs in years 4–8 with an increase rate of 20 percent. In the sensitivity analysis, we adopted the 20 percent and 100 percent of DB's maintenance cost as BEB's maintenance cost as the boundary in our Monte Carlo simulation analysis.

For all the electric buses in SZBG, the bus manufactures take care of the three electrics (electric motor, electric controller and battery) over the agreed lifetime (eight years for heavy-duty buses and five years for medium-duty buses). The K8 models typically need a battery change after 2-4 years of operation, depending on the driving behavior, the route characteristics, and the battery energy density of different batch of products. However, as the manufactures take care of the battery change within the warranty, SZBG does not pay for them and battery cost is excluded from the maintenance cost analysis.

Table 6-7 Maintenance cost for diesel buses and BEBs

Maintenance Cost (yuan/1000 km)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Diesel bus	318	476	502	2706	546	567	581	541
BEB	75	152	211	242	290	348	418	501

6.2.3.3 Operation Subsidies

Transit bus operation relies heavily on the municipal government subsidy for its operation. The Shenzhen Municipal Transportation Commission (SMTC) provided SZBG 244,000 yuan per diesel bus per year of operation subsidy. SMTC provides 422,700 yuan per BEB each year of operation with annual mileage of no less than 64,000 kilometers.

The operation subsidies for both DB and BEB were used for overheads in SZBG. We excluded the operation subsidies in our TCO analysis.

6.2.3.4 Other Costs and Variables

Tax and Fees

With governmental incentive policies, the purchase tax and other taxes are waived for transit buses and for new energy vehicles (NEVs). SZBG still pays mandatory liability insurance of vehicle traffic accident of 3,140 yuan, commercial vehicle insurance of 2,100 yuan every year and operation fees 804 yuan per bus. These taxes and fees are at the same rate for BEBs and diesel buses.

Discount Rate

The typical adopted discount rate in literature lies between 1 and 15 percent. To represent the opportunity cost, we used the discount rate of three percent for the baseline analysis. We conducted a sensitivity analysis to estimate the TCO change with a discount rate between 1 and 7 percent (table 6-8).

Table 6-8 Variables and range adopted in TCO literature

		Vehicle Type	Data and Methodology	Region	Discount Rate	Life year analyzed	Annual Distance
Passenger Vehicle	(Breetz and Salon, 2018)	PHEV,BEV, ICEV		14 states in the U.S.	7% for baseline, 5%, 10%, 15% for sensitivity analysis	5	Varied on average VMT (Vehicle Miles Traveled) of the states
	(Palmer et al. 2018)	PHEV,BEV, ICEV		Japan, UK, California, and Texas (U.S.)	3.5-4% for baseline, 2-11% for sensitivity analysis	3	Varied on regions, range from 6,213 to 15,641 miles
Bus	(Nurhadi, Borén, and Ny 2014)	BEB with different battery size and charging speed	Scenario analysis	Norway	1%	8	93,000 km
	(Lajunen and Lipman, 2016)	BEB, plug-in hybrid bus, CNG bus, fuel-cell bus	Simulation	California (U.S.) and Finland	4%	12	None
Bus	This study	BEB, diesel bus	Real practice data	Shenzhen, China	3% for baseline, 1-7% for sensitivity analysis	8	66,000 km

Residual Value

After their lifetime, buses are phased out from the fleet. Typically, the residual value of a diesel bus and BEB is assumed as only worth five percent of the original purchase price.

6.2.4 TCO results

Without purchase subsidy, the present value of lifetime total cost of BEB would be 2.17 million yuan, 21 percent higher than a diesel bus's total cost of 1.80 million yuan. With government subsidy, the total cost of BEB would be 1.17 million yuan, 35 percent less than that of a diesel bus (table 6-9 and figure 6-1).

Table 6-9 Present value of diesel bus and battery electric bus

	DB	BEB	BEB_subsidy
Capital (k Yuan)	529.13	1645.73	604.13
Energy (k Yuan)	885.76	418.30	418.30
Maintenance (k Yuan)	357.74	123.01	123.01
Tax and fee (k Yuan)	42.11	42.11	42.11
Residual (k Yuan)	-19.10	-59.39	-21.80
TCO Present value (k Yuan)	1795.64	2169.75	1165.74
TCO per kilometer (Yuan/km)	3.40	4.11	2.21
TCO/km to Diesel bus	100%	121%	65%

Figure 6-1 Value of the composition of the bus costs

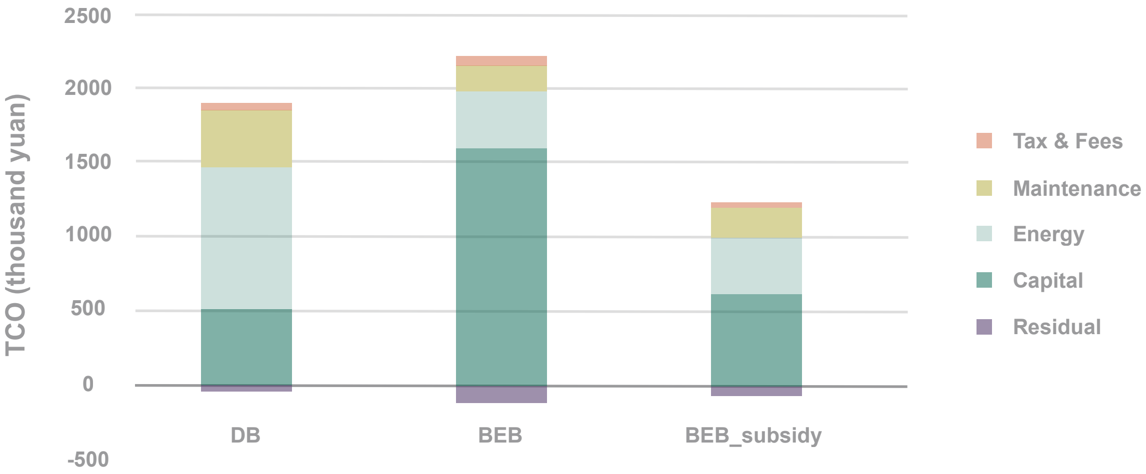


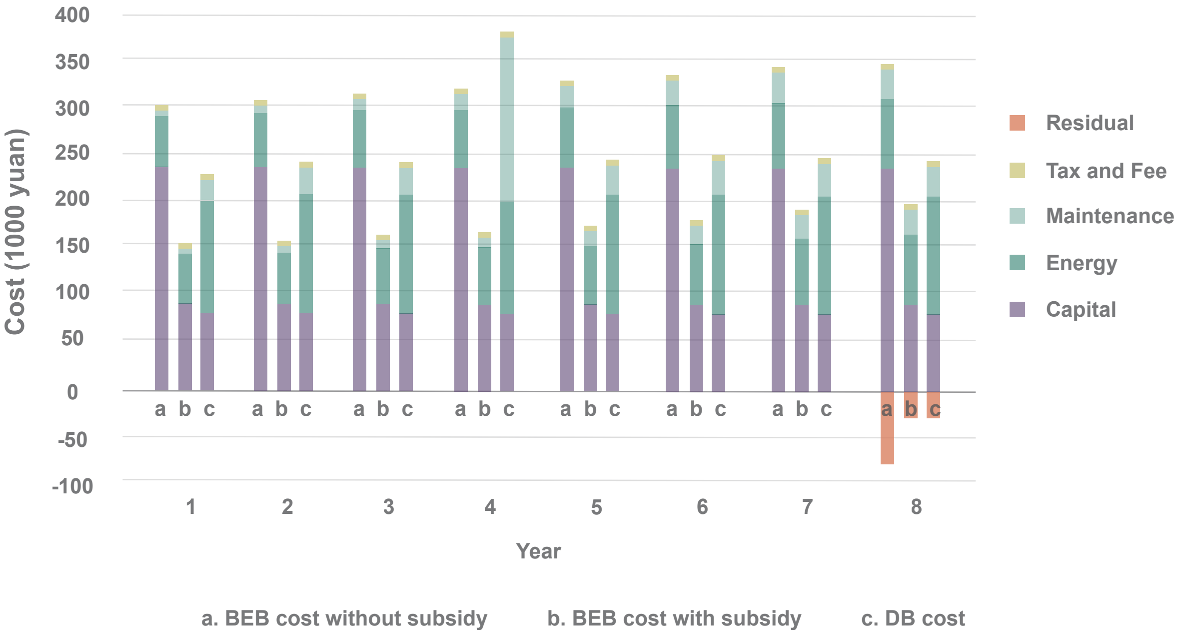
Table 6-10 TCO results compared with results from literature

Studies		Bus Setting	Original Results		Transformed Results	
This study, 2020		Diesel bus			3.40	(¥/km)
		Electric bus with purchase subsidy, without charger			2.21	(¥/km)
		Electric bus without purchase subsidy, without charger			4.11	(¥/km)
Lajunen and Lipman, 2016	Finland cycle	Diesel bus	0.75	(€/mile)	9.34	(¥/km)
		Electric bus without charger	0.95	(€/mile)	11.83	(¥/km)
		Electric bus with charger	1.05	(€/mile)	13.07	(¥/km)
	USA_CA cycle	Diesel bus	1.70	($/mile)	19.04	(¥/km)
		Electric bus without charger	2.10	($/mile)	23.52	(¥/km)
		Electric bus with charger	2.30	($/mile)	25.76	(¥/km)
Nurhadi et al., 2014		Electric bus 1 extra battery and 1 normal charger	8.44	(SKr/km)	11.56	(¥/km)
		Hybrid bus	11.23	(SKr/km)	15.39	(¥/km)

Note: Different currencies represented reflect the region of the referenced studies: €- Euro; $ - USD; SKr – Swedish Kroner; ¥ - yuan.

We compared results of Shenzhen case with other TCO results of BEB operations in Sweden, and simulated TCO with the road cycles in Finland and California (table 6-10). Our results are lower than other research results, mainly because of lower BEB prices, lower maintenance cost and exclusion of battery replacement cost in this study. The lower TCO results for DB were mainly brought by the much lower capital cost of DB in China (83,000 USD in our case) than those in the US (300,000 USD) and the EU (225,000 USD) in the literature.

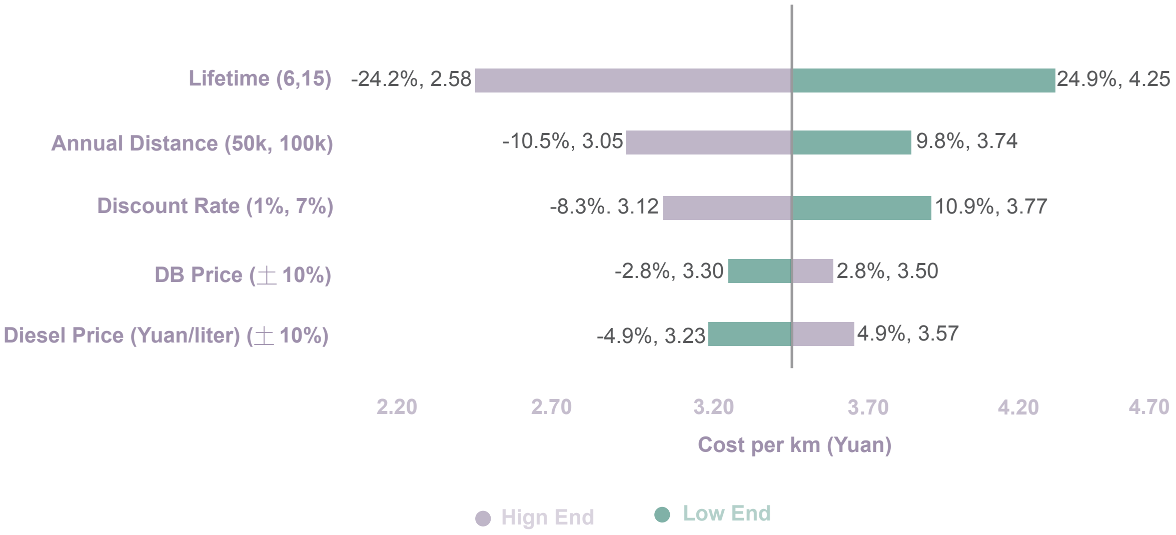
Figure 6-2 TCO results by year



Sensitivity Analysis

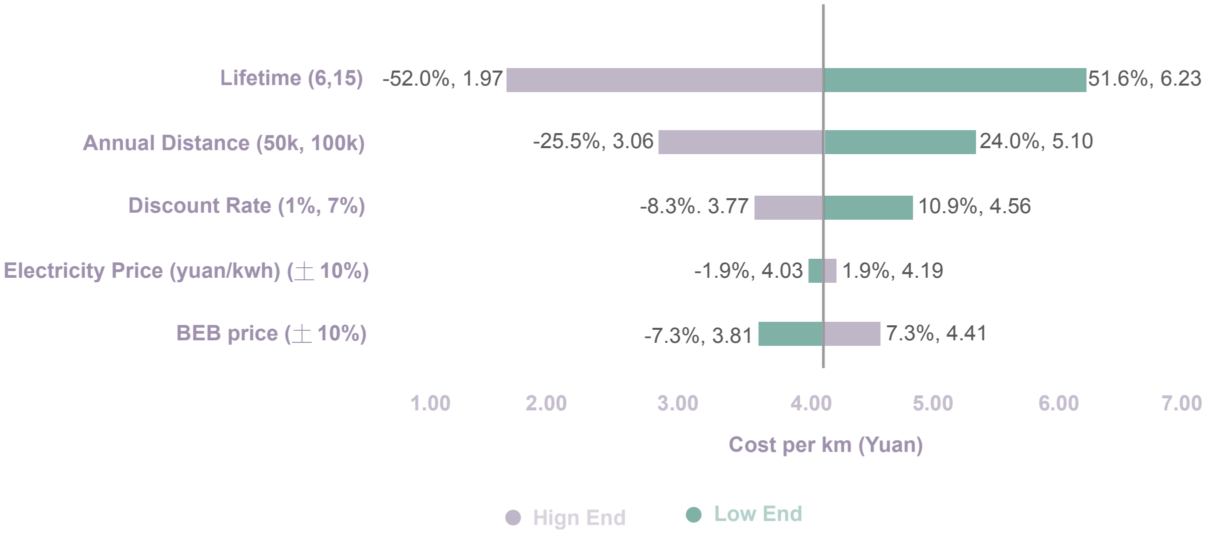
Sensitivity analysis helps diagnose the most important variables that affect the results of the TCO analysis. The tornado plots are used to present the results of the variables affecting the TCO of DB and BEB without subsidy.

Figure 6-3 Variables that affect the diesel bus TCO per kilometer



The increase of lifetime, annual driving distance and discount rate reduces the per kilometer cost of the diesel bus operation by more than ten percent. A ten percent increase in the bus price or diesel price will increase the unit cost by less than five percent. TCO per kilometer changes most significantly with different bus operation lifetimes. If the bus's lifetime decreases from eight to six years, TCO per kilometer will increase 24.9 percent to 4.25 yuan; if the lifetime extends to fifteen years, TCO per kilometer will decrease 24.2 percent to 2.58 yuan. The increase of annual driving distance reduces the share of capital costs per unit mileage. As a result, an increase in the annual operating distance to 100,000 kilometers will decrease the TCO per kilometer to 3.05 yuan, and a shorter annual distance of 50,000 kilometers will increase the TCO per kilometer to 3.74 yuan. The discount rate of one percent results in a unit TCO result of 3.77 yuan, and a seven percent discount rate reduces the TCO to 3.12 yuan per kilometer. A ten percent increase in diesel price will result in a TCO per kilometer to 3.57 yuan, while a ten percent decrease in the diesel bus price will bring the TCO per kilometer to 3.50 yuan. That happens because the energy cost constitutes 49.3 percent of TCO, much higher than that of capital cost at 29.5 percent (figure 6-3).

Figure 6-4 Variables that affect BEBs TCO per kilometer without subsidy



The BEB's TCO per kilometer results mirror similar diesel bus costs with fluctuations in the variables. An increase in the bus prices and electricity raises the TCO per kilometer, and an increase in the operating lifetime, annual driving distance and discount rate decrease the TCO per kilometer. If the operating lifetime decreases from eight years to six years, the BEB TCO per kilometer increases from 4.11 to 6.23 yuan. Extending the lifetime to fifteen years would result in the cost per kilometer decreasing by 52 percent to 1.97 yuan. Extending the annual driving distance to 100,000 kilometers would bring down the cost per kilometer by 25.5 percent to 3.06 yuan. A ten percent increase of the bus price would result in a 7.3 percent increase in the unit cost. With a discount rate of one percent, the cost per kilometer would decrease by 8.3 percent. A ten percent variation of the electricity cost would result in a 1.9 percent in the per kilometer cost (figure 6-4).

Uncertainty Analysis

We employed a Monte Carlo simulation to illustrate our uncertainty analysis to reveal the range of TCOs for the diesel bus and BEB (table 6-11). The triangular distribution is a simplified representation of normal distribution, which sets the base as the highest probability, and together with the minimum and maximum numbers, determines the shape of the variable distribution. The uniform distribution represents that the variable has an equal likelihood in our assumed range. Adopting these two types of distributions, we made assumptions for the distribution of the variables based on our analysis in the base case. By making simulations based on the variable distribution and our TCO model, we can derive the distribution of our TCO results (figure 6-5).

Table 6-11 Monte Carlo distribution settings for diesel bus and BEB

	Minimum	Base	Maximum	Distribution
Diesel price (yuan/L)	4.0	5.09	6.0	Triangular
Electricity price (yuan/kWh)	0.65	0.86	1.45	Triangular
Annual mileage (1000 km)	50	66	100	Triangular
Discount Rate	1%	4.16%	7%	Uniform
Lifetime (year)	6	8	12	Triangular
Fuel Efficiency (L/100 km)	34	37.9	42	Triangular
Energy Efficiency (kWh/100 km)	80	107	120	Triangular
Maintenance BEB or Diesel bus	20%	36%	100%	Triangular

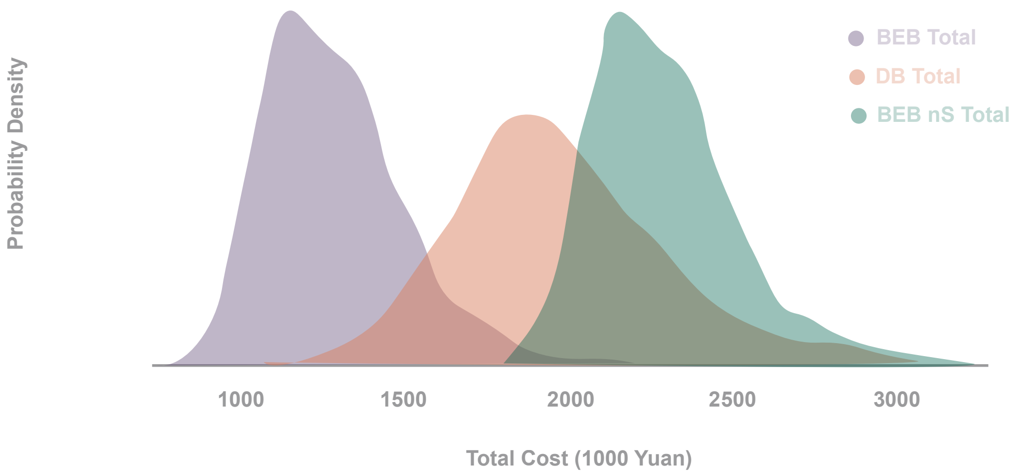
The diesel bus TCO distribution sits between the BEB TCO with and without subsidy, which echoes the results in the baseline analysis. The total cost of a diesel bus is between 1.12 and 3.15 million yuan, the cost of a BEB is between 0.75 and 2.30 million yuan with the subsidy and between 1.75 and 3.30 million yuan without the subsidy.

The energy cost and maintenance cost of the diesel bus comprise 49 percent and 20 percent of its TCO respectively, and the total distance of the bus operation over its lifetime varies accordingly with our lifetime assumptions, annual driving distance, and diesel price. As a result, the TCO of the diesel bus has a wider distribution in our Monte Carlo analysis. With a longer annual distance and longer operation lifetime (on the right side of the curves), a high probability indicates that BEB even without subsidy would have comparable or lower TCO than that of diesel buses.

The total driving distance contributes to the wider distribution of the diesel bus's TCO, while in the per kilometer analysis, the variation in the total driving distance cancels out in the differences of the unit cost. As a result, per kilometer costs for the diesel bus have lower variation compared to the total cost, but augment the fluctuations in diesel price, discount rates, and other variables (figure 6-6).

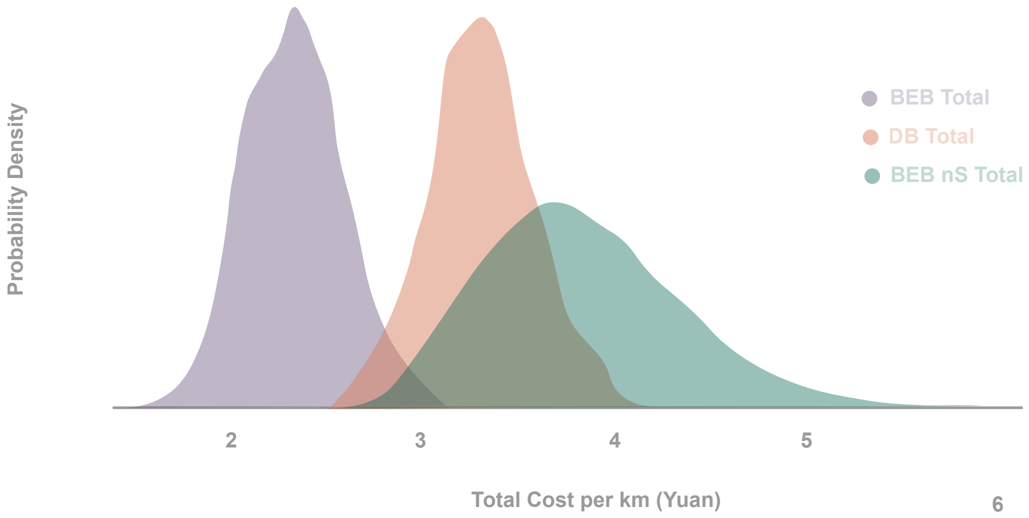
In BEB per kilometer costs, the TCO is significantly affected by assumptions regarding driving distances. As a result, the per kilometer cost of BEBs without subsidy has greater variation than those observed in the total cost. However, the Monte Carlo projection results indicate a high probability that the unit cost of BEBs without subsidy would be comparable or lower than that of the DBs.

Figure 6-5 Total cost distribution



Note: Diesel bus total refers to its TCO, BEB total refers to its TCO with subsidy, BEB nS total refers to its TCO without subsidy.

Figure 6-6 Unit cost distribution



Note: Diesel bus total refers to its TCO per kilometer, BEB total refers to its TCO per kilometer with subsidy, BEB nS total refers to its TCO per kilometer without subsidy.

1

6.3 Charging Infrastructure TCO

Before the electrification of their bus fleet, the SZBG owned two gas stations with several vehicles to provide fuel for their diesel buses. The SZBG also hired specialized staff to fuel the fleet. The charging service providers bear the cost of the construction and operation of the charging station with qualified staff, and the bus company pays only the electricity cost and service fees associated with charging for BEBs. One hundred and four charging stations with a total of 1,707 charging terminals were built to serve the BEB fleet by the end of 2018.

Our study estimates the total cost from the perspective of the charging station owner. The total cost comprises costs of construction of the charging station, the high- and low-voltage lines and devices for transmitting electricity to the charging station, the cost of chargers, land rental, operation of the charging station, and the residual value of the charging station after its service life. The revenues of the charging station owners come from the service fee that the SZBG pays.

Many factors affect the size of charging stations, such as land availability, charging demand at different locations, speed of charging terminals, and grid capability. Our study assumed a typical charging station to contain 20 charge terminals rated at 150 kilowatts and 40 bus parking spots. A BYD K8 electric bus can be fully charged over two hours at a rate of 150 kilowatts. The buses charge during off-peak hours in Shenzhen between 2300 and 0500 hours, and we assumed the serving capacity of the charging station to be 60 buses every day.

Access to land has become increasingly challenging in Shenzhen because of a combination of lack of available land and electricity capacity in the distribution grid. Any new charging station requires significant power grid infrastructure upgrades to increase its capacity. Over the period 2016–18, safety requirements of transformers became significantly more intense, which consequently increased construction costs. Previously, the charging station company could employ a simple container-type transformer that was flexible and had no requirements for housing. However, newer rules require transformers to be properly housed, necessitating both land ownership, and concrete and permanent constructed facilities.

The main stakeholders in the charging business in Shenzhen comprise utility companies, charging station manufacturers, charging service providers, and landowners. Our study used data from the SWT—a charging service provider and charger manufacturer—thereby facilitating relatively lower costs for stations' initial investment and maintenance (figure 6-7).

Figure 6-7 Liuyue charging station operated by Winline

a. (upper-left) BEB at charging dock; b.(upper right) Charging operated by professional charging staff wearing protective glove; c. (bottom) BEBs line up in charging station docks.

6.3.1 Infrastructure TCO model

Estimates of the TCO of the charging station included initial capital cost, operation cost, and residual value (equations 6-4 to 6-6).

$$Cost_{total} = Cost_{initial} + \sum_{t=0}^{T} \frac{Cost_{operation\_t}}{(1+r)^t} - \frac{ResidualValue}{(1+r)^T}$$

Equation 6-4

$$Cost_{initial} = \sum_{j} (n_{Pile_j} * Cost_{Pile_j}) + Cost_{construction} + Cost_{electricitypowerincrease}$$

Equation 6-5

In year t,

$$Cost_{operation\_t} = Cost_{LandRent} + Cost_{labor} + Cost_{maintenance} \quad \text{Equation 6-6}$$

6.3.2 Initial Investment

6.3.2.1 Construction and Grid Connection

Existing bus parking lots could be transformed into a charging lot simply by installing the chargers. A newly constructed charging station would include the construction of the pavement, office, and chargers. Advanced structures like a roof could be built to protect the buses from rain. A solar roof was constructed in some stations to charge the buses with clean electricity.

In the case of a sample charging station with 40 bus parking spots within 10,000 square meters in area, 300 square meters were allocated to the charging facilities and related building. Twenty 150 kilowatts DC fast charging terminals with 40 charging plugs were installed. The construction costs included high voltage cable and equipment, low voltage cable and hardware, charging terminals, safeguard and fire prevention devices, and other miscellaneous civil works construction expenses (table 6-12).

Table 6-12 Cost structure of a charging station construction

	Expenses (million yuan)
High-voltage cable and equipment	2.18
Low-voltage cable and equipment	1.59
Charging terminals	1.62
Safeguard and fire prevention devices	0.19
Construction expenses	2.10
Total	7.68

Often, the high voltage and electricity demands of the charging station exceed the capacity of the existing regional grid. The local grid company must upgrade the distribution network and transformers to accommodate the charging stations. In some cities, this service is a significant cost and constitutes a significant portion of the total cost (Xiong, Zhang,et al. . n.d.). In Shenzhen, the grid company upgrades the network, and the charging service providers pay for the costs.

6.3.2.2 Charging Terminals

The cost of charging terminals has been steadily decreasing over time from about 750 yuan per kilowatt in 2016 to 450 yuan per kilowatt in 2019. Since most of the charging terminals were constructed in 2016 and 2017, we assume the average cost of charging terminals is approximately 700 yuan per kilowatt.

6.3.2.3 Municipal Subsidy

The municipal government provides a subsidy for the construction of charging stations. The municipal government provided a subsidy of 300 yuan per kilowatt for DC fast-charging stations in 2016, and increased it to 600 yuan per kilowatt based on the total power of the charging station in 2017 and thereafter.

6.3.3 Operation Cost

6.3.3.1 Land Rental

Historically, SZBG experienced a shortage of bus parking lots. Before full electrification, about half of the diesel buses parked on the streets during nighttime. However, BEB require parking spaces to be built to accommodate charging during nighttime. Therefore, more bus parking lots had to be built, equipped with charging facilities to meet the demand. Typically, for each bus, an area of 12 meters multiplied by 3.5 meters is allocated, and they are spaced 0.5–0.7 meters from each other. The charging service providers and bus companies worked hard to expand parking and charging facilities. Some of the parking lots and charging stations only have temporary land-use permits by leasing instead of ownership of lands, which leads to higher risks of operation if lands were to be withdrawn by owners for other purposes.

The average monthly land rent in 2016 varied between 10–100 yuan per square meter based on their locations. Our study assumes a base rate of 30 yuan per square meter. In this case, twenty 150 kilowatts charging terminals and related housing are estimated to occupy about 300 square meters land, for which the charging service provider absorbs the cost of rent.

6.3.3.2 Labor

Unlike private electric passenger vehicles, charging is not performed by the driver but rather by specialized electricians at the bus charging stations to minimize safety risks. On average at Winline Technology, the labor allocation is approximately one-seventh to one-tenth electrician per charging terminal, working three shifts per day, and amounted to four staff members with an annual labor cost of about 288,000 yuan.

6.3.3.3 Repair and Maintenance

During our interviews, it was revealed that the repair and maintenance costs were about 3,000 yuan per charging terminal every year. The repair and maintenance costs for 20 charging terminals in this case would approximate to 60,000 yuan annually.

6.3.4 Lifetime and Residual value

Factors that affect the lifetime of the charging stations include the availability of land, the length of time to construct the charging station, and the lifetime of cables, devices, and chargers. In Shenzhen, the most challenging issue affecting the lifetime of the charging station is land availability.

Typically, the designed life of a charger is eight to ten years. Our study assumed that the charging station has permanent land availability, and that the lifetime of charging terminals is eight years. It is to be expected that after eight years of operation, the cost and the technical configuration of the charging terminals could also change substantially on account of technology evolution, and that the charging terminal devices would be replaced with zero residual value. But the cables or tunnels and transformers have a design life of about thirty years with appropriate maintenance. The residual value of the assets at year eight is estimated at 50 percent of the original capital cost.

6.3.5 TCO Results

The total cost of a charging station with 20 charging terminals of 150 kilowatts is 7.32 million yuan at a 4.16 percent discount rate. The cost of cables, initial construction, and labor costs are the largest three contributors to the total cost, followed by the cost of the charging terminals, land rental, maintenance and supporting devices (figure 6-8). The subsidy from the government canceled the charging terminal cost, which relieved the burden for the investors at the initial stages. Distributing the total costs over the 60 buses it services, the value of charging terminal cost is 122,000 yuan per bus.

Figure 6-8 Value of charging station cost components in 2019

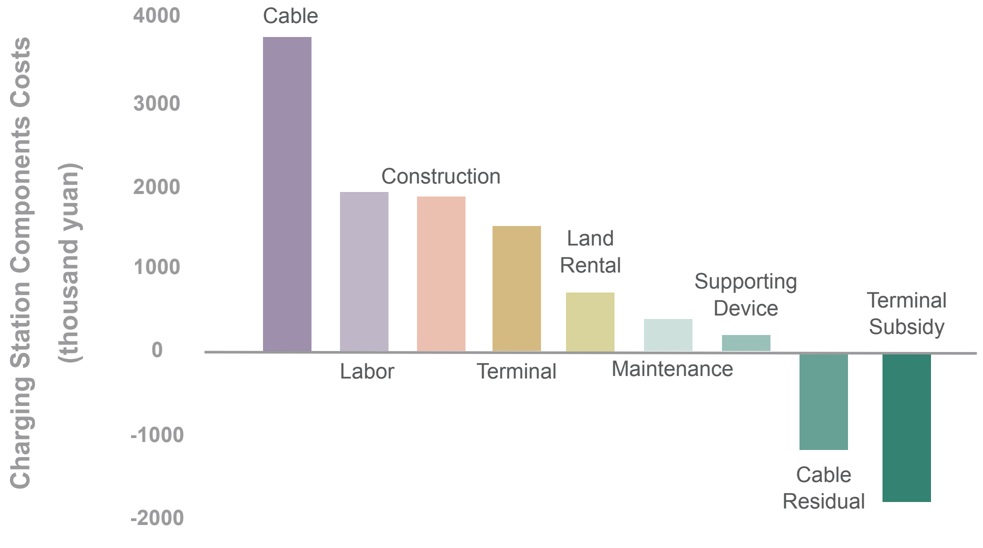
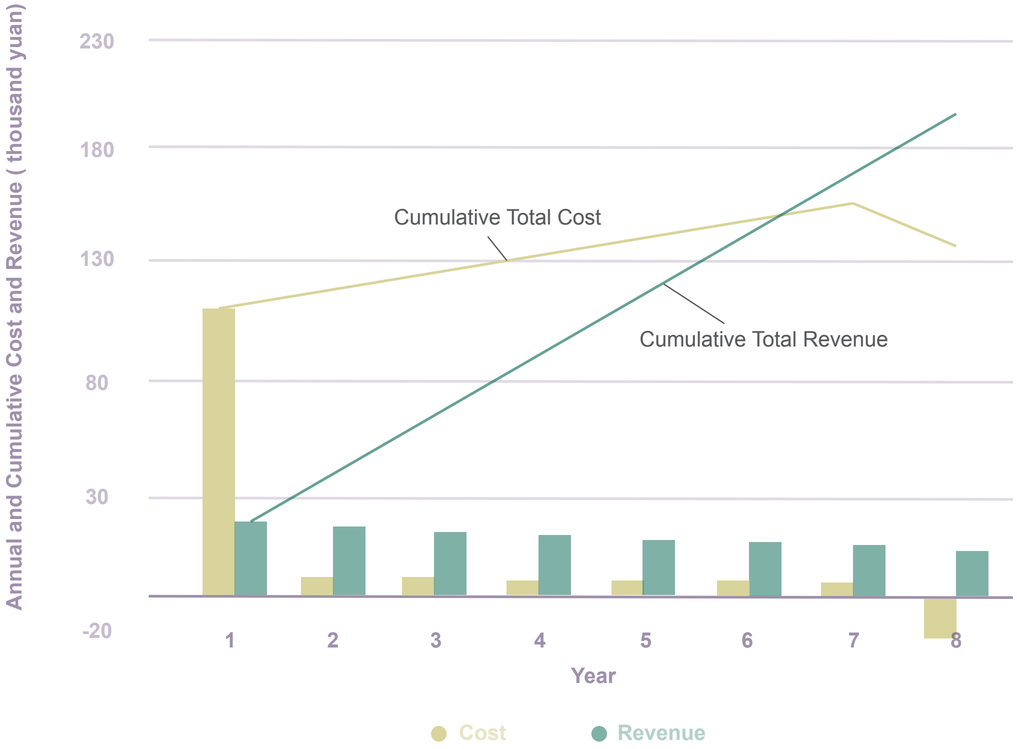


Figure 6-9 Yearly and cumulative costs and revenues for each bus charging



As noted, the charging station operator can get about 58 percent revenue return over eight years when comparing the present value of service fee per bus over eight years of 193,000 yuan. It would take six years to get back the original investment in our assumption of each charging terminal serving only three buses a day (figure 6-9).The payback period could shorten to four or five years taking the cable's residual value into account.

6.4 Discussion

In Shenzhen's massive replacement of the BEB process, government incentives and the manufacturer's full lifetime warranty played a significant role in making BEB's TCO lower than the diesel fleet for the bus operating company. The development and evolvement of BEB technology made it possible to replace the diesel bus with one-to-one ratio. With the technology development and massive production, the TCO of BEB will drop steadily in the following years, making it more comparable with the TCO of a diesel bus.

Lower energy costs and lower maintenance costs could save the transit bus operation company a great amount of money through the operation years of BEBs. With the passenger trips shifting from bus to metro service, bus routes get modified from longer commuting routes to shorter ones, serving more as feeder lines connecting the metro stations with business centers and residential communities. As a result, the annual driving distance is envisaged to decrease further for urban buses. From our analysis, a longer driving distance could improve the cost efficiency of BEBs, and we would recommend that the bus companies extend the lifetime of the buses and extend the warranty with the BEB manufactures to capture more benefits from BEBs.

The charging service providers invest heavily on the charging infrastructure. With the government subsidy at the early stage, charging service providers would need four to five years, on average, to get returns on their investment. The charging stations at bus parking lots serve only BEBs. However, with better operation arrangements, the bus charging stations can provide charging services to electric taxies, electric logistic vehicles and private EVs when a vacancy arises, to increase profits from service fees. Land availability for charging stations remains as one of the key issues in Shenzhen and requires the careful planning and implementation of land use for urban areas.

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Chapter 7

Environmental Impacts

- The life cycle GHG emission of an electric bus accounted about 52% of the emission from similar diesel bus in Shenzhen
- The lifetime GHG emission reduction of one 10.5m bus before and after electrification could reach to 274 tons CO_2
- After electrification, SBG achieved the annual GHG emission reduction about 194,000 tons CO_2 from their electric bus fleet
- Cleaner power grid can generate more reduction benefits of bus electrification

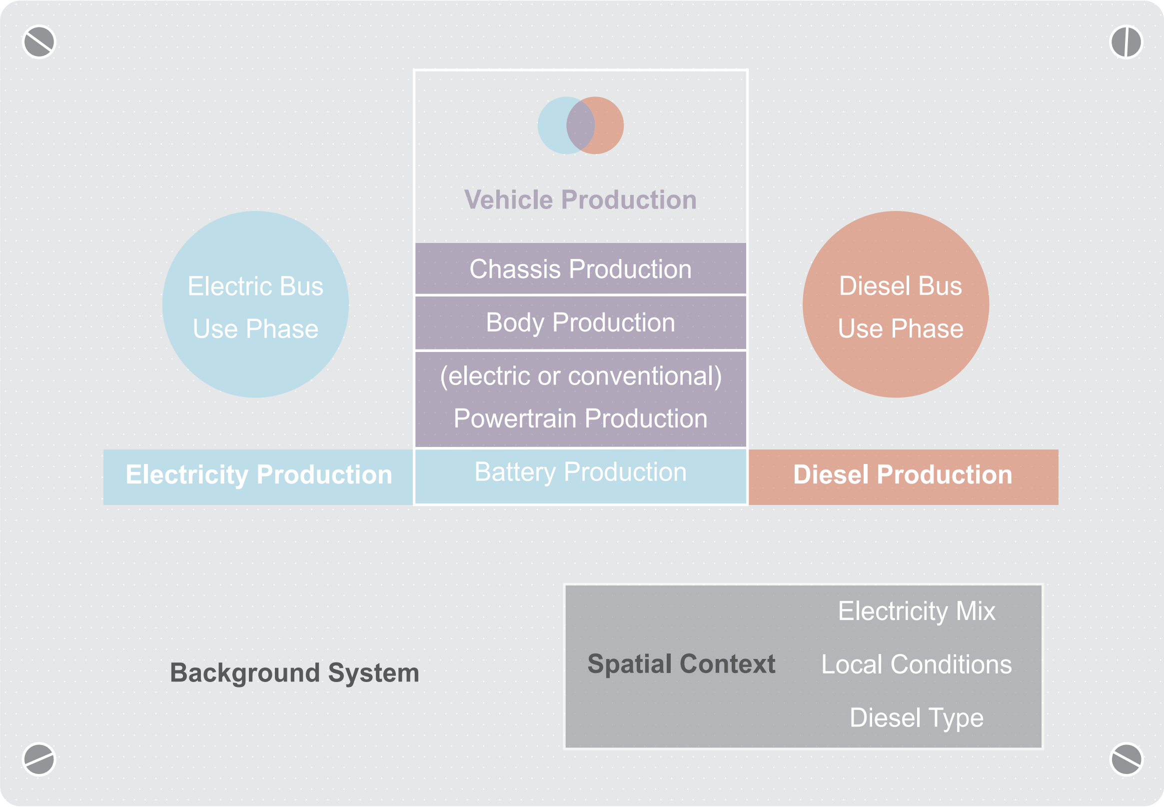
Powered by electricity, electric buses are generally considered to produce fewer emissions that contribute to climate change and local air pollution than diesel buses. However, the exact amount of these emissions depends on multiple factors including driving condition, charging behavior, and electricity mix that vary by geographic location. Our study conducted an environment analysis to complement our TCO analysis (chapter 5) to have a comprehensive view of socio-economic benefits of deploying an electric bus fleet in Shenzhen. In this study, the selected sample vehicles for electric and diesel bus are the same as used in our TCO analysis—namely BYD K8 and Yutong 10.5-meter diesel bus.

7.1 Methods

7.1.1 GHG Emission and Pollutant Emission of BEBs

Studies have shown that the operation or use phase of ICEVs accounts for approximately 83–95 percent of the total life cycle GHG emissions. (Sims et al. 2014; Ambrose and Kendall 2016; Archsmith et al. 2015; Norton and Bass 1987; Ying et al. 2018). The tailpipe emission is zero in EVs because they use electric power rather than gasoline or diesel as their energy. This shifts a greater portion of life cycle emissions to non-operation stages, that is vehicle production phase and electricity generation stage. In addition, studies show that charging EVs on different grids (Zhou et al. 2010) and different patterns of charging (Hawkins et al. 2013) can significantly alter the GHG intensity of EV operation, and present new challenges in calculating GHG emissions for electric vehicles. The charging time and location are regulated for BEBs operated in Shenzhen, which is usually full charging at night at the depot, plus one quick charging during the daytime if needed. A typical full life cycle assessment (figure 7-1) of EV incorporates vehicle and battery production phase, electricity generation, use phase, and end of life (Dér et al. 2018). In this study emissions from the end-of-life stage are excluded because of data unavailability, and because they are considered minor in comparison to production and use phase emissions. In terms of vehicle production phase, production emissions of bus body, chassis, and powertrain of both the electric and diesel bus are similar if the same size and materials are used (Nordelöf et al. 2019). The differences in emissions from vehicle production are mainly from the emissions from battery production for the electric bus, which are estimated in this report.

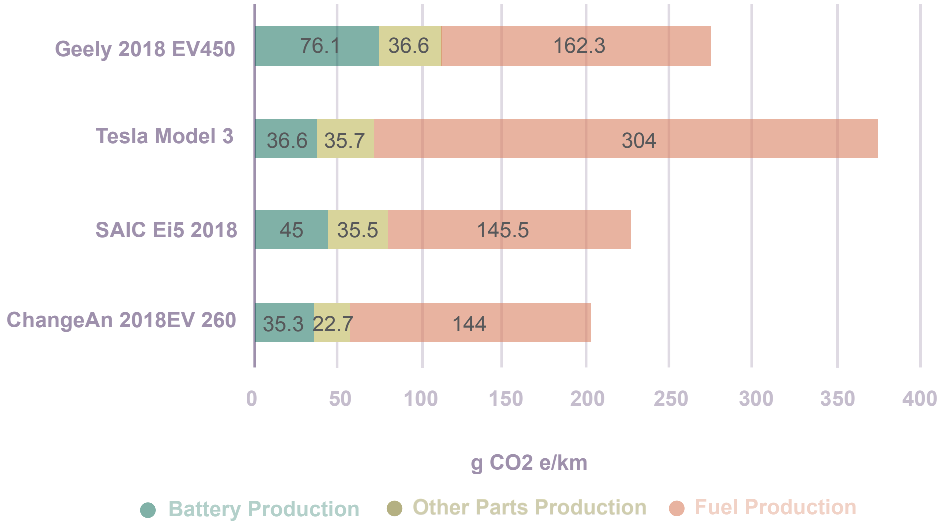
Figure 7-1 Description of comparative life cycle assessment in this study



7.1.1.1 GHG Emission from Battery Production

Emissions from battery production take a large share of the life cycle carbon dioxide emission of EVs. A recent study by China Automotive Technology and Research Center Company (CATARC 2018) details the carbon dioxide emission of top-selling EVs in China, including the production of batteries and other body parts, and EV use-phase emissions or electricity generation (figure 7-2).

Figure 7-2 Average emissions rates across 2018 PEV models in China



Note: Statistics include production of battery, other body parts, and fuel.

Compared to electric passenger vehicles, BEBs have a much larger battery pack and therefore larger battery capacity that would generate more emissions in the battery production phase, including material extraction, cell assembly, packaging, and other part production. EV battery manufacturing emissions have been studied extensively (Ambrose and Kendall 2016; Messagie 2016; Han et al. 2017; Romare and Dahllöf 2017; Wolfram and Weidmann 2017; Dunn et al. 2016) and result in a wide range of estimates. As many of these studies show, the largest share of carbon emissions in battery production comes from the mining and production of raw materials. Table 7-1 compares studies since 2016 analyzing the emissions related to EV battery production using China's grid, except for the study (Ambrose and Kendall 2016) which uses Japan's grid. These studies vary in scope and methodology and provide a range of values for greenhouse gas emissions attributable to battery production. Considering the rapid development of lithium-ion battery industry and the local power mix, this study uses battery production emission factor from the CATARC report (CATARC 2018), generated from market research in China.

Table 7-1 Studies on EV battery production GHG emission

Authors	Year	Emission for battery production (kg CO_2 e/kWh)	Battery type
Hao et al.	2017	127	$LiFePO_4$
		97	LiNiCoMn
		104	$LiMn_2O_4$
Romare and Dalhoff	2017	30–270, average 161	$LiFePO_4$
		30–270, average 161	LiNiCoMn
		50–75, average 55	$LiMn_2O_4$
Ambrose and Kendal	2016	248–258, likeliest 254	$LiFePO_4$
		246–257, likeliest 252	LiNiCoMn
CATARC	2018	207	China market average
		85	$LiFePO_4$

7.1.1.2 Emission from electricity generation

The estimation of carbon emission and other pollutants of electricity generation is complex, and varies in methodology, data and the grid mix from different energy sources. Our study calculated the emission factor using the following variables (equation 7-1).

$$P_i = \sum_{y \in M} A_{i,y} * \frac{Q_e}{\eta_{charge} * (1-\eta_{T\&D})} * e_{i,y}$$

Equation 7-1

Where:

- P_i is the annual emission of pollutant i from electricity generation
- y is the category of energy in the study area
- M is the set of electricity source in the study area
- $A_{i,y}$ is the percentage of energy y used for electricity generation in the study area
- Q_e is the electricity consumption of electric bus (kWh/100 km)
- η_{charge} is the charging efficiency
- $\eta_{T\&D}$ s the rate of energy loss during the transmission and distribution process
- $e_{i,y}$ is the emission factor for pollutant i from use of energy source y.

7.1.2 GHG Emission and Pollutant Emission of Diesel Bus

7.1.2.1 Emissions from bus driving

The most widely used research methods include simulation modeling, bench testing, tunnel experiment, and vehicle testing for ICEVs to account for diesel bus emissions (Tian et al. 2016; Sjodin and Andreasson 2000; Xie et al. 2006). In this study, we selected simulation modeling as the method for calculating emissions in diesel buses. The simulation model can be roughly categorized in two types based on driving condition or on average speed (Ma et al. 2008; Niu 2011; Zhang et al. 2011).

Our study uses an average speed model, the COPERT model, to calculate the vehicular emissions of diesel buses. The COPERT model originated from a vehicle-emission factor study carried out by the European Economic Area (EEA). Most countries of the European Union (EU) use the COPERT model to calculate vehicular emissions, and the Intergovernmental Panel on Climate Change (IPCC) also adopted the COPERT model in its guidelines revised in 2006 (Athanasiadis et al. 2009; O'Driscoll et al. 2016). Engine technology and actual operating conditions in China are comparable to those in Europe, and the tailpipe emission standards in China are also formulated with reference to standards in Europe (CAERCT. U. 2014; Fan et al. 2015; Can and Xie 2010). Thus, it is widely accepted that COPERT model is more applicable to situations in China, compared to other models like MOBILE model (Xie et al. 2006; Fan et al. 2015; Can and Xie 2010). In addition, the COPERT model requires relatively fewer input parameters, and can calculate multiple types of pollutants at the same time. Therefore, this study uses a modified COPERT model to calculate the tailpipe emissions of diesel buses.

Our study conducted an on-site survey at the SZBG headquarters in June 2019 and used the COPERT model to calculate diesel bus emissions with the following considerations:

- Our parameters of diesel buses were collected from desktop research because the unavailability of data for diesel buses that the SZBG used before bus electrification.
- Most tailpipe emission standards in China refer to the European standard system (Zhou et al. 2010; Tian et al. 2016; Sjodin and Andreasson 2000; Xie et al. 2006; Ma et al. 2008; Niu 2011; Zhang et al. 2011; Athanasiadis et al. 2009), and it is reasonable to assume that the Chinese standard, National IV, approximates to the European standard Euro IV.
- The diesel bus has a maximum load of 15 tons and complies with the National IV emission standard. The average driving speed is 20 kilometers per hour on urban roads. According to National Diesel Standard for vehicle use, the sulfur content of diesel is 0.005 percent.
- Based on information from the Shenzhen Meteorological Bureau, the average maximum temperature in the city in the past five years is 34.58°C while the lowest average is 6.02°C, and the average relative humidity is 72.2 percent.

Vehicle emissions considered in this model comprised three parts: emissions during stabilized (hot) engine operation, emissions during cold start, and fuel evaporation emissions. Therefore, the calculation model of emissions of a diesel bus per 100 kilometers can be expressed (equation 7-2).

$$E_{operation,i} = E_{hot,i} + E_{cold,i} + E_{eva,i}$$ Equation 7-2

Where:

- $E_{operation,\ i}$ is the total emission of pollutant i from diesel bus during its running of 100 kilometers
- $E_{hot,\ i}$ is the hot emission per 100 kilometers of pollutant i
- $E_{cold,\ i}$ is the cold-start emission per 100 kilometers of pollutant i
- $E_{eva,\ i}$ is the fuel evaporation emission per 100 kilometers of pollutant i
- i = 1, 2, 3, 4, 5, 6, 7 represents categories of pollutants, namely CO, NO_X, VOC, $PM_{2.5}$, PM_{10}, CO_2 and SO_2.

Our calculations did not include cold start and fuel evaporation emissions because of their small values compared to hot emissions.

7.1.2.2 GHG Emissions from Diesel Production

Our calculations considered emissions from diesel fuel production of well-to-tank for the diesel bus to ensure emissions were comparable with the electric bus for which emissions from electricity generation are included (table 7-2).

Table 7-2 Emissions from the production of diesel used in transportation

Fuel	CO_2 e (g/MJ)	Region and Year
Diesel MK 1	9.25-9.34	Sweden, 2011
Diesel EN 590	9.37-9.44	Sweden, 2011
Diesel	12.4	Spain, 2009
Diesel	9-24	Europe, 2012
Diesel EN590	14.2	Europe, 2010
Diesel	15.9	Europe, 2011
Diesel	14-17	International, 2004

The oil refinery is a complex process which involves several steps such as distillation, vacuum distillation, or steam reforming to produce a large variety of oil products such as diesel and petrol. Several studies have calculated the GHG emissions for variety of fuels, such as diesel, petrol, bitumen, and liquefied petroleum gas (LPG) (Ahlvik and Eriksson 2011; López et al. 2009; Baptista et al. 2010; Edwards et al. 2007; Lambert et al. 2012; Wang et al. 2004).

In this study, GHG emissions from diesel production take the medium value of the three European studies listed in table 6-2 (Baptista et al. 2010; Ahlvik and Eriksson 2011; Lambert et al. 2012), which is 15.8 carbon dioxide equivalent grams per megajoule.

7.1.3 Emission Reduction from Electric Bus Compared to Diesel Bus

We calculated the emission saving per 100 kilometers after the deployment of an electric bus over a diesel bus (equation 7-3).

$$R_i = E_{Dieselproduction,i} + E_{operation,i} - P_{electricitygeneration,i} - P_{battery\ production,i}$$

Equation 7-3

7.2 Emission Results

7.2.1 Emission Calculation for an Electric Bus

7.2.1.1 Emissions from Battery Production

The battery capacity for BYD K8 bus is 291.6 kilowatt-hour (kWh). According to CATARC's market research in 2017–18 (CATARC 2018), the average carbon dioxide equivalent emission of battery production of LiFePO4 is 85 kilograms carbon dioxide equivalent per kilowatt-hour (CO_{2eq} /kWh), which is the type of battery used in BYD K8. Thus, the amount of carbon dioxide equivalent emission from battery production is 24.786 tons. Batteries will be replaced every four years on average; thus, an electric bus's eight-year life cycle will use two brand new battery packages, increasing the total emissions from battery production to 49.572 tons carbon dioxide equivalent. Considering that the total mileage run by an electric bus is about 8 times 66,000 kilometers and equal to 528,000 kilometers, the average emission from battery production per 100 kilometers is about 9.39 kilograms of carbon dioxide equivalent.

7.2.1.2 Emissions from Electricity Generation

According to the 2019 Annual Report of China Electricity Industry Development (China Electricity Council 2019), the major pollutants from electricity generation include nitrogen oxide, carbon dioxide, and sulfur dioxide (NO_X, CO_2, and SO_2) which come from coal-fired power plants. Figure 7-3 shows the share of energy source in electricity generation of China Southern Grid.

Figure 7-3 Energy source for electricity generation by China Southern Grid (2018)

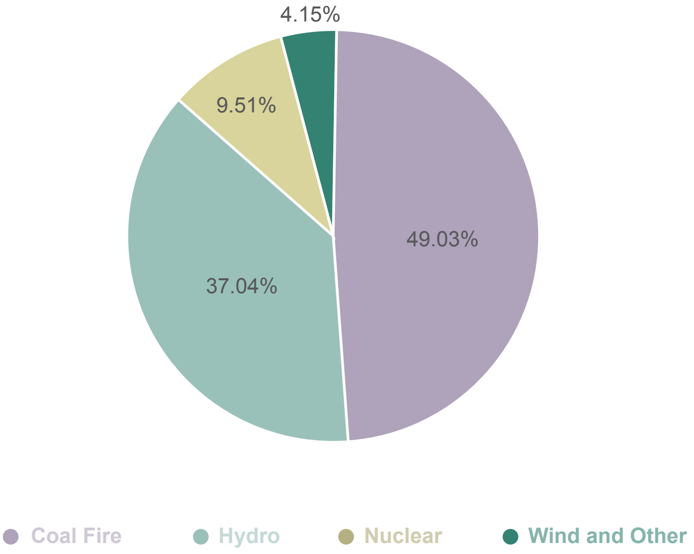


Table 7-3 Emission factors from electricity generation (g/kWh), 2018

Pollutant	Emission Factor for Coal-based Power Plant*	Emission Factor for China Southern Grid
NO_x	0.19	0.093
CO_2	841.00	412.342
SO_2	0.2	0.098

* *Data source：2019 Annual Report of China Electricity Industry*

The average electricity consumption of an electric bus per 100 kilometers (that is,) is 100 kilowatt-hour for the SZBG. According to the statistics provided by the SZBG, electricity loss during charging can be controlled within 8 percent, which means that is 92 percent. The comprehensive line loss rate of China Southern Power grid is 6.31 percent from 2018 data (China Power Industry Annual Development Report 2019). Emissions from clean energy, such as hydropower, wind, and nuclear, are relatively low, and therefore not included inTable 7-4. The table shows the emissions from electricity generation, but excludes emissions that occur further upstream for instance, coal production.

Table 7-4 Emission of an electric bus from electricity consumption (g/100km)

Pollutant	Coal-fire	Hydro power	Nuclear power	Wind	Total Pollutant
NO_x	10.81	0	0	0	10.81
CO_2	47838.42	0	0	0	47838.42
SO_2	11.38	0	0	0	11.38

The resulting GHG emissions of electric bus per 100 kilometers are calculated as in table 7-5.

Table 7-5 GHG emission of an electric bus (g/100 km)

Pollutant	Use phase emission	Electricity production	Battery production	Total GHG emission
CO_{2eq}	0	47838.42	9388.64	57227.06

Note: Calculations included emissions from battery production, fuel production and vehicle- use phase.

7.2.2 Emission Calculation of Diesel Bus

7.2.2.1 Emissions from Diesel Production

With the assumption that the energy density for diesel is 37.3 megajoules per liter, the GHG emission factor from the diesel production phase can be calculated as 589.34 carbon dioxide equivalent grams per liter (table 7-2). Data from the SZBG reporting indicate that the diesel consumption for buses is 40 liters per 100 kilometers (table 7-6).

Table 7-6 GHG emission from diesel production for one diesel bus per 100 kilometers

Pollutant	Emission factor (g/L)	Diesel consumption per 100 km (L)	Emission from diesel production (g/100 km)
CO_{2eq}	589.34	40	23573.60

7.2.2.2 Emissions from bus driving

Our study obtained emission factors for diesel buses and emissions for major pollutants for one diesel bus per 100 kilometers after inserting the value of parameters into the COPERT model (table 7-7).

Table 7-7 Emission of a diesel bus when in operation

Pollutant	Emission factor[a] (g/km)	Emissions for a diesel bus (g/100 km)
CO	1.168	116.80
NOx	5.680	568.00
VOC	0.058	5.80
$PM_{2.5}$	0.045 for PM[b]	11.00
PM_{10}	0.045 for PM[b]	17.64
CO_2	855.295	85529.50
SO_2	0.025	2.50

Note:

a. calculation from COPERT model

b. PM in COPERT model is classified as PM2.5 and PM10

GHG emissions of one diesel bus per 100 kilometers, including the emissions from fuel production phase and use phase are shown in Table 7-8.

Table 7-8 GHG emission of one diesel bus (g/100km)

Pollutant	Use phase emission	Diesel production	Total GHG emission (g/100km)
CO_{2eq}	85529.50	23573.60	109,103.10

Note: Emissions from well-to-tank diesel production, and tank-to-wheel use-phase emission included

7.3 Comparison of Results

7.3.1 GHG Emission Reduction of Electric Buses

We conducted a comprehensive comparison for GHG emission with data on carbon dioxide equivalent emission from diesel production and lithium-ion battery production (table 7-9). During the use phase, a diesel bus generates 85.5 kilograms of GHG emission per 100 kilometers while the electric bus is emission free on the road. However, the GHG emissions of an electric bus appears earlier in the production stages, in electricity generation and battery production. The results show that the average GHG emission per 100 kilometers of an electric bus is slightly more than half of the emission from a diesel bus and the emission reduction is about 51.9 kilograms of carbon dioxide per 100 kilometers.

Table 7-9 GHG emission per 100 kilometers of one diesel and one electric bus (gCO_{2eq})

Stage	Diesel	Electric bus	Emission reduction after bus electrification (gCO_{2eq}/100 km)
Use phase	85,529	0	85,529
Fuel production	23,574	47,838	-24,265
Battery production*	Not applicable	9,389	-9,389
Total	**109,103**	**57,227**	**51,876**

** Note: This is a conservative calculation, since the battery displaces engines and other powertrain parts in a conventional diesel bus for which the emissions are not included in this calculation.*

With the unit carbon dioxide equivalent reduction per 100 kilometers, the lifetime GHG emission reduction of an electric bus (BYD K8) can be calculated for an eight-year lifetime and 66,000 kilometers annual mileage. The total GHG reduction could reach about 274 tons of carbon dioxide.

BYD K8 represents about two-third of SZBG's total electric bus fleet. On the assumption that the carbon reduction of BYD K8 represents the average reduction in all models of electric bus, then the annual GHG reduction of the SZBG from bus electrification would be 194,000 tons of carbon dioxide, with a total annual bus operation mileage of 374.11 million kilometers in 2018.

7.3.2 Air Pollutant Emission Reduction

Battery electric vehicles produce zero tailpipe emissions, which specifically helps improve air quality in urban areas. Electric buses running on the road emit none of the smog-forming pollutants, such as NO_x, and other pollutants harmful to human health. In addition, strict environmental control measures enforced on power plants in China have resulted in significant reductions in the pollutant emissions from coal-based power plants (table 7-10).

Table 7-10 Comparison of emission of 100 kilometers for one diesel and one electric bus (g)

Pollutant	Diesel Bus[a]	Electric Bus[b]	Emission reduction after bus electrification
CO	116.80	0	116.80
NO_x	568.00	10.81	557.19
VOC	5.80	0	5.80
$PM_{2.5}$	11.00	0	11.00
PM_{10}	17.64	0	17.64
SO_2	2.50	11.38	-8.88

Note:

a. Analysis of diesel bus includes emission when driving.

b. Analysis of electric bus includes emission when driving (zero) and emission from electricity generation.

With the results in table 7-10 and the assumption that the total driving mileage in an eight-year lifetime is 528,000 kilometers, we calculated the lifetime emission reduction of BYD K8 and the annual emission reduction of SZBG's electric bus operations, which is the difference between a BYD K8 and a Yutong 10.5-meter diesel bus. The annual emission reduction from bus electrification is then calculated for the total number of buses in the SZBG fleet (table 7-11).

Table 7-11 Pollutant emission reduction of bus electrification

Pollutant	Lifetime emission reduction of electric bus (BYD K8) (kg)	Annual emission reduction of SZBG from bus electrification (ton)
CO	616.70	436.96
NO_x	2941.98	2084.49
VOC	30.62	21.70
$PM_{2.5}$	58.08	41.15
PM_{10}	93.11	65.97
SO_2	-46.87	-33.21

The electric bus has significantly lower life cycle emissions than a conventional diesel bus because emissions are lower for electricity generation than from burning diesel. The amount of these emissions depends on the region's electricity mix (figure 7-3). The electricity mix in Shenzhen is greener than the average China's grid mix, with renewable energy having a share of more than 50 percent. The cleaner grid in Shenzhen contributes to a larger emission reduction for the electric bus operation.

The annual emission saved from bus fleet electrification is significant, which indicates the high potential of electric buses for tackling climate change and air pollution issues. However, not all pollutants are reduced after bus electrification. Sulfur dioxide formed through the combustion of coal in electricity generation increased because of a higher density of sulfur in coal than in diesel. In this context, it is worth mentioning that diesel emissions usually occur in an urban center where a larger population is likely to be exposed, while emissions from electricity production for electric buses occur in coal power plants in less densely populated areas.

7.3.3 Comparison of Emission Reduction between Different Regions in China

Emission reduction is highly dependent on the grid mix of different regions. On average, most of the electricity in China comes from coal, which accounted for 60 percent of the electricity generation mix in 2018. However, regional disparities exist in relation to energy used. Table 7-12 shows the share of energy used in electricity generation in different regions of China. For example, China's east coast and the north region are dirtier—more than 70 percent of electricity comes from coal firepower plant—by comparison. This is partly because of geographic limitation to install wind power generators and hydropower infrastructures and the economic reason that the northeastern parts of the country have historically relied on cheaper energy sources like coal.

Table 7-12 Share of energy use in the power grid in different regions in China (2018)

	Hydro	Coal Fire	Nuclear	Wind & Solar
South Region	37.04%	49.03%	9.51%	4.15%
South West Region	12.47%	53.56%	0.00%	33.97%
Central Region	40.91%	47.47%	0.00%	11.62%
East Region	8.14%	71.45%	5.89%	14.51%
North East Region	5.60%	64.84%	3.05%	26.52%
North Region	1.99%	73.82%	0.30%	23.88%
China Avg.	18.60%	60.20%	2.40%	18.90%

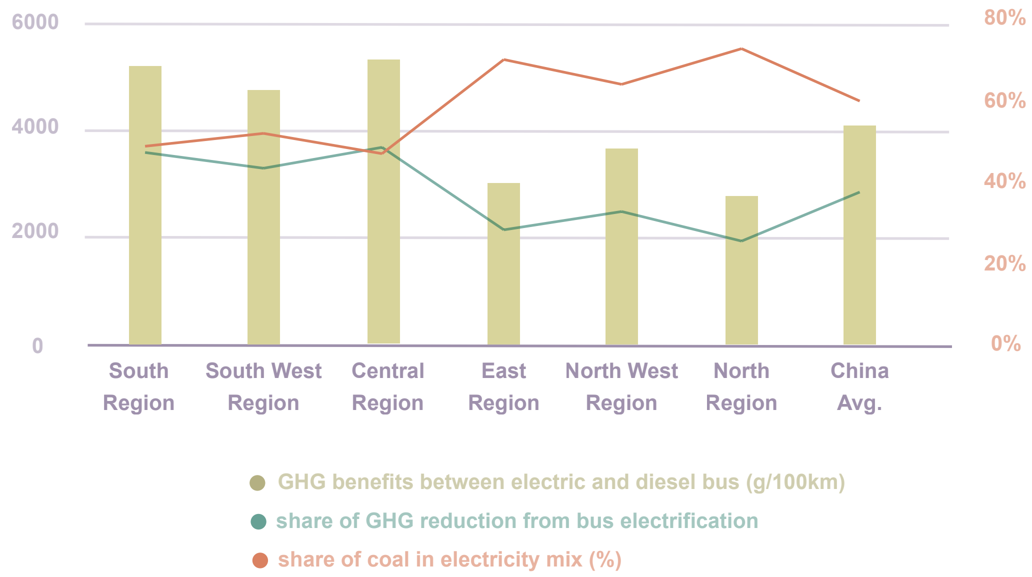
Data source: *2019 Annual Report of China Electricity Industry*

Shenzhen lies in southern China, one of the cleanest regions relative to energy generation. Thus, the power supply for an electric bus results in a larger emission reduction in Shenzhen compared to other regions in China. Table 7-13 lists the carbon dioxide equivalent emission of electric bus per 100 kilometers by different regions in China, taking the same assumption that the electricity loss during charging is eight percent, and the comprehensive line loss rate[1] is 6.31 percent.

Table 7-13 Benefits of electric bus in different regions in China

CO_{2eq}	Reduction after bus electrification (g/100km)
Electric bus (South Region)	51,876
Electric bus (South West Region)	47,451
Electric bus (Central Region)	53,399
Electric bus (East Region)	29,997
Electric bus (North East Region)	36,455
Electric bus (North Region)	27,686
Electric bus (China average)	40,978

Figure 7-4 Relationship between share of coal and benefits of bus electrification



In our study, analysis shows that bus electrification reduces a significant amount of GHG emissions, but with variations in different regions in China. On average, an electric bus in China can reduce 37.56 percent of GHG emissions compared to a diesel counterpart from a life-cycle perspective. In regions utilizing higher share of clean energy in electricity generation—that is in the central region of China—the benefits of electrifying buses can increase up to 48.94 percent., In regions with high dependence on coal for example, in the northern region, electric buses can also be used as a method to achieve cleaner transportation, with about 25 percent, of GHG reduction compared to diesel buses (figure 7-4). This finding is significant since it shows that even under a very dirty electricity mix, electric buses are still cleaner than diesel buses.

Notes

1 Loss of energy, across power lines, during the transmission of electricity.

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Chapter 8

Cost-Benefit Estimation

8.1 Introduction

Criteria air pollution (CAP) emissions from diesel bus operation and power generation can harm human health, impair visibility, and damage buildings among many other negative externalities. GHG emissions from transport accelerate global warming and its negative impacts on the planet. China's President Xi Jinping has announced at the United Nations General Assembly in 2020 that China will strengthen its 2030 climate target, peak emissions before 2030, and aims to achieve carbon neutrality before 2060. Every sector including the transport sector, which has the highest growth rate of GHG emission among all sectors in China,1 needs to take every effort both in policy guidance and technology transformation to achieve this ambitious goal. When evaluating the adoption of new technologies like battery electric buses, cost–benefit analysis helps present its social and environmental benefits making them comparable to traditional technologies that often have lower direct costs but high external costs on account of CAP and GHG emissions. When analyzing alternative technologies, the avoided emissions are benefits of the implemented environmentally friendly alternative.

The damage–cost approach adopts a multistep damage function to analyze the effects on air quality from pollutant emission, the relationship between air quality and health effects, the causality of population exposure and population characteristics, the morbidity and mortality caused by the air pollutants, and the statistical life value to monetize damage caused. As each step involves uncertainty and assumptions, cumulatively, the results show high levels of variability. Therefore, the result is usually presented with a wide range, while the high end can be very high due to high statistical life value assumptions based on local salary levels, for example.

In this study, we calculate the life cycle CAPs and GHGs emission benefits of BEB based on the cost analysis in chapter 6 and environmental assessment results from chapter 7.

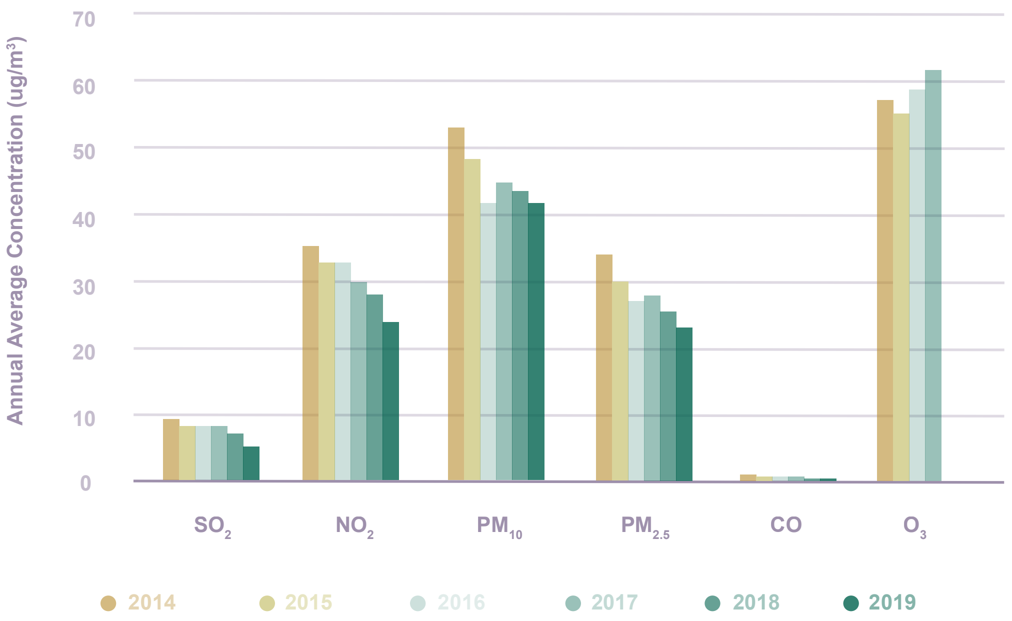
$$Cost_{environment} = Cost_{CAPs} + Cost_{GHG}$$

We include CAPs of $PM_{2.5}$, PM_{10}, NO_X, VOC, and SO_2; and GHGs of CO_2, CH_4, NO_2 in the CO_{2eq}.

8.2 CAPs and GHGs

We consider two strategies for assessing the damage costs of CAPs and GHGs. For GHGs, we adopt global GHG marginal cost in the estimation to account for its impact on climate change. CAPs valuation, on the other hand, should be based on local air quality impacts, city population characteristics, and statistical life value for residents. Shenzhen is leading Chinese cities on air quality and air emission control. The annual average pollutant concentrations in Shenzhen from 2014 to 2019 (figure 8-1), are better than most Chinese cities, and have been dropping for PM2.5, PM10, NO2, and SO2. To account for the air quality and residents' income benefits in Shenzhen, we adopted the EU's 28 countries' average damage cost for CAPs owing to the unavailability of local data.

Figure 8-1 Annual average air quality in Shenzhen during 2014-2019



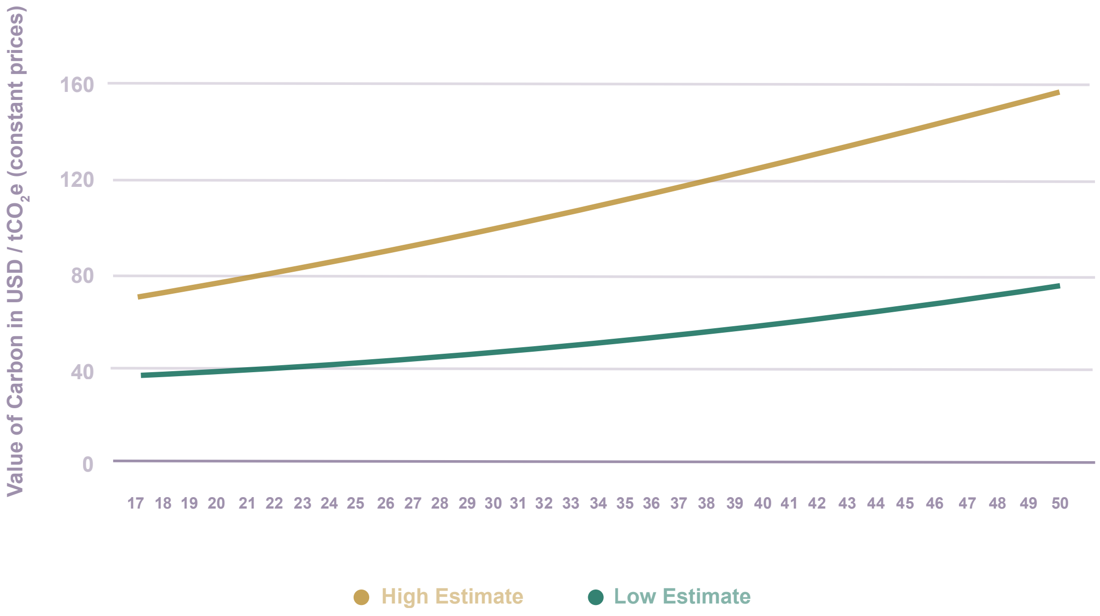
Source: Shenzhen Ecology and Environment Bureau, Shenzhen Environmental Status Bulletin 2014-2019, http://meeb.sz.gov.cn/xxgk/tjsj/ndhjzkgb/

Note: The O3 statistic record changed from annual average concentration to 90 percentile concentration in and after 2017 and is not included here.

Based on analysis from the IPCC, the UNFCCC Paris Agreement states that world temperature should not increase by more than 2 degrees Celsius in 2100 compared to the pre-industrial levels and strong efforts should be made to stay within 1.5 degrees Celsius. China is a signatory to the Paris Agreement and has committed to reduce its GHG emissions. Shenzhen is one of the seven pilots for carbon trading markets in China. The trading price of carbon on the Shenzhen market in 2019 was 20–30 yuan per ton (USD 2.86–4.29/ton) (Slater et al. 2019), much lower than the amount from the US and the EU.

The GHG emissions are global externalities and the market prices mentioned above are not high enough to achieve the goals of the Paris Agreement. In order to capture social benefits from reduced GHG emissions or costs from increased emissions in economic analysis, the shadow price of carbon is adopted in GHG accounting in World Bank financed projects.2 Instead of a central estimate, a range of values is used to justify the uncertainty and the need to consider the country context. From 2017 to 2050, the lower value of shadow price of carbon ranges from USD 37 to 78 per ton carbon dioxide equivalent and the higher value from USD 75 to 156 per ton carbon dioxide equivalent (figure 8-2).

Figure 8-2 Shadow price of carbon in USD per 1 metric ton of CO2 equivalent (constant prices)



Year	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Low	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	55	56	57	58	60	61	63	64	65	67	68	70	71	73	75	76	78
High	75	77	78	80	82	84	86	87	89	91	94	96	98	100	102	105	107	109	112	114	117	120	122	125	128	131	134	137	140	143	146	149	153	156

8.3 Marginal Cost for Damage Estimation

The CAP estimation should ideally be based on local data. However, environmental cost data available for Shenzhen or Guangdong area are either focus on or cover only one or several specific pollutants (Zhang and Duan 2003; D. Huang, Xu, and Zhang 2012) (Li et al. 2019; Duan et al. 2019). Considering that the economy, air quality, and fleet composition of Shenzhen are similar to European cities (Sun et al. 2014), and that the European Commission (CE Delft 2019; Schroten et al., 2019) cost factor data are comprehensive reflecting all relevant environmental impacts including health effects, crop loss, biodiversity loss, and material damage, we used the EU 28 average cost factor for the transport sector for the CAP externality estimation as an approximation (table 8-1).

We adopted the values for the price of carbon for 2017 to 2024 (table 8-2) from the World Bank Shadow Price of Carbon Guidance Note for the eight-year life cycle of BEB.

Table 8-1 CAP cost from EU 28

Unit	NO_X	VOC	$PM_{2.5}$	PM_{10}	SO_2
USD/ton	23856	1344	426720	24976	12208

Table 8-2 Shadow price of carbon (USD/tCO_{2eq})

Year	2017	2018	2019	2020	2021	2022	2023	2024
Low	37	38	39	40	41	42	43	44
High	75	77	78	80	82	84	86	87

8.4 Emissions and Benefits

We concluded the environmental damages from CAP as calculated in chapter 7 and GHG over eight years from BEB and DB (table 8-3, table 8-4, and figure 8-3).

Table 8-3 Estimated economic benefits from air pollutant emissions reduction for the bus fleet

Pollutant	NO_X	VOC	$PM_{2.5}$	PM_{10}	SO_2
Diesel bus (ton/year)	0.375	0.004	0.007	0.012	0.002
Electric bus (ton/year)	0.007	0.000	0.000	0.000	0.008
Difference (ton/year)	0.368	0.004	0.007	0.012	-0.006
USD per year	8772.9	5.1	3098.0	290.8	-71.5
USD per 8 years (i.e. life cycle) (with discount rate of 3%)	61118.6	35.8	21582.8	2025.8	-498.5

Table 8-4 Estimated economic benefits from the reduction of GHG emissions from the bus fleet

Year	2017	2018	2019	2020	2021	2022	2023	2024
Low	1267	1301	1335	1370	1404	1438	1472	1506
High	2568	2636	2671	2739	2808	2876	2944	2979
Average (USD)	1917	1969	2003	2054	2106	2157	2208	2243
USD per 8 years (i.e. life cycle) (with discount rate of 3%)	14434							

Figure 8-3 Bus operation pollution damage from DB and BEB

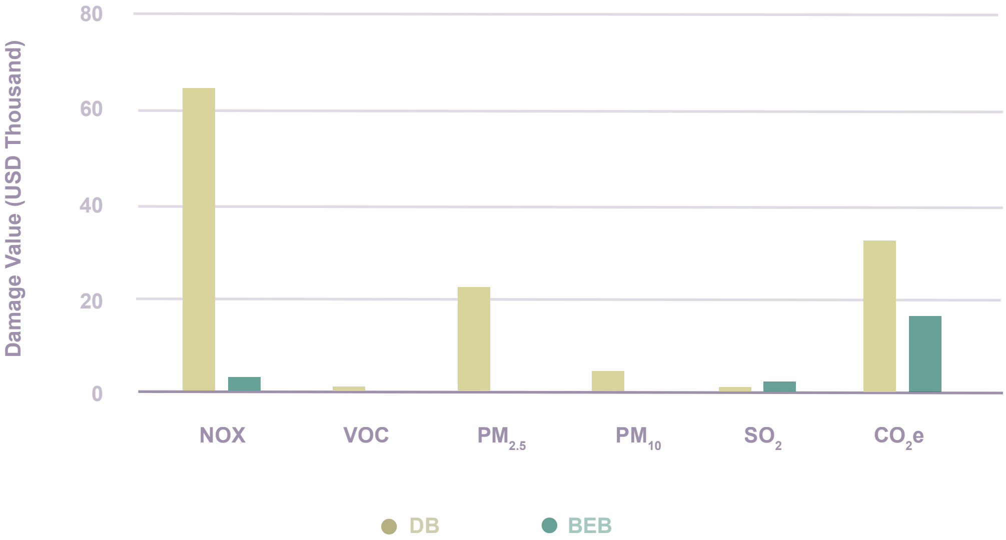
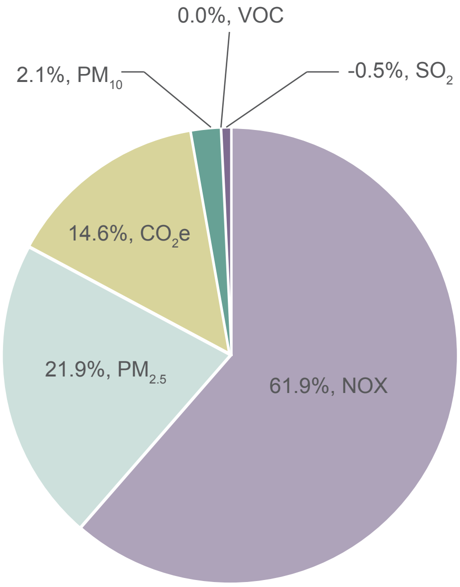
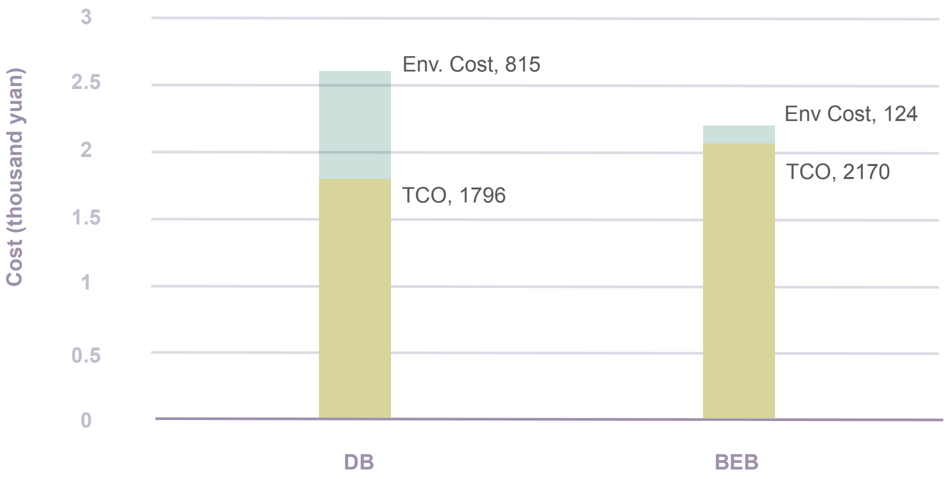


Figure 8-4 Economic benefits from BEB avoided CAPs and GHGs in 8 years



We assume the environmental benefits of BEB deployment as the avoided damage from DB pollution. This results in a total environmental benefit of one BEB over a lifetime of eight years over one DB of USD 98,699 of which 61.9 percent is from NOx reduction, 21.9 percent from PM2.5 abatement, and 14.6 percent from GHG emission reduction (figure 8-4).

Figure 8-5 TCO and environmental cost of DB and BEB



Note: Environmental cost is abbreviated "Env. Cost" in figure.

The total cost of operating with DB including the environmental costs would be higher than that of BEB (figure 8-5)—demonstrating the high economic benefits of fleet electrification.

The total subsidy that the SZBG received from the national and local governments for one bus was one million CNY (equivalent to about USD 0.15 million) in 2016. The benefits from CAPs and GHGs are 30 percent less than the subsidy. Government incentives in 2016 exceeded the environmental benefits with our conservative assessment, and the lowered subsidy in 2017 matched the benefits. However, at the introductory stage of the new technology, a lower subsidy may not be enough to stimulate the manufactures to invest in the uncertain industry. A higher subsidy is necessary to jump start a new technology, and it can later be reduced once the technology gets more competitive.

8.5 Discussion

Cost–benefit analysis provides a critical reference for designing and adopting effective emission reduction policies, and to account for the negative externalities from the fossil fuel consumption. We estimated the environmental benefits of the replacement by comparing BEB with DB on the CAP and GHG benefits. Our result shows that air emission reduction benefits from the adoption of BEB in SZBG are about 70 percent of the government subsidy.

As with our cost analysis, we kept the same mileage, the number of buses, and passengers transported before and after electrification. However, in practice, the numbers vary on the operation. The transit bus lines were restructured to accommodate the operation and charging schedules; the number of passengers and distance of passenger travels was also affected by the operation of the city subway system and other transportation modes. We evaluated the comparison of the same activity of DB and BEB on a one-to-one ratio. When other cities consider adopting BEBs, the cost and benefit differences caused by the fleet number and operation structure adjustment should be factored in.

The monetized benefit from air pollutants emission is equal to about 70 percent of the subsidy from the governments. The benefit supports the subsidies for incentivizing the transit fleet electrification. The benefit estimation is conservative since we did not include other benefits, such as noise reduction, passenger and driver comfortability improvement, grid stability improvement, easier data collection to improve bus operation, fleet management, and monitoring. We are confident with the results that transit bus fleet electrification brings significant economic benefits to local residents.

Notes

1 Data from National Center for Climate Change Strategy and International Cooperation http://www.ncsc.org.cn/yjcg/fxgc/201801/P020180920510030806443.pdf

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Part III
Key Findings:

Total Cost of Ownership of Electric Buses

In the case of the SZBG, government subsidies and the manufacturer's full lifetime warranty played a significant role in making the electric buses' total cost of ownership (TCO) lower than the diesel fleet for the bus operating company. The TCO is 36 percent lower for BEBs than for DBs; a promising and great statistic due to the lower energy and maintenance cost of the BEBs. However, if the subsidies are excluded, the TCO of BEBs is 21 percent higher than DBs.

Driving distance and operating lifetime are the two major factors that could improve the TCO of battery electric buses without subsidies. Extending the bus lifetime to fifteen years—as is common practice in many countries around the world—would result in the cost per kilometer for electric buses decreasing by 25 percent. Likewise, increasing the annual driving distance from 66,000 to 100,000 kilometers would reduce the cost per kilometer by 18 percent. We, therefore, recommend that bus companies extend the lifetime of the buses and extend the warranty with the BEB manufactures to capture more benefits for BEBs, and take advantage of the longer potential lifetime of BEBs due to better technology.

Charging Infrastructure

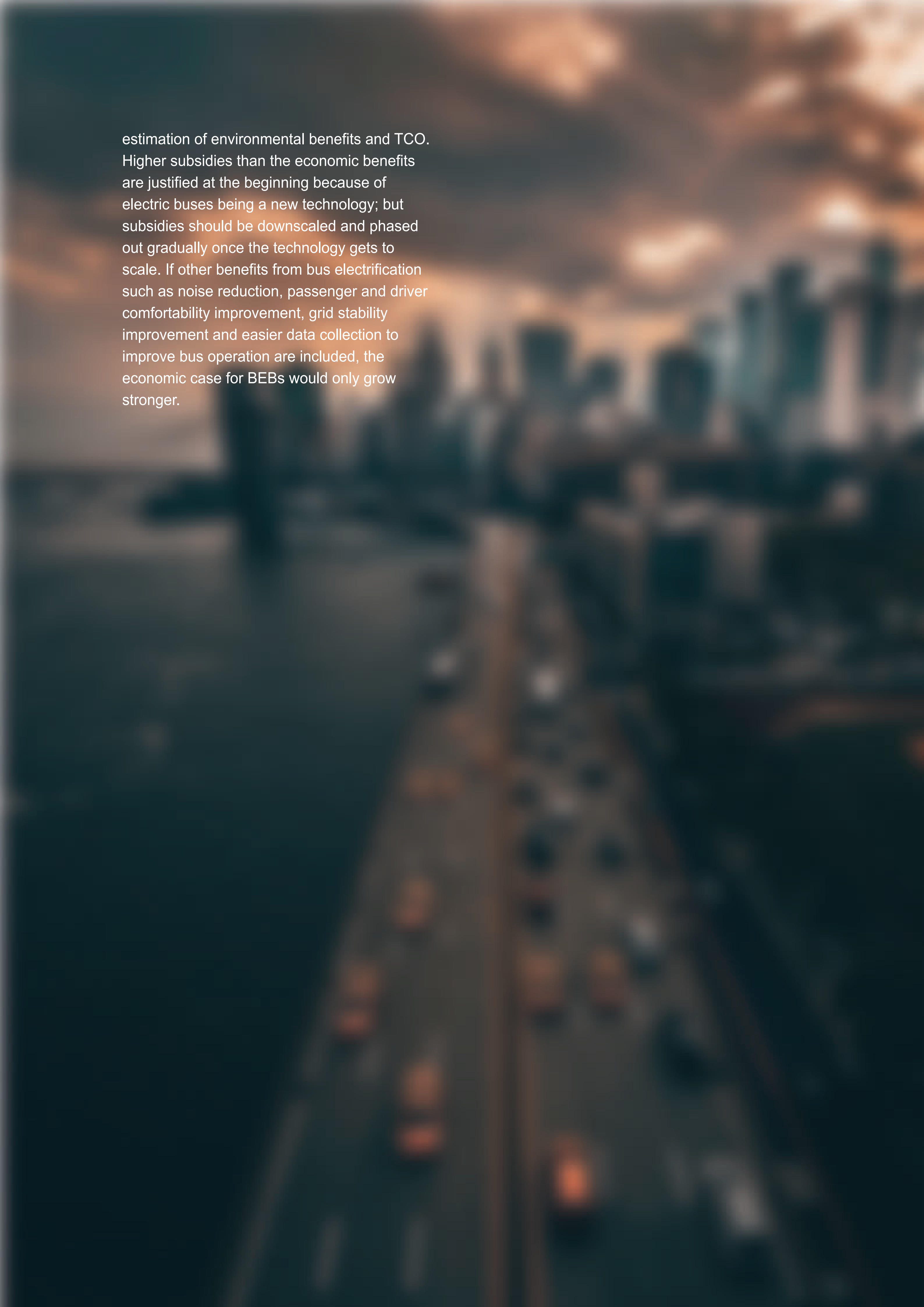
The average cost for charging infrastructure is 121,000 yuan per bus. As with the bus subsidies, government subsidies for charging stations make it a profitable business. On average, a charging station operator can break even in about five years, considering only bus charging. If the charging station operator broadens its business to provide charging for other vehicles and ancillary services, the business could become profitable sooner or without subsidies. Land availability for the installation of charging stations remains one of the key issues in Shenzhen and requires the careful planning and negotiation with the municipality. This should not be an afterthought but a key consideration during the planning phase to avoid delays and service disruptions.

Environmental Benefits of Electric Buses

Electric buses have a high emission reduction potential for greenhouse gases as well as for air pollutants. The life cycle GHG emission of an electric bus is only about half of the emission from a similar diesel bus in Shenzhen. The SZBG reduces about 194,000 tons of carbon dioxide equivalent per year because it has electrified its bus fleet. In addition, the emissions of CO, VOC, $PM_{2.5}$ and PM_{10} are zero for electric buses. The only air pollutant that is higher for BEBs is sulfur dioxide, formed through the combustion of coal in electricity generation. While a cleaner power grid will generate higher environmental benefits even under a scenario of a grid mix with over 70 percent electricity from coal, electric buses still compare favorably with diesel buses in GHG and CAP emissions.

Cost-Benefit Analysis

We observe that subsidizing electric buses provides strong economic benefits while at the same time making technology financially viable for the bus operator, taking the results from the



estimation of environmental benefits and TCO. Higher subsidies than the economic benefits are justified at the beginning because of electric buses being a new technology; but subsidies should be downscaled and phased out gradually once the technology gets to scale. If other benefits from bus electrification such as noise reduction, passenger and driver comfortability improvement, grid stability improvement and easier data collection to improve bus operation are included, the economic case for BEBs would only grow stronger.