Case Study: Electric buses in Shenzhen, China

Berlin, A., Zhang, X., Chen, Y. (2020) (with ESMAP support)[1]

1. Introduction

Shenzhen has the world's first and largest fully electric bus and taxi fleets. Its electrification journey offers a valuable opportunity to understand the challenges and opportunities of transitioning to a completely new technology for public transit. Based on a comprehensive study undertaken by the World Bank, Shenzhen Bus Group Co. Ltd. (referred as SZBG), UC Davis and China Development Institute, this case study outlines the main aspects of the full transition to electric buses of SZBG, one of the three major operators in Shenzhen.

Shenzhen is located in the southeast of China, adjacent to Hong Kong. It has a subtropical climate with average temperature of 23 ℃ and annual precipitation of 1935.8 mm. In 1978, Shenzhen was designated as an economic special district, allowing for flexible local regulations and market-oriented strategies. With a population of 12.13 million, an area of 1991 square kilometers[2], and GDP of ￥2.42 trillion (approx. US$356 billion) in 2018[3] , Shenzhen is one of most developed cities in China.

Public transportation in Shenzhen is mostly served by buses, metro and taxis with their respective shares shown in Figure 1. Due to the rapid development of the metro system, the bus ridership dropped from 2.2 billion in 2013 to 1.6 billion in 2018. SZBG operates about 1/3 of the city's total bus routes, buses, and takes 40% of annual bus passenger trips in 2018. Its ridership decreased on an average of 8% from 2013 to 2018. This trend was reversed after the full electrification of the bus fleet in 2017, with an increase in ridership of 2.4%. How much of this increase in ridership is due to the electrification is unclear, as SZBG also introduced more flexible routes to connect suburban communities and metro stations as well as on-demand services that can be ordered through a mobile application.

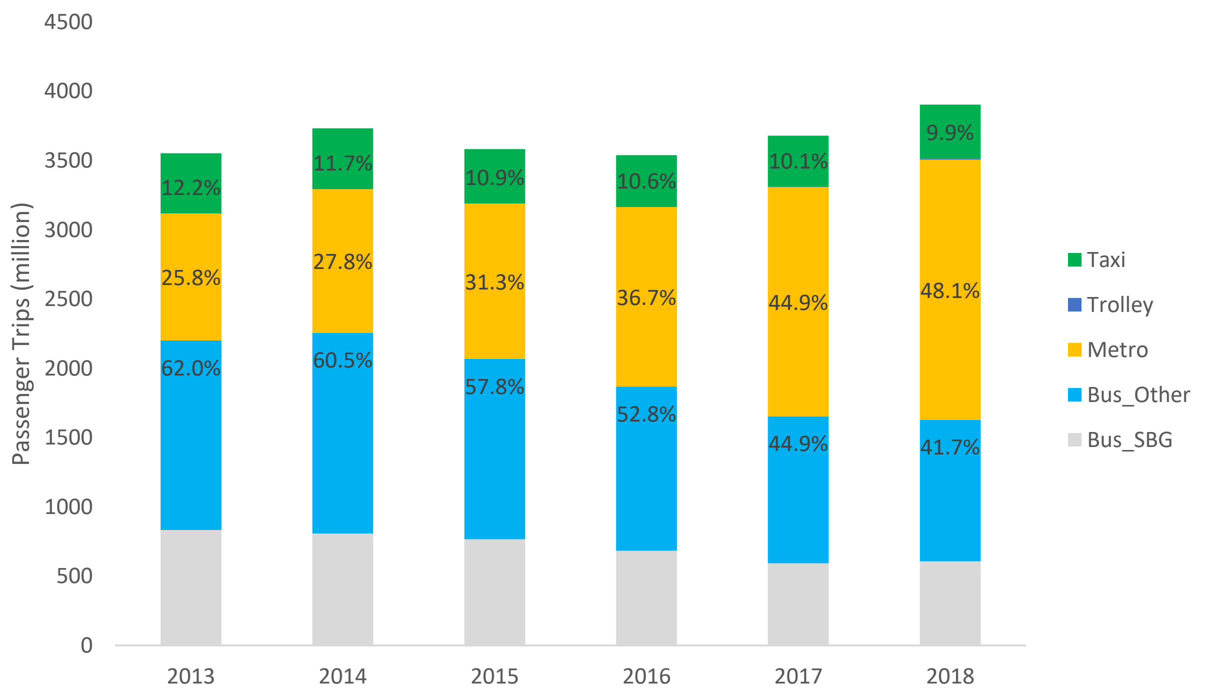

Figure 1 Transit transportation trips composition in Shenzhen (Data source: SZBG annual report 2014-2018)

[1] Case Study: Electric buses in Shenzhen, China; extracted from World Bank, Shenzhen Bus Group, UC Davis, China Development Institute (forthcoming): The Electrification of Public Transport – a Case Study of Shenzhen Bus Group.
[2] http://worldpopulationreview.com/world-cities/shenzhen-population/
[3] https://www.chinadaily.com.cn/a/201902/28/WS5c7720fda3106c65c34ebd70.html

2. Technical implementation

By the end of 2017, all urban buses in Shenzhen, around 17 thousand buses, are electrified. SZBG's fleet of 6,053 electric buses is composed of 4,964 heavy-duty and 1,089 medium-duty (shorter than 10 meters) buses. Heavy-duty buses run for eight years on average, while medium-duty buses run for five years with an average yearly driving distance of 66,000km. SZBG electrified its whole bus fleet from 2009 to 2017: a demonstration stage in 2009-2011, followed by small pilots from 2012-2015, and a large-scale electrification from 2016-2017 (Figure 2). The buses were procured from three manufactures: BYD (79.1%), Nanjing Golden Dragon (17.0%) and Wuzhoulong (3.9%) (Figure 3).

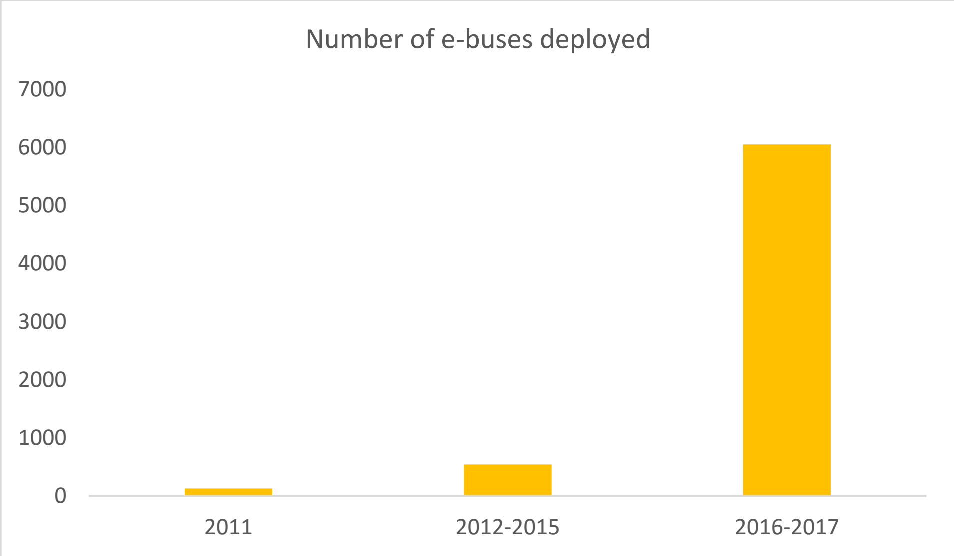

Figure 2 Three Phases of Electrification of SZBG

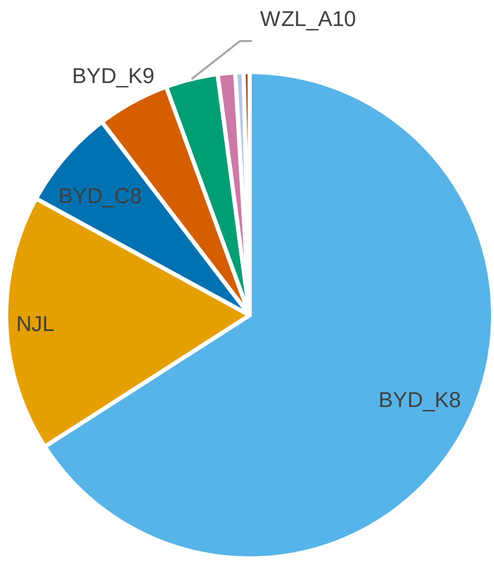

Figure 3 E-bus models SZBG

Buses. Aiming for large-scale adoption in a very short time, SZBG decided to choose a model that would require minimal changes to the current bus routes and scheduling. Unlike other cities that tested different e-bus technologies, Shenzhen stuck to a single, proven vehicle technology – electric buses with a large battery – to achieve the daily mileage its operation requires. Shenzhen's e-buses are dominated by BYD's K8 bus (66% of the fleet as shown in Figure 3), which is 10.5-meters long with a theoretical 250km battery range, featured by 2 hour direct-current fast charging (or 4-5 hour alternating-current slow charging) (Figure 4). With an average daily operation distance of 190km, these buses can run the whole day and only need recharging at night for most routes.

Figure 4 Dominant bus model BYD K8

Table 1 Specification of different bus models used by SZBG

Model	Sub-Model	Capacity (kWh)	Voltage (V)	Length (mm)	Width (mm)	Height (mm)	Power Output (kW)	Passenger Capacity
C8	C8A	290.08	518	10490	2500	3520	180*2[4]	24-44[5]
	C8B	255.74	473.6	10490	2500	3520	180*2	24-46
K8	K8	291.6	540	10490	2500	3150	90*2	87/30-39[6]
	K8S	331.56	614	10200	2500	4200	100*2	72/14-62
	K8S	253.44	422.4	10200	2500	4200	100*2	77/14-62

Charging. By June 2019, SZBG had 1707 charging terminals at 104 stations (mostly at bus terminals and depots). The charging facilities are constructed and managed by nine operators. A state-owned enterprise, Potevio and a private company Winline, are the major two operators with a share of 35% and 33%, respectively. The majority of the charging terminals are equipped with 150kw (50%) and 180kw (19%) 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 location of the charging station, number of buses to be served, space requirements and other factors.

On most of the routes the range of the bus is longer than the daily operating distance, so buses get charged at nighttime when they are not running. However, some of the buses running on longer routes need to get recharged for about 30 minutes during the day. All routes have charging stations at both bus terminals. Overall, there is one charger for every five buses, while the targeted charger-bus ratio is 1:4.

In 2016, SZBG piloted the 'network charging concept' with compact design of one charging terminal having several charging plugs/chargers so that up to four buses can charge at the same time (see Figure 5). If for example 4 buses are charged at the same time, each bus receives ¼ of the power output, increasing the average charging time per bus from 2hs to 6hs. Although it takes longer time to charge, the advantage of this arrangement is that it

[4] Power output per motor, multiplied by 2 motors
[5] BYD C8 model is an all-sit bus type with customized seat capacity between 24 and 44.
[6] BYD K8 seat number of 87/30-39 means, 30-39 seats, with total passenger capacity (including standing passengers) of 87.

significantly reduced the need to move buses at nighttime, which saves labor cost. A more flexible charging concept was later introduced with the charging terminal adjusting the power output of each charger to maximize efficiency.

Figure 5 Charging terminal with four chargers

Total cost of ownership. The government mandate to completely shift to clean energy buses, accompanied by generous national and local government subsidies supported the fast and full electrification of the bus fleet in Shenzhen by significantly lowering the upfront cost. In 2015, the national subsidy was 500,000 RMB per bus for buses of over 10 meters. This subsidy was matched by the local government of Shenzhen for local e-bus purchase during and before 2016. Subsidies were directly paid to the bus manufacturers. Without the purchase subsidy, the present value of the total cost of ownership of an electric bus would be 2.02 million RMB, 21% higher than that of a diesel bus (1.67 million RMB). With the government subsidy, the total cost of ownership of the electric bus (BEB) is 1.07 million RMB, 36% less than that of a diesel bus (DB) (see Figure 6).

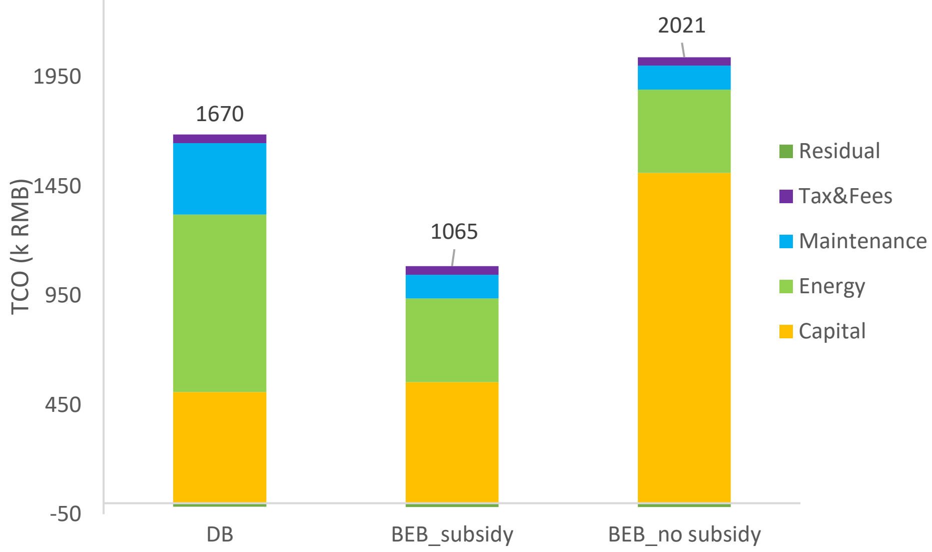

Figure 6 Total cost of ownership result for Diesel and electric buses in a with and without subsidy scenario over the bus lifetime of 8 years.[7]

[7] The TCO for electric buses is based on the BYD K8 and includes the cost of the charger as the charging fee in the energy cost (electricity + service fee) which is paid by SZBG to the charging company.

SZBG does not own or operate the charging infrastructure but pays charging service fee to the charging service provider who constructs the charging infrastructure (including charging terminals, transformers and other charging related facilities) and provides charging services (including hiring technicians to perform daily charging and maintenance). This arrangement turns 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.

From the charging service provider's perspective, the business model is viable since the investment in bus charging stations breaks even in five to six years, with government subsidies included. The Shenzhen municipal government adopted a strategy (so called "Shenzhen Blue Plan") that provided subsidies for charging station construction. For DC fast charging, every charger received a subsidy of 600 RMB/kW. AC charging facilities with power rates exceeding 40 kW received a subsidy of 300 RMB/kW whereas AC charging facilities rated less than 40 kW received a subsidy of 200 RMB/kW. Land availability is the bottleneck for building charging infrastructure as SZBG did not have sufficient parking space for all buses at depots and terminals before the electrification. From 2016 through 2017, the local government provided a simplified and fast process for all land use applications and approvals for charging infrastructure construction.

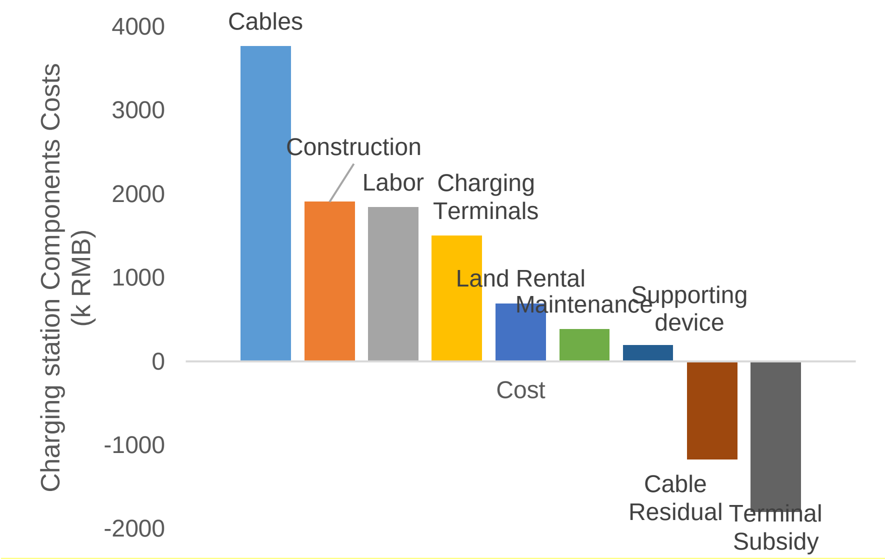

Figure 7 Present Value of Charging Station Cost Components 2019

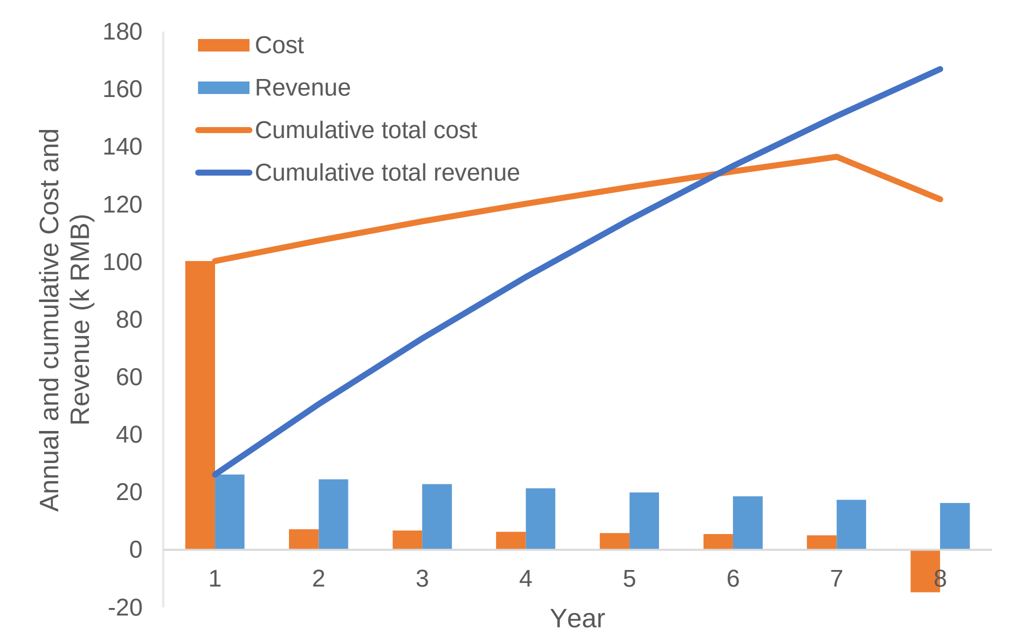

Figure 8 Annual and Cumulative Costs and Revenues for Bus Charging

3. Institutional implementation

Fostering the shared responsibilities among vehicle manufacturers, charging service providers, and bus operators, and assigning the risks (and costs) to the appropriate party as outlined in Figure 8 was crucial to the success of SZBG's electrification.

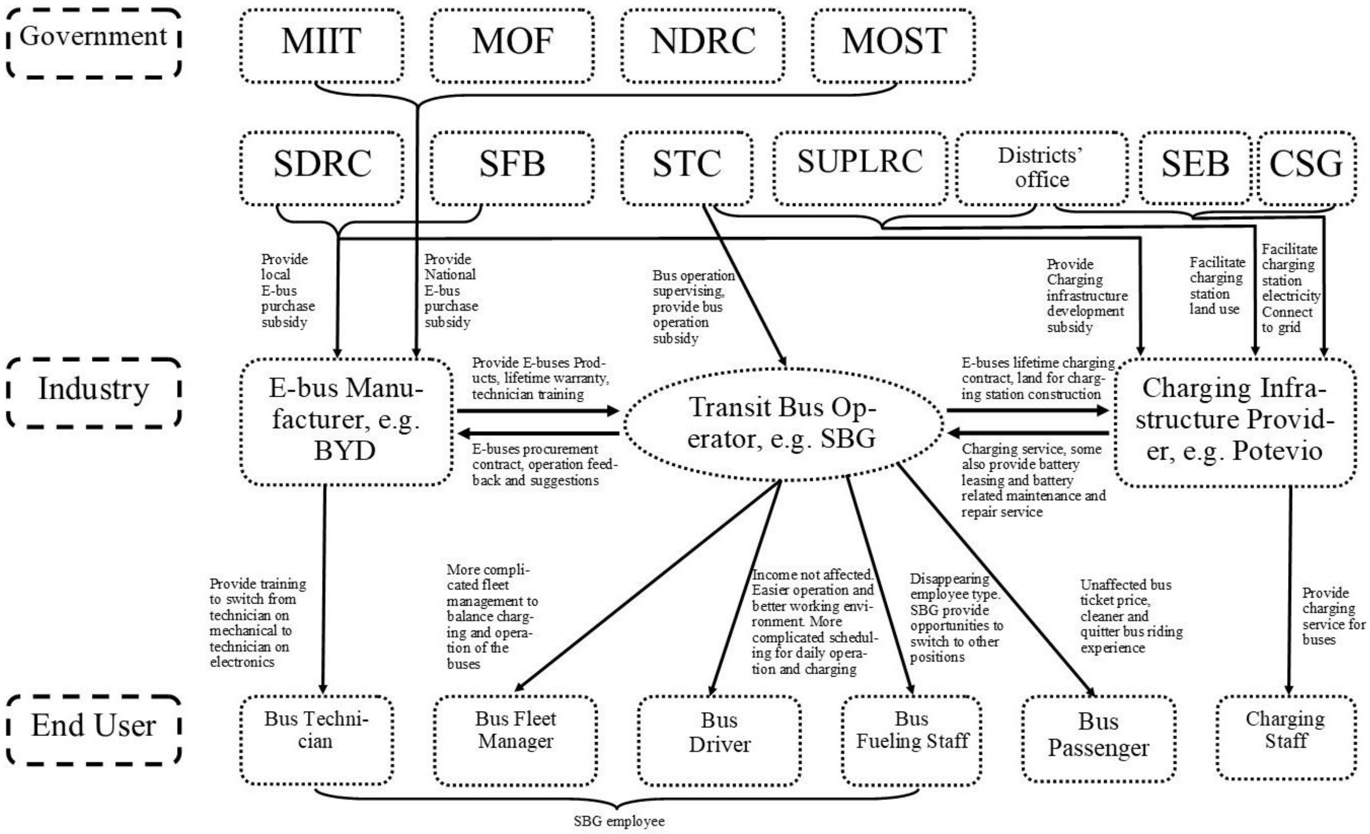

Figure 9 Stakeholder map

The **main public stakeholder** was the Shenzhen Energy Conservation and New Energy Vehicle Demonstration and Promotion Leading Group (SNEVLG) which facilitated the cooperation among the municipal departments. The main **private stakeholder** was the bus manufacturer. The manufacturer not only provided an 8-year product warranty[8], which covers the lifetime of a bus in Shenzhen but also maintenance support, as well as training for operator staff. This not only relieved the operator's concern over technology uncertainty and reduced the maintenance cost, but also incentivizes the manufacturers to keep innovating and improving e-bus performance.

In order to reduce upfront costs of the complete fleet renewal, SZBG introduced a financial leasing model which used a **financial leasing company** who purchases and owns the vehicles and leases them to the SZBG for a period of eight years. The bus operating company takes ownership of the vehicles after the leasing period is over. The batteries are returned to the manufacturer for recycling and disposal, 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/lease payments (see Figure 9).

[8] Traditional bus manufacturers provide warranties of 2-4 years

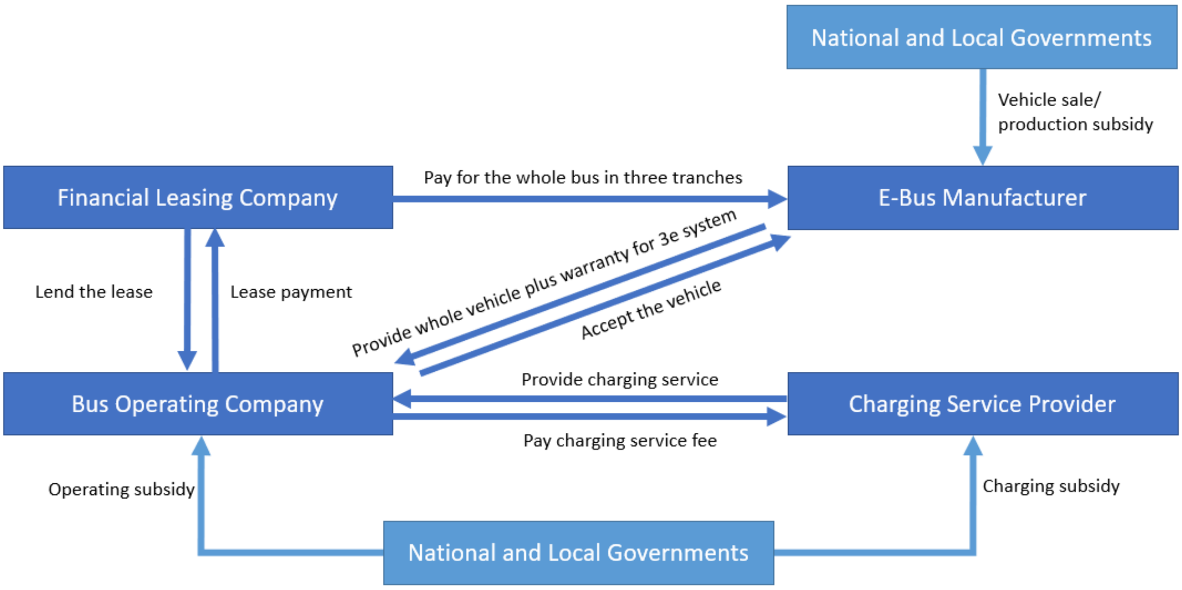

Figure 10 Financial leasing model used in SZBG since 2015 (Note: 3e System includes battery, electric motor, and controller)

4. Positive and negative impacts

Impacts on bus operations. At early stages, e-buses were only used on specific routes with shorter operating distance, making bus operations less flexible. Through improvements in technology and operational planning that balances the charging schedule to ensure that the route frequency is not affected, e-buses are now used on all routes.

Impact on local air pollution and GHG emissions. A comparative analysis of emissions for e-buses operated by SZBG showed a significant reduction in both local air pollutants and GHG emissions as indicated in table 2 and 3. The electric buses of SZBG save on average 194,000 tons of carbon dioxide annually, using the total annual bus operation mileage of 374.11 million kilometers in 2018.

Table 2 GHG emission per 100 kilometers of one diesel and one electric bus (gCO2)

Stage	Diesel	Electric bus	Emission reduction after bus electrification (gCO_2/100 km)
Use phase	85529.50	0	85529.50
Fuel production	23573.60	47838.42	-24264.80
Battery production	Not applicable	9388.64	-9388.64
Total	**109,103.10**	**57227.06**	**51876.04**

Table 3 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	/	116.80
NO_X	568.00	10.81	557.19
VOC	5.80	/	5.80
$PM_{2.5}$	11.00	/	11.00
PM_{10}	17.64	/	17.64
SO_2	2.50	11.38	-8.88

Impact on electricity grid. The rapid roll out of electric buses from 2016 to 2018, required the acquisition of land for charging stations which is challenging in a large and densely populated city like Shenzhen, since there is no planned land area left for this purpose. The electricity capacity for each zone is also previously set. As the electricity consumption of a charging station adds new localized demand, the utility has to install transformers and electricity lines to allow for a capacity increase in the zone.

Impact on bus operator staff. Bus drivers from SZBG state an easier driving experience with the new buses and the rate of vehicle breakdown rate is much lower according to SZBGs records. A step-by-step staff transformation plan (including training, re-assignment, incentives, talent attribution and compensation) was made for each team in each maintenance and repair workshop, taking into consideration the differences with the new system based on specialty, age, and experience. Staff training was crucial to increase acceptance for the new technology.

Impact on bus users. For bus users according to a regular satisfaction survey, comfortability was rated highest, followed by safety and affordability. This is mainly due to the smoother ride with an electric engine. E-buses also run quieter than diesel buses and the smell of diesel exhaust at bus stations disappeared. Additionally, the bus fare has been maintained at the same low level for the passengers, leading to a throughout positive user feedback.

5. Conclusions

In Shenzhen, all buses and taxis are electrified. Private cars, garbage trucks and other heavy-duty vehicles are currently transitioning towards electrification. The major remaining challenge for future bus replacements and other electric vehicles is the remaining **high upfront cost**, even more so as government subsidies are decreasing. The life cycle cost of electric buses over diesel buses is still not economically viable in Shenzhen. While maintenance and repair standards and procedures are set up to minimize service disruptions and ensure safety and environmental compliances, overall maintenance on repair costs are lower for electric buses. The manufacturer provides an 8-year warranty on the 3e system (battery, electric motor and controller) making the traditional overhaul maintenance required for diesel buses obsolete.

The difficulty of **acquiring land** with a clean ownership title for the construction and continuous operation of charging infrastructure is another challenge, since it implies higher cost and delays. Although SZBG transferred the land risks (ownership right, resettlements, land use changes and lease disputes) to the charging service providers by leasing charging facilities, land availability for charging stations has become a bottleneck.

Shenzhen is a fast-growing city with an expanding metro system. Many bus routes are changing to become feeder routes as the metro network expands. This results in a shorter **daily operating distance** that can easily be met by current e-bus models and overnight charging. Other cities, however, might require longer-range buses or an on-route charging network to match their operational needs. On the other hand, a longer driving distance improves the cost competitiveness of e-buses due to lower operation vs. capital costs from a total cost of ownership perspective - whereas for diesel buses, operating cost per kilometer are higher.

Lessons learnt. The major lesson learnt from this case is the importance of creating a collaborative environment for transitioning to a **new system**. The partnership among bus operators, bus manufacturers, financial organizations and charging companies significantly alleviated the technology uncertainty and spread the cost burden. By working closely with government agencies, SZBG was able to be on top of policy developments and lobby for favorable support. Besides government and industry partners, SZBG also worked closely with private enterprises and non-profit organizations including Huawei, Didi and the International Association of Public Transport (UITP) to pilot innovations including intelligent dispatch system, on-demand bus services, and autonomous driving technologies. SZBG also improved the collaboration within its own company by establishing a technology department, whose major mandate is to facilitate the cross-department coordination for the adoption of the new technology including fleet management, maintenance and repair, finance, procurement, IT, HR, and strategic investment.